Increasing Wheat Production in Central Asia through Science and International Cooperation

Proceedings of the
First Central Asian Wheat Conference

A. Morgounov, A. McNab,
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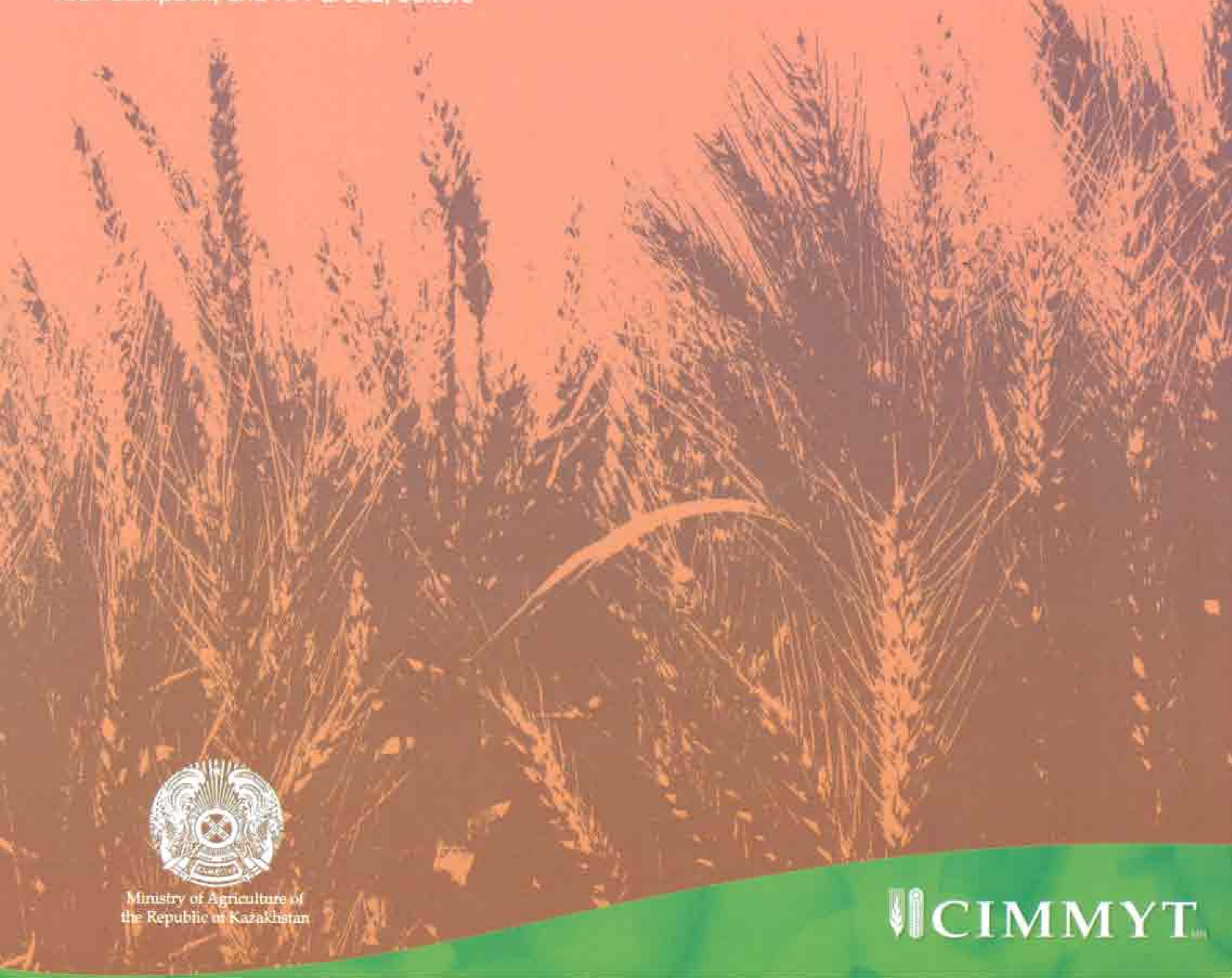

Ministry of Agriculture of
the Republic of Kazakhstan

CIMMYT

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Proceedings of the First Central Asian Wheat Conference

Held in

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THE FIRST CENTRAL ASIAN WHEAT CONFERENCE
June 10-13, 2003
Almaty, Kazakhstan

German Technical Cooperation Agency (GTZ)

WINROCK INTERNATIONAL

CIMMYT

WASHINGTON STATE UNIVERSITY

ICARDA

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CIMMYT® (www.cimmyt.org) is an internationally funded, not-for-profit organization that conducts research and training related to maize and wheat throughout the developing world. Drawing on strong science and effective partnerships, CIMMYT works to create, share, and use knowledge and technology to increase food security, improve the productivity and profitability of farming systems, and sustain natural resources. Financial support for CIMMYT's work comes from many sources, including the members of the Consultative Group on International Agricultural Research (CGIAR) (www.cgiar.org), national governments, foundations, development banks, and other public and private agencies.

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Preface

The objective of the First Central Asian Wheat Conference, held on 10-13 June 2003 in Almaty, Kazakhstan, was to assess the current status of wheat research and cooperation in Central Asia, particularly in the areas of wheat breeding, genetics, plant protection, biotechnology, and agronomy. Also evaluated were the achievements of regional cooperation in promoting winter and spring wheat varieties, seed production activities, and the exchange of information among academics and specialists from Central Asia and foreign countries.

The Conference was organized and supported by a number of government and international organizations:

- Ministry of Agriculture of the Republic of Kazakhstan;
- German Technical Cooperation Agency (GTZ), on behalf of Germany's Federal Ministry of Economic Cooperation and Development;
- International Maize and Wheat Improvement Center (CIMMYT);
- International Center for Agricultural Research in the Dry Areas (ICARDA);
- United States Agency for International Development (USAID);
- Washington State University (WSU), USA;
- Food and Agriculture Organization of the United Nations (FAO); and
- Winrock International (WI), USA.

Attending the Conference were 244 participants and 22 invited guests from 29 countries, including Afghanistan, Armenia, Azerbaijan, Canada, the Czech Republic, Denmark, France, Germany, Hungary, India, Iran, Italy, Jordan, Kazakhstan, Kyrgyzstan, Mexico, Nepal, Pakistan, Philippines, Romania, Russia, Syria, Taiwan, Tajikistan, Turkey, Ukraine, United Kingdom, United States, and Uzbekistan.

During the first four days of the Conference, plenary sessions and group discussions were continuously conducted within the framework of seven basic topics: modern tendencies of wheat production, winter wheat breeding and genetics, spring wheat breeding and genetics, wheat biotechnology, wheat grain quality, wheat breeding for biotic and abiotic stresses, and wheat cultivation technologies. The participants presented papers and posters illustrating research on these subjects. Within the sessions scientists reported and exchanged opinions on recent and ongoing activities at their respective institutions and on joint projects with CIMMYT, FAO, GTZ, and ICARDA in related fields. They also discussed the current status of wheat research and priorities in breeding, seed production, and modernization of wheat production technologies. Issues such as the challenges of developing new approaches for promoting and stabilizing wheat yields and grain quality, as well as the prospects for international cooperation on the regional and global scales, were also put forth for discussion.

The last day of the event was devoted to visiting experimental fields of the Kazakh Scientific and Production Center for Farming and Plant Science. The participants had the opportunity to observe new wheat varieties and novel technologies now being offered to farmers, including bed-planting, in which wheat is sown on top of raised beds. This technology allows farmers to use low seeding rates (up to 80-120 kg) and results in great water savings.

In the course of the Conference, several joint programs addressing wheat genetics, breeding, biotechnology, and agronomy were discussed and approved. Group discussions on the following topics were reported:

- Yellow Rust Regional Network: it was recommended that this highly successful network continue monitoring the rust pathogen populations and evaluating wheat germplasm for rust resistance, placing more emphasis on rapid seed multiplication and promotion of new rust resistant varieties.
- Wheat Grain Quality: the group recommended establishing a regional framework for evaluating the bread-making quality of new wheat varieties. The framework should take into account existing facilities and improvement of quality labs in the countries of the region.

- Winter Wheat East European Yield Trial: the objective of this trial is to promote formal germplasm exchange among countries of Central Asia, Eastern Europe, and the USA. The group shared the advances achieved over the past five years and concluded that the trial is a highly effective mechanism for germplasm exchange. Group recommendations focused on enhancing the efficiency of the trial and the technical aspects of germplasm exchange.
- Kazakhstan-Siberia Network on Spring Wheat Improvement: This network is composed of 14 breeding programs from North Kazakhstan and Siberia. The group recommended developing uniform methodology and placing more emphasis on coordinated evaluation of germplasm for important traits.
- Satellite meeting on the application of biotechnology in wheat breeding: the group identified research priorities, as well as potential areas of regional collaboration. A project proposal will be prepared for submission to potential donors.
- Pre-conference workshop "Explore on-farm:" A set of pamphlets providing guidelines specific to regional conditions for planning and implementing on-farm experiments were developed during this FAO-sponsored workshop. The pamphlets will be available in Russian to all interested parties.

Dr. Sanjaya Rajaram, Chairman of the International Organizing Committee, summarized the work and results of the First Central Asian Wheat Conference. He concluded that the Conference had proved very successful and fruitful, for it demonstrated the increasing connection between wheat improvement research and wheat production practices in the region and the world as a whole. He stated that breeders, seed producers, and other wheat specialists will undoubtedly continue to cooperate at both the regional and international levels. Speaking on behalf of donors, Mr. K. Metzler, from GTZ-Almaty, expressed satisfaction with the results of the Conference and indicated the donor community is interested in supporting regional and international collaboration on wheat research and production.

Finally, it was determined that the Conference should be held every three years in different countries of the region, and a new International Organizing Committee was created and approved. Two countries expressed interest in hosting the Second Central Asian Wheat Conference, to be held in the summer of 2006. The participants voted and determined that the next conference will take place in Bishkek, Kyrgyzstan.

Is Conventional Plant Breeding Still Relevant?

S. Rajaram
Chairman, International Organizing Committee, First Central Asian Wheat Conference

Developing countries are projected to increase their demand for cereal grains by about 80% between 1999 and 2020 (Pinstrup–Anderson and Pandya-Lorch, 1997). Rosegrant et al. (1997) estimate that over the next two decades global demand for wheat could rise by 40%. By 2020, it is expected that 67% of world wheat consumption will occur in developing countries. Average wheat production in recent years has been 590-600 million metric tons. By 2020, this amount has to increase to a total of approximately 840 million metric tons, two thirds of which have to be produced in developing countries.

The Asian continent (West, Central, South, and East) is an important region of the globe, where wheat is the number one crop. At least 104 million hectares are planted to all kinds of wheat in this region. Compared to Asia, in the African continent only 8 million hectares are sown to wheat, and in South America, another 8 million hectares. The current global average yield of wheat is approximately 2.5 t/ha. By 2020, this yield has to go up to 4.2 t/ha if we are to meet global demand. This means an increase of 1700 kg/ha, which translates into an annual increase of 85 kg/ha over the next 20 years. The issue is whether we have strong science and technology in place to handle such an enormous job. Though the role of governments and farmers is paramount to this issue, here I have taken the liberty of dealing with scientific issues that would affect productivity gains in the future.

Fully aware of this situation, the developed world has strong public institutions and also allows strong intervention by private companies. Public and private institutions are now working together, and strong capital investment has allowed farmers to purchase heavy machines that are critical to implementing low-cost agricultural technologies such as zero tillage, crop residue retention, and timely planting and harvesting operations. The market is fully developed based on quality and international trade.

The application of biotechnology in crop breeding has been strong. Currently 42.7 million hectares of transgenic crops are grown in the developed world, compared to 16.0 million hectares in the developing world (James, 2002; Figure 1). Developed-world companies have invested heavily in biotechnology, but they have not abandoned conventional plant breeding. Indeed, Monsanto has bought many seed companies that are very strong in conventional plant breeding.

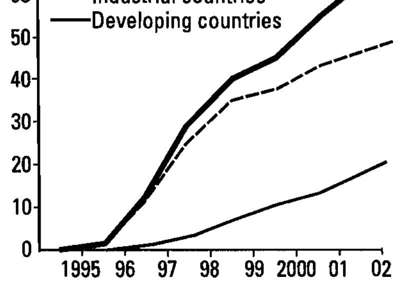

Figure 1. Global area of transgenic crops, millions of hectares (1996-2002).
Source: Clive James, 2002.

The situation in the developing world is strikingly different. With the exception of a few countries such as China, India, and Brazil, the research budget for both conventional plant breeding and biotechnology is measurably low. In many instances, the conventional plant breeding budget is so low that most research facilities have become obsolete and nonfunctional. In some situations public sector scientists cannot fully apply their talents despite good training in advanced countries. Private sector evolution parallel to that in the developed world has not occurred due to many causes, but mainly to low seed industry profits.

Irrespective of differing trends in developed and developing country agriculture, the first Green Revolution, based on improved seed and optimum use of fertilizers, water, and other inputs, triggered a quantum leap in productivity in many parts of the world. The process was subsequently repeated in many environments including rainfed agricultural lands. Many environmental groups and civil societies have criticized the Green Revolution; nonetheless, they have not come up with any meaningful alternative solution to world hunger and malnutrition. Indeed, many of the shortcomings associated with high-input agriculture have been curtailed in the last 15 years. The concept of a doubly Green Revolution has been proposed to meet global food supply (Conway, 1997).

Since Mendel's time, there have been many advances in genetics that have been exploited in conventional plant breeding, such as hybrid vigor, polyploidy, biometrics, chromosomal translocations, and, more recently, biotechnology. Each advance was incorporated into current breeding methodology. Of all those advances, mutation genetics was perhaps the least successful in crop improvement, though parallel programs were set up in many countries. Does biotechnology require the same arrangement? Unfortunately, this is being done due to misguided policy. Many in the policy arm/a also believe that the vast *ex situ* germplasm collections could solve future food problems. Unfortunately, many such stored germplasm collections are in shambles, museum pieces, and unless vast resources are allocated for classification, quantification,#{nd genetic analysis, the stored germplasm is useless. Not surprisingly, the highest yield gains and associated plant breeding advances have occurred thanks to the implementation of the most advanced genepool in the breeding program (Rasmusson and Phillips, 1997). I strongly believe that this trend in the use of paramount germplasm will be the norm, rather than the exception, in 20 years' time. The vast landrace collections in the genebanks perhaps will remain museum pieces at most.

What role would conventional plant breeding play in a highly charged biotechnological environment? Would there be resources for such an undertaking? Perhaps not as much as needed. As conducted today, conventional plant breeding is not one discipline, but rather encompasses many related disciplines such as plant pathology, genetics, nutrition, soils, and water. It has incorporated many methodologies refined over the past 100 years. A strong conventional plant breeding program would be required to take full advantage of a strong biotechnology program, because a variety, as a product, is the outcome of multiple gene manipulation in one package.

Looking into the future, both conventional plant breeding and biotechnology would have a strong role in manipulating genes with the aim of achieving 840 million metric tons, the global production goal, by 2020. Some untapped possibilities for achieving this goal are mentioned below.

Breaking the Yield Barrier

It is a great satisfaction to note that there have been continuous gains in yield potential through the utilization of paramount germplasm and special genetic stocks such as *Triticum tauschii*, as illustrated in Figure 2. The graph illustrates the yield performance of varieties such as Sonora 64, released in 1964, and a Kambara wheat derivative tested in 2003. This gives a yield gain of 100 kg/ha/year over a period of 32 years. Wheats in which the *Lr19* gene was recently incorporated have achieved further gains over Kauz, Baviacora, and synthetic derivatives (Singh et al., 1998). The large-spike wheats offer a much greater possibility of transforming overall wheat morphology and ideotype. It is quite possible that future wheats will bear larger spikes, larger number of grains, and larger seed. As Director of the Wheat Program at CIMMYT, I revived the creation of this new wheat type that I like to call Agropolitetra wheat (*Agropyron + polinicum + tetrastichon*). While I cannot assure its continuation at

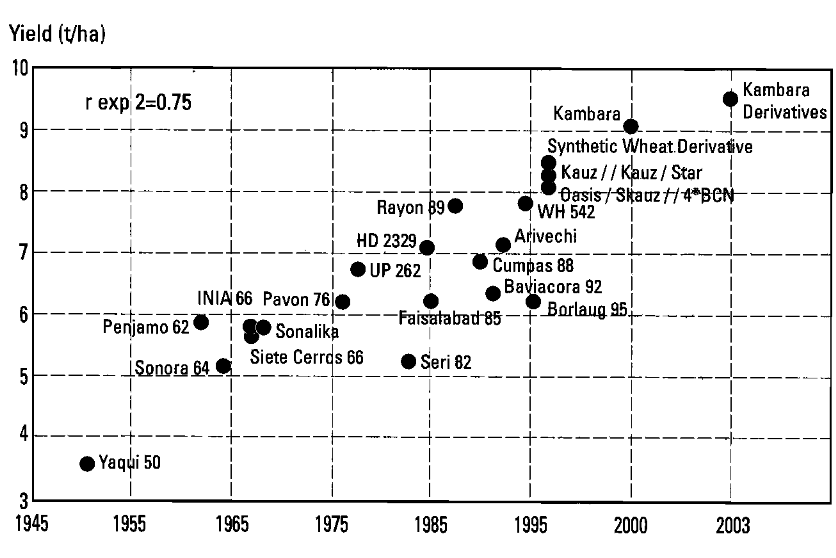

Figure 2. Yield vs. year of release, 2003 cycle, Ciudad Obregon, Mexico. Yield of Kambara provided by Dr. Ravi P. Singh (CIMMYT).

CIMMYT, I would plead with you to acquire this germplasm and use it in your breeding programs.

Durable Disease Resistance to Protect Yield Gains

Until a quarter of a century ago, wheat rusts, the most serious and economically important diseases of wheat, periodically devastated wheat production. This happened every time that susceptible varieties, favorable environmental conditions, and pathogen adaptability combined to create large-scale epidemics. The Yaqui Valley in Sonora, Mexico, experienced a continuous rust epidemic in the 1970s and early 1980s.

Starting in the 1950s, the CIMMYT Wheat Program (or rather, its predecessor, the Office of Special Studies) led by Dr. N.E. Borlaug, in its breeding efforts combined the durable stem rust resistance of Hope (*Sr2* complex), a variety bred by McFadden in South Dakota, USA, and the durable leaf rust resistance in Frontana, a Brazilian variety.

Based on CIMMYT's research over the last 30 years, our national program partners have released over 500 bread wheat cultivars. Many of them trace their durable rust resistance to Hope, Frontana, and other diverse sources. This resistance is conferred by minor genes that interact additively to protect the crop from the rust pathogens. Most importantly, the resistance conferred by minor genes is durable (historically) and phenotypically results in slow (or dilatory) rusting, which has a negligible effect on yields.

Farmers all over the world have reaped the economic benefits of disease resistant cultivars that produce the same yield with and without fungicide protection (Figure 3; Sonora's Yaqui Valley). In a recent study on the benefits of incorporating leaf rust resistance into modern varieties, CIMMYT scientists estimated that gross benefits generated in the Yaqui Valley from 1970 to 1990 through the incorporation of disease resistance totaled US $17 million (in 1994 real terms) (Smale et al., 1998).

Despite great advances in breeding for durable leaf rust resistance at CIMMYT, it is still too early to say whether we can bring global stability to rust resistance. In the early 1990s, a virulent stem rust race devastated Ethiopia variety Enkoy; losses were estimated to be US$ 40 million. During the 1990s stripe rust was pandemic from Pakistan to Egypt, including Iran, Turkey, and other middle eastern countries. In 2001 and 2003 a virulent leaf rust on durum wheats devastated most advanced lines in the CIMMYT program, and the epidemic in the Yaqui Valley was averted in 2003 only through the large-scale application of fungicides over 110,000 hectares, at an estimated cost of US$ 9 million. The 2001 epidemic in the Yaqui Valley also required massive applications of fungicide to avoid disaster.

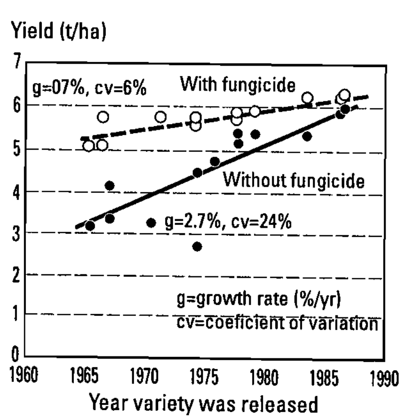

Figure 3. Yield of historically important varieties (released 1964-86) with and without fungicide, Ciudad Obregon, Mexico, 1990-91.
Source: Kenneth D. Sayre (CIMMYT).

The stripe rust threat in Central Asia is real and endemic. My strong appeal to you is to look for alternative sources of durable resistance and simply backcross these into your most adapted varieties. Molecular markers can help to select some of these genes. Conventional methodologies developed at CIMMYT (Singh et al., 2001) can accelerate their incorporation. I would like to honor Dr. Ralph Caldwell (now deceased), of Purdue University, who in the early 1970s inspired me to shift the paradigm from immunity to slow rusting.

Moving beyond Marginal Yields in Marginal Environments

Limited water availability is probably the most common stress that affects farmers in marginal environments, but they also have to contend with factors such as diseases, acidity, extreme temperatures, waterlogging, and mineral deficiencies and toxicities. A region is defined as marginal when wheat production drops to 70% of optimum yield levels, as in, for example, the highlands areas from Turkey to Afghanistan, the dryland areas of West Asia and North Africa (WANA), much of Ethiopia, and the dryland areas of central and southern India (Table 1). Northern Kazakhstan is an extreme case of a droughty region.

I proposed a breeding system for the CIMMYT Wheat Program in which yield responsiveness is combined with adaptation to drought conditions. Because most semiarid environments differ significantly in the amount and distribution of annual precipitation, it is prudent to construct a genetic system in which plant responsiveness provides a bonus whenever higher rainfall improves the production environment.

Why do I believe this can be done? One compelling piece of evidence comes in the form of Veery "S", which combines high yield performance in favorable environments with adaptation to drought in more marginal areas.

The variety Baviacora and its derivatives (such as Weebil and Kambara), whose origin traces back to Veery "S", fit this model even better. Various reports in the literature have suggested that yield potential *per se* would buffer better in droughty marginal environments. This does not appear to be the case, because many high yielding genotypes that are well adapted to optimum environments show very poor performance in drought conditions. Genotypes such as Baviacora and its derivatives show exceptional performance under both types of conditions, which indicates that responsiveness and drought adaptation genes are embedded in the same genetic system. Drought adaptation in Baviacora is highly heritable because only one limited backcross was used to derive lines such as Weebil and Kambara, which combine the recipient parent's high yield and drought adaptation, and express durable leaf rust genes.

Given that annual precipitation in Central Asia is highly variable, the region would benefit from the implementation of such a breeding scheme to improve genotypic performance. CIMMYT has catalogued many sources of drought adaptation—for example, genotypes carrying the IB/IR translocation (Villarreal et al., 1995) and *Triticum tauschii*-derived synthetic hexaploid wheats (Rajaram et al., 2001).

Conclusion

In summary I would like to say that global wheat production in 2020 could increase by 40%, provided there is a well-integrated, multidisciplinary wheat program well funded by either the public or private sector. More emphasis needs to be placed on improving yield potential, durable disease resistance, and stress tolerance, and adopting better resource conservation systems (Table 2). Both biotechnology and conventional plant breeding, supported by other disciplines, would be critical to achieving these advances.

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Table 1. Portions of wheat producing regions of the world that are defined as marginal.

Region	Total wheat area (000 ha)	Percent marginal
West Asia/North Africa	28,300	65
Central Asia and the Caucasus	15,000	80
South Asia (Subcontinent)	34,500	35
East Asia(including China)	30,100	13
Eastern Africa	1,500	27
Southern Africa	1,300	91
Southern Cone of South America	7,400	60
Andean Region of South America	300	18
Mexico/Central America	900	43
Total	**119,300**	**45**

Table 2. Contribution of various factors to the increased productivity needed to achieve 840 million metric tons by 2020.

Factors	Productivity growth (%)
Yield potential	10
Disease resistance	10
Drought tolerance	10
Improved production system (e.g., zero tillage)	10
Total	**40**

Prospect for Wheat Production in Central Asia

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At present the total volume of world wheat production is about 600 million tons (mln t), which is higher than last year. Wheat yield increased in many wheat-exporting countries: the United States, Canada, Australia, the European Union, Argentina, and NIS countries such as Russia, Kazakhstan, and the Ukraine. Production of wheat for both food and feed increased.

The main wheat-exporting countries are Canada, USA, Argentina, Australia, EU, and Kazakhstan. The wheat-importing countries are Iran, Iraq, Saudi Arabia, Jordan, countries of North Africa, Nigeria, Baltic Republics, Philippines, and the Central Asian Republics of Tajikistan, Turkmenistan, Uzbekistan, and Afghanistan, plus the Caucasus Republics. As it did before the transition to a market-based economy, Kazakhstan has an important role to play as the producer of high-quality wheat.

For 50 years, beginning when virgin lands were developed, Kazakhstan has produced mostly high quality grain and, until 1999, delivered grain to many republics of the Soviet Union (Russia, Byelorussia, Caucasus Republics, Baltic Republics, and especially the Republics of Central Asia). This was of ecological and economic benefit to each. Unfortunately, this connection was broken after the Soviet Union desintegrated and the Republics gained their independence.

Over the past 10 years, each Republic has tried to solve complex production problems independently. To a certain extent this is step backward to a subsistence economy where the operative principle is "I produce everything I consume." Of course this implies ecological mutation and collapse. We could agree with this principle if the environment and the economy of each Republic were improving, but they are not because the main causes of the problems remain.

However, the economies of many republics of the former Soviet Union have started to stabilize. And I think in future the governments and the people will take better care of the environment.

Due to temperature deficiency and the special soils needed to grow crops such as rice, cotton, and oilseeds, they cannot grow in Northern Kazakhstan, Russia, and many Eastern European countries. On the other hand, wheat of excellent quality grows in the sierozem soils of Central Asia, where trees for wood and other products are lacking. All of this has contributed to many negative processes in the economies of these countries.

The grain quality of wheat grown in Central Asian countries does not fulfill international quality standards and must be improved in order to achieve high quality production.

For 12 years very few, if any, mineral and organic fertilizers were applied. Monoculture is practiced by many farmers, crop rotations have changed, and the science-based agricultural system and the seed production system have broken down. Not enough attention has been paid to conserving soil fertility of arable lands for 50 years. This has led to a 20-30% reduction in humus, the main soil component. Under such conditions, it is not possible to produce high quality grain. The same situation is observed in other NIS countries.

In any case Kazakhstan will be the principal deliverer of high quality grain, particularly to the Central Asian Republics, because of their eco-geographical location. We have the required scientific, ecological, and economic conditions to do this. We hope not only to make positive connections but also to become more integrated into the different economies of these countries (Table 1).

Table 1. Wheat cultivated area, production, and yield in Kazakhstan, 1954-2002.

Years	Sowing area (000 ha)	Yield (t/ha)	Production
1954-1960	25001.0	0.80	2002.7
1961-1965	23927.6	0.61	14525.1
1966-1970	23350.8	0.89	20667.9
1971-1975	242256.0	0.89	21633.8
1976-1980	25403.0	1.08	27496.0
1981-1985	25352.0	0.83	21330.0
1986-1990	23991.0	1.04	25118.0
1991-1995	21638.8	0.82	17870.6
1996-1999	14324.8	0.77	11058.7
2000	12400.0	0.94	11600.0
2001	13174.4	1.40	18372.7
2002	14000.4	1.31	18272.4

Grain production in Central Asian countries is as follows. Kazakhstan produces 17-18 mln t of cereal grains annually, including 13-14 mln t of wheat, of which 7-8 mln t go to satisfy its own wheat demand (Table 1).

In Uzbekistan wheat production increased sharply at the expense of expanding the cultivated area and increasing yields. The country imported 3-4 mln t of wheat in 1990, but now it produces enough to satisfy 80-85% of its domestic demand. Average wheat yield has increased from 2 t/ha to 4-5 t/ha, and wheat production in 2002 reached 4.7 mln t.

The area sown to wheat increased in Tajikistan and Kyrgyzstan, but not in Uzbekistan. Yield levels in these countries tend to grow, especially in Kyrgyzstan, where average yield is 2.4 t/ha. In Tajikistan average yield is not very high, 1.2-1.4 t/ha. Of course the deficit of high quality grain is higher in Tajikistan. And so our neighbors will import high quality grain for different reasons, e.g., limited cultivated area and the need to conserve soil fertility.

It is evident from Tables 2 and 3 that the economies of many Central Asian countries (except Kazakhstan) are based mostly on agricultural development. Besides needing to ensure food security, they have such problems as: 1) 25-40% of the population lives under the poverty line, and 2) about 50% of the poor population lives in rural areas. There is also an urgent need to conserve soil fertility and develop disease resistant varieties.

Seed production

Scientific global studies have indicated that variety and high quality seeds account for 40-50% of yield growth. Wheat varieties preserve their genetic traits for several generations, beginning the year the variety was originally released (4-5 years). But due to many factors such as inadequate fertilization and rotation, the seed produced on many farms is not in perfect condition, and elite seeds soon begin to lose their characteristics. Analyses show that in many farms the percent of high reproduction (elite and IV reproduction) seed sown decreased from 85% to 39%. A similar reduction in yield was also observed.

Analyses of wheat yield data are given depending on seed production: In elite seed production farms where the main agronomic recommendations are followed, there is a 12.6% difference between elite and IV reproduction of seed in favor of elite. In large-scale seed production farms where agronomic recommendations are not followed, the yield difference between elite and IV reproduction of seeds is 46%, and 37% between elite and III reproduction of seeds. This tendency is observed in other Central Asian countries as well.

Therefore, improving the seed production system is essential for raising wheat production in Central Asia today.

Seed potential of varieties

Frost and cold tolerant wheat varieties with two or three recessive *vrn* alleles are required to survive the harsh winters in Kazakhstan and most of Kyrgystan. In Tajikistan, Turkmenistan, Uzbekistan, and the Osh region of Kyrgystan, facultative wheat grows well because of the mild winter climate. Only spring wheat is grown in Northern Kazakhstan.

Data on yield, quality characteristics, and yellow rust resistance of newly released varieties in Kazakhstan and other Republics of Central Asia are shown in Table 4. Yubilynaya-60, Naz, and Sapaly have high quality indexes, compared to check varieties Bezostaya-1 and Steklovidnaya-24.

Quality parameters of newly released and advanced Kazakhstan winter wheat varieties submitted to

Table 2. Key indicators for the Central Asian Republics.

Country	Total area (000 km²)	Farm-land (mln ha)	Population (mln)	Population % rural	GNP per capita (US$)	GDP (US$)	Farming as % of GDP
Kazakhstan	272.0	24.0	14.9	44.0	1,363	22.6	9.1
Kyrgyzstan	19.8	1.4	5.0	65.6	280	1.5	37.9
Tajikistan	14.3	0.8	6.2	72.4	170	1.1	23.0
Turkmenistan	48.0	1.4	5.3	55.2	950	6.0	27.3
Uzbekistan	44.7	5.0	25.1	63.3	550	11.3	36.0

Table 3. Cultivated area, production, and yields of wheat in the Central Asian Republics, 2001-2002.

Country	2001 Cultivated area (000 km²)	2001 Production (x 1000 ha)	2001 Yield (t/ha)	2002 Cultivated area (000 km²)	2002 Production (x 1000 ha)	2002 Yield (t/ha)
Kazakhstan	10826	12990	1.2	11000	13750	12.5
Kyrgyzstan	478	1190	2.5	502	1305548	26.0
Tajikistan	343	406	1.2	650	750	11.6
Turkmenistan	750	1200	1.6	720	2300	34.0
Uzbekistan	9231	3600	3.9	1100	4700	43.0

Table 4. Yield, quality, and yellow rust resistance of new Kazakhstan winter wheat varieties. Advanced yield trial, rainfed conditions, 1990-1993.

Parameter	Nas	Sapaly	Yubileuy-naya-60	Steklovid-naya-24	Bezostaya-1	Progress
Yield (t/ha)	2.3	2.3	2.3	2.1	1.6	2.1
Test weight (g/l)	806	792	885	830	806	795
1000-kernel weight (g)	40.8	36.2	42.1	38.0	36.2	38.0
Vitreousness (%)	74	92	90	69	71	60
Wet gluten (%)	39.4	39.2	40.1	38.6	38.5	36.8
Protein (%)	15	16.2	18.1	15.9	15.8	14.9
W-gluten strength, a.v.	385	404	501	344	334	270
Valorimeter value (%)	79	76	80	74	70	60
Loaf value (ml)	1000	1095	1130	1099	1010	900
General baking score	4.3	4.2	4.4	4.1	3.9	3.5
Days to maturity	277	275	273	270	280	285
Plant height (cm)	99	86	86	90	88	79
Resistance to YR	1/7	1/10	1/20	2/35	2/30	3/45

Table 5. Quality parameters of new Kazakhstan winter wheat varieties.

Variety	Test weight	Protein %)	Wet gluten (%)	Gluten strength (W)	Valori-meter value (%)	Loaf volume (ml)	General baking score	Yield (t/ha)
Arap	805	14.0	27.1	260	50	875	3.4	7.0
Almaly	805	14.2	27.6	360	66	840	3.6	6.8
Eritrosper-mum-2000	740	12.8	23.0	240	40	933	3.7	6.1
Reke	910	16.1	35.0	320	69	950	3.8	6.3
Aliya	800	14.2	31.7	220	44	860	3.6	6.6
Sultan-2	900	15.0	34.0	392	65	943	3.7	6.4
Egemen	800	14.0	27.0	190	40	860	3.3	6.9
Zhetysu (st)	895	14.5	30.1	277	60	853	3.5	5.7
Progress (st)	890	13.9	27.1	250	48	812	3.3	5.8

the State Testing are shown in Table 5. The variety Almaly is of particular interest. It was released in many regions of Kazakhstan and is characterized by good tolerance to frost, cold, and drought. Reke and Sultan-2 have been submitted to State Testing (Table 5).

Quality characteristics (gliadin and glutenin-coding loci) of varieties from different regions of Central Asia are shown in Table 6. Of Kazakhstan varieties, 50% have high glutenin quality (a score of 10). Among Kyrgyz cultivars, Adyr is of greatest interest. Of the Uzbek varieties, Yanbash and Sanzar-4 have high quality potential. Among Tajik varieties, Somoni has the highest glutenin quality score.

In recent years, significant progress has been achieved in improving not only the yield potential, but also the quality of wheat varieties in this region. This success is the result of international collaboration with large-scale international organizations such as CIMMYT (Mexico), GTZ (Germany), and ICARDA.

Table 6. Gene diversity of gliadin allele and high-molecular-weight glutenin subunit composition of winter bread wheat from the CAC regional nursery.

	Gli-coding loci						Glu-coding loci				
Copra	A1	B1	D1	A2	B2	D2	A1	B1	D1		Country
2	3	4	5	6	7	8	9	10	11	12	13
Azeri	b	b	b	b	b	b	2*	7*+9	5+12		Azerbajian
Ekinchi	f	l	a	b	a*	b	0	7+9	2+10		- // -
Mirbashirskaya-128	b	b	j	f	b	r*	0	7*+8	2+10		- // -
Gyimatly 2-17	l	e	b	b*	b*	b*	0	7+9	2+12		- // -
Taragi	o	x	a	b+x	o	e	2*	7+9	2+12		- // -
Pirshahim	f	c	a	f	b	r	2*	17+18	5+12		- // -
Krasnovodopadskaya-25	b	b	a	b	b+o	b	2*	7*+8	5+10		Turkmenistan
SN64/SKE	c	b	b	b	o	r	2*	7*+9	2+10		- // -
BDME 9	b	b	b	b*	a	r	2*	7*+8	2+12		- // -
HYS/7C	c	e	b	b*	b*	b	2*	7*+9	2+10		- // -
Turkmenbashi	c+o	l+b	b	b	o	r+e	2*	7*+9	5+10		- // -
Skiphyanka	b	d	b	b+f	b	e	2*	7*+9	5+10		- // -
Armyanka-60	b+c	d	b+x	b*	b+o	r+b	0	7*+8	2+10		Armenia
Ani -326	l+c	d+l	b	b	b	b	0	7+9	2+10		- // -
Satheni-22	m	n	b	b	b*	e	0/2*	17+18	5+10/2+10		- // -
Satheni-332	o	n	b	b	b	b	0	13+16	2+10		- // -
Nairi-68	n	b	b	b	b	b	2*	13+16	5+10/2+10		- // -
Nairi-149	c	e	b	b	b+o	b+r	0	7+9/7*+9	2+10		- // -
Nairi-131	n	l	b	b	b+o	b	0	7+9	2+10		- // -
Nairi-290	n	d	f	b	b+a	b	0	6*+9/6+8	2+10/2+12		- // -

Table 6. Gene diversity of gliadin allele and ....cont'd.

	Gli-coding loci						Glu-coding loci			
Copra	**A1**	**B1**	**D1**	**A2**	**B2**	**D2**	**A1**	**B1**	**D1**	**Country**
Ani-352	b+n	l	b	b	o	b*	0	7+9	2+10	- // -
Ani-435	o	e	b	b	b+a	b	0	13+16	2+10	- // -
Ani-591	n+b	l	b	b	b	b*	0	7+9	2+10	- // -
Jalvar	l	l	b+f	b	a+b	b	2*	7+9	5+10	- // -
Lori-24	o	b	f	b	b*	b	0	7*+8	2+10	- // -
Lori-292	n	e	f	f*	a	b	2*/0	7*+8/6+8	2+10	- // -
Tilek	n	n	a	f*	1+x	b	2*	13+16	5+10	Kyrgyzstan
Kyal	b	x**	j	b	o	b	2*	7*+9	2+10	- // -
Eritrosper.- 9945	b+c	b	b	x	b	e	2*	7*+9	5+10	- // -
Adyr	b+c	b	b*+a	x	b	e	2*	7*+8	2+10	- // -
Kyzyl Dan	g	b	b	b	b*	r	2*	7*+9	5+10	- // -
Bermet	m	l	b*	b	b	r	0	7*+9	2+10	- // -
Eritrosperm. –760	c	b*	a	x	b*	e	2*	7*+9	5+10	- // -
Eritrosperm.- 13	b+c	b*	b+j	x	b	e*	2*	7*+9	2+10	- // -
Zhetycu	b+c	b	g	b	b	b	2*	7*+8	2+10	Kazakhstan
Progress	b+m	b	b+g	f	b	b	2*	7*+9	5+10	- // -
Eritrospermum-350	b	b	b+g	b	b	b	2*	7*+9	5+10	- // -
Zernokormovaya-50	l	n	g	b	b	b	2*	7*+9	5+10	- // -
Steklovidnaya-24	b*	b	a	b	o	b	2*	7*+8	5+10	- // -
Yuzhnaya-12	b	l	a+g	b*	o*	b*	2*	7*+8	5+10	- // -
Karlygash	c	b	f	f*	b*	e	2*	7*+9	5+10	- // -
Sapaly	b*	b	j	f	o	b	2*	7+8	5+10	- // -
Naz	l	n	b	f	b	b	2*	7*+9	5+10	- // -
Bogarnaya-56	l	n	b	b	b	b	2*	7*+9	5+0	- // -
Lutescens-72	m	e	b+a	b*	b	r	2*	7+9/7*+8	2+10	Kazakhstan
Krasnovodopads-210	g+	b	a	f+b	b	b	2*	7*+8	5+10	- // -
Krasnovodopads.-25	b	b	a	b	b	b	2*	7*+8	5+10	- // -
Yuzhnaya-12	b	b	a	b	o	b*	2*	7*+8	5+10	- // -
Pamyat-47	m	b	f	b	o	r	2*	17+18	5+10	- // — // -
Altyn Masak	g	c	a	b	b+o	r	2*	17+18	5+10	- // -
Oktyabrina-70	b	b	b	b	b	b	2*	7*+8	5+10	- // -
Karaspan	m	b	a	b*	o	b	2*	7*+8	5+10	- // -
Krasnya zvezda	g	b	a	b*	b	b	0	7*+8	2+10	- // -
Mtsketskaya-1	c+m	l	b	b*	a	b	0	7*+9	2+10	Georgia
Yanbash	m	x	b	b	b	r	2*	20	5+10	Uzbekistan
Ulukbek	o	l	b	b*+f	o	e	0	7*+9	2+10	- // -
Sanzar-4	c+b	c	j+b	b+f	b+o	r	2	17+18	5+10	- // -
Sanzar-8	c	d	g+j	b	b	r	2*	7+9	2+10	- // -
Sharora	c	l	f	b	o	b	2*	7+9	5+10	Tajikistan
Somoni	b+m	x	f	f+b	b	b	2*	7*+8	5+10/2+10	- // -
Ozoda	m	l	f	b	o	b*	2*	7*+9	5+10	- // -

Conservation Agriculture in Mongolia

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The production of spring wheat, the only major crop in Mongolia, was . mechanized through the introduction of techniques and farm equipment from Russia in the 1960s. Collective state farms covered large areas of up to 20,000 ha under centralized management with a paid labor force of some one hundred people. Since 1992 most state farms have been privatized, split into smaller units of some 1000 ha, and leased to either private individual owners or groups of owners as a shareholder companies with leasing periods of up to 20 years. As the wheat area has shrunk, following the abandonment of many marginal state farms, there is presently adequate farm machinery for the cultivated wheat area of some 300,000 ha. At present mounting production costs, farmers' inability to obtain credit, scarcity and high cost of essential inputs (fuel, herbicides, fertilizers, spare parts, etc.), poor condition of farm machinery, low producer prices, and low crop productivity have resulted in heavy indebtedness of farmers and pushed them to the brink of bankruptcy.

Following a request by the Government of Mongolia, FAO implemented the TCP project "Improved Cereal Production Technology." The project was launched in the 2000 cropping season and ended in 2002. Its main objective was to introduce conservation agriculture technologies in Mongolia to improve cereal productivity and farm profitability on a sustainable and environmentally friendly basis.

Major Constraints on Agricultural Production in Mongolia

Mongolia is noted for its harsh, cold, dry continental climate, which places severe limitations on crop production. A short growing period of only three months (end of May to early September), low and erratic rainfall (200-300 mm), and extremely low winter temperatures (-30 °C) only allow the cultivation of early maturing spring crops—mostly spring wheat, plus some potatoes and fodder crops. However, one of the most serious environmental problems is caused by strong winds, particularly during April and May, that dry out the top soil and create serious wind erosion from unsuitably prepared fallow.

Wheat is the major cereal in Mongolia, accounting for 98% of the cultivated area. The wheat area has dramatically decreased by more than 50% from about 650,000 ha in 1990 to some 300,000 ha in 1998. The current cropping system is a spring wheat monocropping system. Average wheat yields of 1.4 t/ha were achieved in the 1980s but have fallen to 0.6 t/ha, although yields of 2 t/ha are achievable in more favorable years on better-managed farms. Wheat yields have been dropping for reasons such as poor crop and land management, the use of little or no fertilizer, agrochemicals, improved seed, and lack of spare parts.

Lack of soil moisture, especially at seeding and during crop establishment in May and June, is the primary constraint on wheat yields. The common practice is to fallow one year in two often under strip cropping where cropped and fallowed fields (strips) alternate in order to prevent wind erosion. Wheat grown consecutively on the same land for two years yields only some 0.5 t/ha during the second planting year. The fallow is cultivated up to five times with broad-sweeps and/or disc cultivators to control weed growth. It is also believed to conserve the accumulated precipitation during fallow as soil moisture for the next year's crop. However, many research results have shown that frequent mechanical cultivation accelerates loss of stored moisture from the rooting profile.

Food security is a major issue for Mongolia. It is a landlocked country and border issues and shortages in international wheat production can disrupt supplies. The government is particularly concerned because of the continued decline in crop production. In 1995 a government resolution reconfirmed that self-sufficiency in wheat production is a national priority, flour being the single major staple food. In response to the serious threat of interrupted grain supplies, stocks of wheat and flour have been set aside to act as buffer stocks against production shortfalls.

Demand for wheat is mostly for human consumption. Wheat is sold to flour mills and distilleries. Total milling wheat requirement is 236,000 t. This is based on a population of 2.3 million people, with a per capita consumption of flour of approximately 100 kg. Based on 1998 harvest figures (about 180,000 t) and the total amount of wheat consumption (236,000 t), Mongolia needed to import some 56,000 t of grain to satisfy the demand. Actual wheat imports in 1998, however, totaled only 38,000 t, leaving a deficit of about 18,000 t of wheat.

Impact of Conservation Agriculture on Crop Production

One key to farmers' economic survival in producing cereal crops in a difficult climate is efficient crop and land management. The current practice of frequent cultivation of fallow land is unsustainable both from a technical and financial point of view. Weed control is very poor, soil moisture losses are high and fuel and spare parts for tractors are scarce and costly. The project's objective was to test and validate resource-saving conservation agriculture technologies that address the major production constraints and to train farm managers and farmers to use these practices for improved and sustainable cereal production.

The essential elements of CA include the following soil and crop management practices:

- Elimination of any land cultivation (plowing, harrowing, etc.) and direct seeding of wheat through crop residues.
- Retention of crop residues on the soil to improve soil fertility, moisture retention (water and snow), crop emergence, and weed control, and protect the soil surface from the direct impact of rain and sun.
- Diversified crop rotations for better managing soil fertility, weeds, diseases, pests, workload, and risks.

Conservation agriculture has been successfully adopted in Brazil, USA, Canada, and Australia and is being adopted in Africa and Asia. It offers important benefits that intensive or conventional tillage cannot match:

- Improvement of soil fertility owing to more plant residue;
- Protection of the soil surface from sunlight and decreasing the evaporation of water;
- Promotion of soil micro-organisms and improved soil structure;

These advantages of CA are the main reasons it can increase and stabilize yields and decrease environmental risks.

In Mongolia, CA is possible only in combination with an alternative weed control method, which replaces the conventional mechanical fallow cultivation. As in Canada and the Northern Great Plains (USA), chemical fallow based on the use of non-selective herbicides appears to be an appropriate weed control method. Cover crops for weed control do not seem to fit well into the cropping system especially because rainfall is low and fallow is needed to accumulate soil moisture for the subsequent wheat crop.

Conservation agriculture with minimum or no-tillage and direct planting leads to reduced labor requirements, time saving, reduced machinery wear, and fuel savings. No-tillage, for instance, requires as little as one trip for planting compared to two or many more soil tillage operations plus planting for conventional tillage. Fewer trips also save on machinery wear and maintenance and fuel costs. Fuel and energy saving in CA systems can range between 30 and 60% (Doets et al., 2000).

Reduced weight and horsepower requirements with no-tillage can help minimize soil compaction. Additional field traffic required by conventional tillage breaks down the soil structure, promoting compaction. No-tillage increases soil particle aggregation (aggregate stability, continuous macropores), which makes it easier for water to move through the soil and allows plants to use less energy to establish roots.

Crop residues, when left on the soil surface, reduce water evaporation from the top few inches of soil, and no-till can make additional water available for growing plants during the season. Crop residues act as tiny barriers to slow water runoff from the field, allowing the water more time to soak into the soil. Channels (macropores) created by soil macrobiota and old plant roots that are left intact also increase infiltration. All this helps significantly reduce or eliminate field runoff. Crop residues on the soil surface also reduce water and wind erosion. Depending on the amount of residues present, soil erosion can be reduced by up to 90% compared to an unprotected, conventionally tilled field.

Resource-saving farming is not new to Mongolia; minimum tillage and the appropriate equipment (V-shaped shallow sweeps) were introduced by scientists from the

Soviet Union about 15-20 years ago. The technology was adopted by farmers because of the serious weed problem, which they tried to control by frequent fallow cultivation. The introduction of chemical fallow based on non-selective herbicides could solve the weed problem and allow the introduction of no-till technology.

The proposed CA technologies, which have been shown to work under similar conditions in North America, had a positive impact on crop production in Mongolia. Since virtually all farm equipment is of Russian origin, the project updated mainly Russian-made machinery. The major advantage of local equipment is its immediate availability, low price, and farmers' familiarity with it. Equipment from western countries is probably more efficient but also more sophisticated; it is also much more expensive to maintain than equipment from Russia.

Project Activities and Results

The project focused its activities on the Central Cropping Region, situated north of Ulaanbaatar, the country's capital, which is the main cereal-growing area in Mongolia.

Five large-scale farms were selected for participating in the test and demonstration program. Each farm allocated 200 ha to the program, of which 100 ha were used for testing conservation agriculture technologies and 100 ha for multiplying quality seed. All selected farms were privately owned and used farm machinery that could be adapted to conservation agriculture practices.

The following technologies were tested, adapted and validated together with farmers:

- Improved weed control
- Improved crop residue management
- No-tillage and direct planting of crops
- Seed production and crop diversification

Chemical fallow (improved weed control)

In Mongolia the main grassy weeds are quackgrass (*Agropyron repens)*, wild oat (*Avena fatua*), and proso millet (*Panicum miliaceum*). The major broad-leaved weeds are sagebrush (*Artemisia dracunculus*), sagebrush/wormwood (*Artemisia sieversiana*), Canada thistle (*Cirsium arvense*), and Tartary wheat (*Polygonum tataricum*).

Currently most farmers control weeds by cultivating the soil 2-3 times during the fallow period especially against root-spreading weeds (e.g. quackgrass: *Agropyrum repens*), some of the most harmful weeds, which can reduce yields by 50%. This inefficient and costly cultivation was replaced by the use of non-selective herbicides (desiccants or burndown herbicides) such as glyphosates (e.g. Roundup). The desiccant was usually applied once during fallow (application rate: 2.5 kg/ha, in conjunction with a surfactant) to kill existing vegetation before planting. In case all weeds have not been properly killed, an additional early preplant application of 1.5 kg/ha was necessary. If there were only broad-leaved weeds growing, the desiccant was replaced with 2,4-D to save costs.

Because existing boom sprayers were old and in a bad state of maintenance due to lack of spare parts, the precise and even application of desiccants was not possible. Spraying is much more difficult than cultivation, mainly because mistakes are not detected until the effect of the chemical is seen; then it may be too late to spray because the weeds are too big. Therefore the project provided update-kits (a new pump, distribution system, controls and spraying nozzles) with which participating farmers upgraded their own boom sprayers. The installation and use of the upgraded sprayers was supported by special training. Farmers were also provided with the non-selective herbicide (Roundup) and the surfactant. For maximum effectiveness farmers were advised to apply the herbicides when the weeds were at least 20-cm high.

Chemical fallow has shown good effectiveness in controlling both broad-leaved weeds and grasses. Two sprayings as indicated above has shown to be more effective than one spray. A shift in weed composition from annual to hard-to-control perennials, which is often observed when changing from conventional to conservation agriculture, has not yet been observed but could become a problem in the long run.

Crop residue management

Efficient residue management, the key to good CA, begins at harvest. Spring wheat is harvested in Mongolia with combine harvesters in August. Farmers usually cut and thresh in one pass, but frequently wheat is swathed before full maturity and threshed at a later stage. Although farmers have to pass twice with their combines over the field, which is an increased expense, this system has the important advantage that the wheat crop can be harvested early in the season thus avoiding early frost in late August or early September.

Wheat straw remains in the field but is frequently grazed in winter and summer during the fallow period by livestock from nomadic herders. As a result, often about half or even less of the crop residue is available for residue management under CA.

Another constraint is the uneven distribution of crop residues after harvest, especially with the two-stage harvest, where the straw of two rows is placed in one line. The accumulation of straw in windrows behind the combine causes a number of planting problems and results in an uneven crop stand because of poor performance of the direct seed drill and because the seeds take longer to germinate and grow, leading to significant yield reduction. The reasons for that are:

- Unsatisfactory weed control from herbicide interception
- Poor protection of the soil from soil moisture evaporation and erosion between windrows
- Increased demands on planter equipment
- Poor seed-to-soil contact
- Increased pest infestation
- Increased weed seed concentration
- Poor plant nutrient uptake

The project locally developed a straw spreader that attachs to the combine harvester. It uses two horizontal rotating disks to achieve uniform straw distribution on the ground. This straw-spreading system works relatively well in fields that have been harvested with the combine in one pass. The advantages of this modification are:

- Spreads to about 5 m, which is close to the combine's cutting width.
- Saves energy. Only 5% of engine power goes into spreading, compared to up to 30% with a straw chopper.
- Low dependence from wind.
- Spreads straw and chaff evenly.
- Construction is local and easy.

The disadvantages are:

- The straw spreader was designed for an average straw yield of about 1 t/ha. However, some farmers swathed straw into double windrows thereby doubling the quantity of straw in one line. This made it difficult for the spreader to handle the straw quantity, requiring strengthened drive belts.
- The initial rubber transmission belt was not strong enough to handle the straw load held at the disk.

Straw chopping by the combine harvester has been considered but does not appear to be a feasible solution because of the high power requirements, the underpowered Russian combines, the almost doubled fuel consumption, and reduced labor productivity of the combine.

Direct seeding

The wheat crop was seeded directly through the crop residue into the non-cultivated soil. The project worked with the conventional seeders of Russian origin (SZS 2.1) used by farmers. The seeders were modified to adapt them to direct seeding of wheat:

- The wings of duckfoot or sweep opener were shortened to reduce soil disturbance and draft requirements.
- An additional seed spreader was inserted in the coulter outlet to spread the seed within the row and reduce the accumulation of seed and fertilizer in a narrow band.
- The sweep was replaced by a hoe or knife opener.
- The press wheels were modified by flattening their conical shape.

Direct drilling with the modified hoe drill encountered some problems in heavy crop residues, which clogged the seeders. Coulters (cutting disks) that cut through crop residues and open the soil need to be mounted. However, in general the modified seed drill works satisfactorily under farmer conditions. Some neighboring farmers have started adapting their own machines in the same manner.

In addition to local modifications, some direct drill coulters were imported from Brazil to install on a Russian hoe drill. The units included a cutting disk coulter and a set of offset double disks or, alternatively, a narrow chisel coulter, followed by a presswheel.

Each row unit had independent suspension and was mounted on support bars that had been welded onto the frame of the Russian hoe drill. The advantages of this modification were better residue handling, less soil disturbance, and more uniform depth placement due to independently suspended row units. Less weed germination due to less soil disturbance is expected, as well as more uniform seed germination, which will allow reduced planting depths (Dambros, 2002).

This modification was an efficient way of upgrading existing equipment to high quality direct seed drills at a low cost. Only the crucial soil engaging elements were replaced with state-of-the-art kits; the rest of the seed drills were used without any changes. Similar adaptations of seed drills facilitated the introduction of CA in Brazil. Planting accuracy is very important for the success of no-till farming, but the cost of complete, good-quality, no-till seed drills is often prohibitive for farmers just planning to adopt CA.

Conventional seeding rates currently used by farmers (some 180 kg/ha) are high, and a seeding depth of 7-10 cm is very deep. This practice is the result of frequent fallow cultivation for weed control, which pulverizes and dries out the topsoil before and during planting. Farmers are forced to sow at great depths to allow emerging seeds to tap into deeper soil moisture layers. Consequently, seeds have great difficulty in emerging and develop into weak plants. To compensate for the high percentage of weak and/or non-emerging plants, farmers use high seeding rates.

The benefits of the no-till/direct seeding system are obvious: it preserves scarce soil moisture, allows shallow seeding, and helps to develop a vigorously emerging grain crop. Participating farmers have reduced their seeding depth to 4-6 cm. However, they continue to use a high seeding rate because they fear a dry spell during crop emergence/early plant development, which is typical of Mongolian agroclimatic conditions and which can kill a high percentage of young plants. A lower seeding rate under direct drilling is expected to increase tillering and save soil moisture. This presupposes, however, good control of both grass and broadleaf weeds.

Seed production and crop diversification

During the transition towards a market economy, Mongolia's seed production system has broken down. In the last decade farmers have used only farmer-saved seed of decreasingly low quality, and no new varieties are being developed by the seed system. The project provided improved wheat seed to participating farmers and trained them in on-farm quality seed multiplication.

Farmers in Mongolia monocrop spring wheat because it is the only crop that has a market and offers farmers a reasonable price. It is also the only crop for which improved seed is sometimes available (imported from the Russian Federation). Continuous monocropping has contributed to current low production levels and the long-term unsustainability of the production system.

The project has identified a need for locally produced malting barley; at present all malt for the relatively large local brewing industry is imported. Spring barley is one of the most suitable grain crops for Mongolia and has been produced by farmers in the past. It is more drought-tolerant than wheat and also higher yielding. The project has provided participating farmers with quality barley seed for the 2001 season so that they can produce malting barley seed to sell to other farmers. Other suitable alternative crops are buckwheat, canola, sunflower, and chickpea, but they need to be tested to identify appropriate varieties.

Impact of Conservation Agriculture on Farm Productivity Parameters

The impact of CA on farm productivity has been measured by three main parameters:

- Soil moisture retention
- Yield
- Farm economics

Soil moisture was measured prior to seeding and after harvest, under both chemical and mechanical fallow and a soil depth of up to 60 cm (see Table 1).

Moisture content under chemical fallow was on average 10% higher than under mechanical fallow. This is a great benefit for farmers in Mongolia, where because of lack of precipitation a wheat crop can be grown only every other year. Conservation agriculture technology also had a significant

Table 1. Soil moisture analysis in 2001 (mm).

		Prior to seeding		After harvest	
Farms	Soil depth (cm)	Chemical fallow	Mechanical fallow	Chemical fallow	Mechanical fallow
Khan Jargalant	0-10	11.0	11.6	14.5	13.7
	10-20	13.2	12.7	15.4	12
	0-60	46.9	45.8	59.3	42.1
Urgatsiin Undraa	0-10	21.3	22.6	10.4	10.8
	10-20	22.5	20.6	12.4	10.3
	0-60	92.0	87.8	43.7	47.1
Zurt Undur	0-10	5.6	5.4	10.8	10.8
	10-20	9.4	8.1	12.3	12.3
	0-60	36.9	36.6	46.9	46.9
Enkhganga	0-10	25.8	21.0	16.5	11.8
	10-20	25.8	18.5	19.0	12.8
	0-60	99.5	68.4	63.0	40.3
Àr Tarkhi	0-10	18.5	26.2	18.2	17.3
	10-20	24.8	33.7	18.5	18.2
	0-60	89.6	98.0	68.5	70.7
Average	0-10	16.4	17.4	14.1	12.9
	10-20	19.1	18.7	15.5	13.1
	0-60	73.0	67.3	56.3	49.4

Source: PSARTI (National Agricultural Plant Research Institute).

impact on wheat yields, as shown in Table 2. On average yields increased by about 70%, from 0.6 t/ha to 1.1 t/ha.

A cost assessment has been made for both conventional mechanical fallow and chemical fallow. The relevant cost elements are listed in Table 3.

The main cost of chemical fallow is herbicide (Roundup), and the economic viability of conservation agriculture depends to a large degree upon the cost of glyphosate herbicide. Under mechanical fallow, which is based on the intensive use of machinery, major costs are fuel/lubricants, depreciation, and spare parts.

The cost of chemical fallow has been estimated at 18,118 tugricks per ha, which is about 12,000 tugricks, or 40%, less than moldboard fallow, and at 7,000 tugricks per ha, or 28%, less than blade plow fallow.

Table 2. Comparative yields in project farms, 2001.

Project farms	Long-term average yield (t/ha)	Yield from mechanical fallow (t/ha) (2001)	Yield from chemical fallow (t/ha) (2001)	Changes in yield (%) (2001)
Khan Jargalant	0.3	0.11	0.64	+480
Urgatsiin Undraa	1.02	1.03	0.88	- 15
Zurt Undur	0.48	0.38	0.8	+110
Enkhganga	0.56	0.54	0.8	+ 48
Àr Tarkhi	1.27	1.14	2.4	+110
Average		0.64	1.10	+ 72

Table 3. Estimated costs of chemical fallow and conventional fallow (tugrics/ha).

Cost items	Chemical fallow	Mechanical fallow: With mold board plow	Mechanical fallow: With wide blade plow	Difference: With mold boardplow	Difference: With wide blade plow
Variable costs					
Fuel	1480	16040	12560	-14560	-11080
Lubricants	125	1600	1200	-1475	-1075
Wages	300	2100	1400	-1800	-1100
Herbicide	14000	-	-	+14000	+14000
Water Transport	430	-	-	+430	+430
Food allowance	160	900	700	-740	-540
Total variable costs	***16495***	***20640***	***15860***	***-4145***	***+635***
Fixed costs					
Depreciation	850	5600	5400	-4750	-4550
Spare parts	360	3030	3100	-2670	-2740
Land fee	560/390	560	390	-	-
Labor protection	23	50	50	-27	-27
Loan interests	-	500	350	-500	-350
Total fixed costs	***1623***	***9740***	***9290***	***-8117***	***-7667***
TOTAL COSTS	18118	30380	25140	-12262	-7032

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The Role of Wheat in the Diversified Dryland Cropping Systems of Central Asia

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Wheat is the major dryland crop in Central Asia and one of the two major irrigated crops. Dryland agriculture is the main production system in Kazakhstan, while in the rest of the region irrigated agriculture predominates. In northern Kazakhstan spring wheat is traditionally grown in summer fallow-small grains programs; in the rest of the region winter wheat is cultivated in fallow-based rotations in the drylands and in cotton-wheat rotations under irrigation. Between the collapse of the Soviet Union in 1991 and the establishment of independent states in Central Asia, the role of wheat changed dramatically in all countries of the region. In most countries the role of wheat increased, whereas in Kazakhstan the area under wheat decreased markedly. Studies in the dryland areas of Central Asia were conducted to determine the possibilities for reducing or eliminating the area under fallow, because it is subject to soil erosion. Also, several crops were tested as possible alternatives to spring or winter wheat as part of an effort to increase sustainability of production systems though crop diversification.

Materials and Methods

The Shortandy site in northern Kazakhstan is located in the semiarid steppe on chernozem soil (heavy clay loam with 3.5% humus content). Annual average precipitation is 350 mm with maximum rainfall in July; one third of precipitation falls as snow. Annual average air temperature is 1.2^{0}C.

Studies on crop rotations were conducted during 2000-2002. The widespread crop rotation fallow-wheat-wheat-barley was taken as control. In two other rotations summer fallow was replaced by oats or dry pea. The establishment of crop rotations started earlier so that during the study years it was possible to evaluate all crops included in the three-crop rotation. Phosphorus fertilizer (60 kg P/ha) was applied once every four years during fallow or before planting the crop after fallow.

Experiments in rainfed conditions of southeastern Kazakhstan (Almalybak) were conducted on light chestnut soils (heavy clay loam with 2.4% humus content). Annual average precipitation is around 350 mm, and annual average air temperature is 7.5^{0}C. Studies on crop rotations were conducted during 2001-2002 under arid and semiarid conditions. In the semiarid zone nine crops were sown on stubble-covered land. In the arid zone (annual average precipitation: 220 mm) a comparative study of eight crops was conducted on fallow (two years) and stubble-covered land (one year).

The Krasniy Vodopad site in southern Kazakhstan is located in the semi-arid steppe (average annual precipitation: 420 mm, mostly in winter and early spring). The climate is continental, but much warmer (average annual temperature: 14.1^{0}C) than in the southeast. The major crop is winter wheat usually sown on fallow. In a crop rotation experiment, winter wheat sown during two years after summer fallow and after alfalfa was compared to wheat sown after chickpea and to continuous wheat.

The Zhany Pahta site in Kyrgyzstan is located in the semiarid steppe (average annual precipitation: 300 mm; average annual temperature: 8.5^{0}C). Crop rotation studies included winter wheat after fallow compared to winter wheat after field pea and safflower. Fertilizers were applied at 60 kg/ha of P before fallow, or crops replacing fallow, and 45 kg of N to wheat. Two more treatments of improved fallow were studied: with manure applied at the rate of 30 t/ha and retention of straw of the harvested crop.

Results

Studies on crop rotations in dryland conditions were conducted in Shortandy, northern Kazakhstan, to compare four-year rotations. The standard crop rotation was a generally adopted rotation of summer fallow with three consecutive years of small grains: summer fallow-wheat-wheat-barley. This was compared to continuous cropping in which summer fallow was replaced by oats or field pea.

Yield data were collected in 2000, 2001, and 2002. All three years were relatively favorable as far as precipitation rate is concerned. The year 2000 was characterized by a very rainy period prior to sowing and before tillering of small grains and a very dry period between wheat tillering and heading. In contrast, 2001 featured dry cool weather during the first part of the spring wheat vegetative period and a very rainy period from jointing to grain-filling, which caused a rather intense outbreak of plant diseases. During the 2002 vegetative period rainfall was well above average and accompanied by warm temperatures, leading to a higher than normal occurrence of plant diseases. On average for the three years and during each of them, grain yield was affected by placement of wheat after fallow or other preceding crops (Table 1).

Spring wheat grain yield was highest after summer fallow, with an advantage of 20-25% over wheat yield after oats and dry pea, respectively. The advantage in terms of available stored moisture of summer fallow over stubble-covered land at spring wheat sowing time during two years amounted to 20-30 mm in a 1-m layer, but in 2001 it was 20 mm higher in stubble-covered land. There was no significant difference between the yield of wheat sown after wheat compared to wheat after oats or dry pea.

Barley yields were higher than those of wheat by 65%. However, barley yielded more in rotation with oats and fallow, and less in rotation with dry pea, which indicates that in dryland conditions of northern Kazakhstan food legumes do not play a positive role as predecessors of small grains. An additional negative factor associated with the dry pea rotation was weed infestation, which was notably higher than in the small grains-summer fallow-or-oats rotations. Average weed density in the dry pea rotation was substantially higher, especially of grass weeds (mostly wild oats). Average dry weight of weeds for the three years was 9.9, 10.1, and 19.2 g/m^2 in rotation with fallow, oats, and dry pea, respectively. It is important to emphasize that the dry pea was not treated with chemicals, while the small grains were sprayed with 2,4-D herbicide.

When oats replaced fallow, which led to continuous cropping, it yielded as much as barley, and dry pea grain yields were comparable to those of spring wheat. Thus, replacing summer fallow with oats and dry pea considerably increased grain yield of the total area, including summer fallow.

In all three years grain yield from the total area, including fallow land, was the lowest from the fallow-wheat-wheat-barley rotation. Replacing fallow with oats increased grain production by 30% on average, with little difference among the three years. When fallow was replaced by dry pea, total production increased by 10%. Thus, the two treatments with continuous cropping instead of small grain-summer fallow rotations increased grain production from the total area. Most important is the fact that reducing or removing summer fallow from the cropping system will contribute significantly to conservation agriculture, because fallow is the only farming practice causing soil erosion and losses of organic matter under soil conservation tillage.

Studies have shown there are real possibilities for crop diversification in northern Kazakhstan. When sown after summer fallow, bread wheat provided the highest grain yield but proved to be least economical because grain prices are currently affected by the world market, and there has been surplus grain production in Kazakhstan for three years in a row and, in 2002, good grain production in the rest of Central Asia and Russia (Table 2). Durum wheat provided yields comparable to those of bread wheat but was more profitable thanks to better prices.

Food legumes did well as far as economics is concerned. The best in terms of yield was field pea, with grain yield two third of bread wheat. Lentil was a little lower yielding, but the profit margin was

Table 1. Average grain yields of wheat, barley, oats, and dry pea in three crop rotations, northern Kazakhstan, 2000-2002.

Crop sequence	Crop rotation F-W-W-B	O-W-W-B	P-W-W-B
	Grain yield (t/ha)		
Fallow (or oats, pea)	-	2.67	1.60
Wheat	2.07	1.72	1.64
Wheat	1.71	1.48	1.50
Barley	2.62	2.84	2.24
	Grain yield from total rotation area (t/ha)		
	1.59	2.07	1.75

Table 2. Comparing average yields and profit margins of different crops in northern Kazakhstan, 2000-2002.

Crop ranking	Grain yield (t/ha)	Crop ranking	Profit margin (%)
1. Bread wheat	2.45	1. Lentil	176
2. Durum wheat	2.40	2. Dry pea	170
3. Field pea	2.02	3. Buckwheat	103
4. Millet	1.67	4. Millet	78
5. Buckwheat	1.47	5. Durum wheat	61
6. Lentil	1.43	6. Mustard	46
7. Mustard	1.14	7. Bread wheat	22

the same: 170% and 176%, respectively. Chickpea failed in one out of three years, because the Russian variety used in experiment proved to be susceptible to Ascochyta blight. New chickpea varieties from ICARDA resistant to Ascochyta blight were identified, but they have not yet been released yet. In the two years when chickpea did not fail, its yields were comparative to that of field pea and higher than that of lentil.

Millet (proso) on average gave significantly lower grain yields than bread wheat. It did not do well in favorable weather with good rainfall, but better in relatively dry years. But even at lower grain yields it proved to be much more profitable than bread wheat, with a profit margin as high as 78%. Buckwheat grain yields were on average 60% those of bread wheat, which was enough to have a better profit margin (103%). Buckwheat competed better with wheat under favorable weather conditions. Oilseeds failed mostly because of serious damage by insect pests, despite control treatments. As one can see, all alternative crops were more profitable than bread wheat due to low wheat prices.

Studies were conducted in arid and semi-arid rainfed areas of southeastern Kazakhstan. In the dryland area, no crop management practice was as successful as alternate summer fallow and crop (Table 3).

Barley is suitable for planting in spring for it will produce grain yields equal to winter wheat yields. Oat grain yields were less stable than barley yields (higher than barley in wet years and lower in dry years). Food legumes were low yielding (50% of winter wheat yield), but they may compete, because their market prices are three to four times higher than wheat prices. Safflower is another alternative oilseed crop with good potential. The yields of safflower were about 67% of wheat yields. In 2002 wheat price went down, while safflower price went up, making this crop very promising for farmers. Many conclusions reached in the dryland area were repeated in the semi-arid area with more reliable rainfall, but growing on stubble land was feasible.

During three years at the Krasniy Vodopad station, in addition to growing winter wheat two years after summer fallow and two years after alfalfa, winter wheat was sown after chickpea. Of the three years, 2000 and 2001 were dry, and 2002 was rainy (60% more rainfall than usual). The data obtained very distinctly showed that chickpea is a very good alternative as a food legume and to improve wheat yield (Table 4).

Continuous winter wheat produced a double crop in the wet year, but on average it was rather low. In both dry and favorable years summer fallow provided very reliable grain yield, on average increasing wheat yield by 76%. But the second year after summer fallow, wheat yield fell dramatically, with only a 23% advantage over continuous wheat. Alfalfa grown for four years proved to be very good preceding crop for wheat, providing 63% higher wheat yield than continuous cropping and 93% of wheat after summer fallow. Remarkably, the second wheat cycle after alfalfa produced more grain than wheat sown the second year after fallow. But most importantly, chickpea proved to be of the same value for consecutive wheat as alfalfa. This is explained by the fact that legumes improve nitrogen availability for crop. Fallow increased nitrate content in the arable layer at sowing and heading time by 30-34%, alfalfa, by 41-46%, and chickpea, by 34-42%. It is important to note that alfalfa's carryover was noticeable for two years, while the second year after fallow nitrate content was only 17-25% higher than in continuous wheat. Thus, in the conditions of southern Kazakhstan, the best cropping system may include growing wheat for one year after fallow, two years after alfalfa, and one year after chickpea.

Chickpea itself gave very low grain yields in dry years: 0.29-0.45 t/ha and good yield (1.24 t/ha) in wet year. On average chickpea grain yield was almost half that of continuous wheat. But the crop produces good income for the farmer, because market prices are four times higher than for wheat.

Table 3. Comparative crop yields on fallow and stubble-covered land in arid rainfed area in southeastern Kazakhstan.

Crop	On fallow 2001	2002	Mean	On stubble in 2001
	Grain yield (t/ha)			
Winter wheat	0.63	1.79	1.21	0.33
Spring wheat	0.40	1.00	0.70	0.19
Spring barley	0.68	2.27	1.48	0.22
ats	0.38	2.40	1.39	0.11
Millet (proso)	0.37	1.39	0.88	0.09
Lentil	0.29	0.89	0.59	0.08
Chickpea	0.32	0.99	0.65	0.13
Safflower	0.77	0.85	0.81	0.43
$LSD_{5\%}$ (t/ha)	**0.11**	**0.35**		**0.06**

Table 4. Wheat grain yield as affected by crop sequence in southern Kazakhstan.

Preceding crop or fallow	Year 2000	2001	2002	Mean
	Grain yield (t/ha)			
Continuous wheat	0.70	0.96	1.78	1.15
Summer fallow	1.62	1.42	3.01	2.02
Wheat after fallow	0.93	1.10	2.22	1.42
Alfalfa	1.47	1.32	2.86	1.88
Wheat after alfalfa	1.27	1.40	2.17	1.61
Chickpea	1.53	1.38	2.74	1.88

In Kyrgyzstan the mos common crop rotation in dryland farming is summer fallow followed by grains two-three years continuously. In our trials there were three types of fallow with an attempt to improve it by applying manure or straw. It was compared to replacement of fallow with chickpea, dry pea, and safflower. The most important advantage of summer fallow is moisture accumulation. In both years there was no significant difference between fallow treatments in soil moisture content in spring.

Cropping reduced soil moisture, but not very much: by 12-14%. Wheat grain yield wasn't significantly affected by improved fallow practices and was reduced by replacing fallow with safflower but not dry pea (Table 5).

Types of fallow didn't significantly affect wheat yields. Application of manure during fallow on a background of commercial fertilizer gave some positive results. Sowing dry pea instead of summer fallow was very successful, because wheat yield was only slightly lower than after summer fallow. At the same time dry pea produced 1.34 t/ha of grain without fertilizers and 1.58 t/ha with fertilizers. Chickpea was tested only in 2002 and provided grain yield comparable to field pea. Safflower apparently was not the best preceding crop for winter wheat on dryland, reducing wheat yield by 24% as compared to fallow. The safflower crop produced 1.46-1.95 t/ha of seeds without fertilizer and with it, respectively, which definitely compensated for some of the reduction in wheat yield.

Economical assessment has demonstrated that the current practice of fallow-wheat rotation was the worst possible scenario for farm profitability. Most important were market prices, which were not in favor of wheat. During the 2002 harvest, market prices for 1 ton of different crops were the following: wheat: $130; dry pea: $425; chickpea: $930. Because of this net profit from one hectare of wheat, dry pea and chickpea amounted to $87, $717, and $1355 respectively. Even if the chickpea price were somewhat lower and farmers harvested the chickpea by hand, it would still be much more profitable than wheat. With this level of difference in favorable years, farmers can absorb losses in very dry year if chickpea fails. Remarkably, fertilizers were not profitable for wheat, reducing net profit per hectare from $87 to $27, whereas fertilizer application on field pea and chickpea was profitable, increasing net profit by $28 and $105, respectively.

Discussion

Crop rotation studies have provided new data for improved cropping systems. They have shown that crop production from total cropland in northern Kazakhstan can be increased. More importantly, they lead to a reduction in the area under summer fallow. This will have a positive environmental effect as summer fallow causes wind and water erosion. Recommendations justifying fallow usually recognized this danger but recommended practicing strip-cropping. Actually this recommendation was never carefully followed in the Soviet Union and completely stopped after the system of governmental control was replaced by private farming. Today this practice is more like weedy fallow because farmers don't have the resources to cultivate fallow during summer.

The experiment was laid out on rather small plots, where soil processes were observed purely with no interference of wind erosion, while large commercial farms in the region fallow standard 400 hectares fields. According to Eskov (1996), 80-90% of soil humus losses in northern Kazakhstan are associated with soil erosion. According to Shiyatiy (1996b), summer fallow fields erode most during snowmelt runoff. If soil losses from runoff on wheat stubble of southern chernozem are equal to 1, then this coefficient after summer fallow would be 33. In the spring of 1983, he observed that intense runoff of snowmelt on fallow caused rill erosion as deep as 10-20 cm and soil losses of 60 to 450 t/ha in washed out areas. Conservation tillage using regular equipment for weed control during fallow destroys all wheat crop residues (1.5-2 t/ha) after three operations, whereas at least four tillage are done during the season.

In a number of studies in northern Kazakhstan and Siberia, soil nitrates were observed to leach during fallow to a depth of 3-5 m and deeper (Kiryushin, 1996).

Table 5. Winter wheat grain yield as affected by summer fallow or preceding crops in dryland conditions of Kyrgyzstan.

Fallow or preceding crop	No fertilizer		Mean	Fertilizer		Mean
	2001	2002		2001	2002	
	Grain yield (t/ha)					
Fallow	1.36	2.66	2.01	1.56	3.24	2.40
Fallow+ manure	1.43	2.39	1.91	1.70	3.36	2.53
Fallow+straw	1.28	2.64	1.96	1.48	3.10	2.29
Dry pea	1.29	2.50	1.90	1.48	3.08	2.28
Safflower	0.93	2.19	1.56	1.14	2.51	1.82
$LSD_{5\%}$	0.09	0.10		0.09	0.16	

Summarizing studies in these two regions, the author concluded that more frequent summer fallow leads to greater nitrogen losses, especially under intensive mechanical tillage and insufficient phosphorus fertilizer. At Shortandy, organic matter losses were not substantial during 35 years and depended on frequency of fallow (Akhmetov et al., 1998). After 35 years, under wheat-fallow rotations with 50, 33, and 25% fallow, a loss of organic matter made 10%, 11%, and 2% of original humus respectively since 1962, when humus content comprised 3.9%. Under six-field rotation (17% fallow) and under continuous wheat, no changes were observed at all. It should be noted, conservation tillage in combination with straw spreading of the harvested crop was used during all years of the experiment.

The issue of reducing the area under summer fallow was raised by Suleimenov (1988) 15 years ago but has not been accepted by scientists in Kazakhstan despite 20 years of data supporting it. The abstracts of a recent conference in Astana, Kazakhstan, indicate that there was just one paper suggesting replacement of black fallow with cover crop fallow for forage production (Konopyanov, 2003). In another paper (Khabirov et al., 2003) it was stated that there was no difference in wheat yield obtained after black fallow and fallow with cover crops oats and oats-pea used for forage, but the authors reached no conclusions based on this fact. The practice of summer fallow once every four years was advocated for so long that nobody wants to oppose it now. Many farmers don't use fallow but scientists still continue to recommend the practice.

Dvurechenskiy (2003) emphasized that summer fallow should occupy 25-33% of area under crop rotation. Shiyatiy (1996a) also concluded that summer fallow should occupy 33% of rotation area. Viurkov (2003) once again recommended that summer fallow should include sowing kulissy (mustard strips sown on fallow land 10-12 m apart in July to produce short barriers) to trap snow drift during second winter of fallow for improving water storage. This was recommended by Bakayev in 1975, but worked well only on small plots. When producers tried it on a large scale, it caused severe erosion by water and was stopped. This is a very important issue: scientists often conduct trials on small plots and test developed technologies on a small scale. Later when the technologies are implemented on a large scale, they may cause serious problems that exceed any advantages they were supposed to bring farmers.

Scientists working in the steppe zone of western Siberia also are in favor of summer fallow once every four or five years (Moshchenko and Bormotov, 2000). However, a farmer (Schnider, 2002) recognized as the best in the region relates that distinct from other farmers in the region he practices continuous grain cropping: wheat (67%) and barley and oats (33%). Since his farm was established in 1994, the area cropped increased from 1,500 ha to 21,000 ha by leasing land from other less successful landowners. This farm is located near the border with North Kazakhstan province (average precipitation: 300 mm). Average grain yield on this farm was 2.25 t/ha and 1.87 t/ha in 1994-1998 and 1999-2001, respectively, or 27% and 21% higher than the local average from fallowing 12.2% of the cropland. One of reasons for his success is the use of John Deere machinery, but the fact that he eliminated summer fallow contrary to recommendations by scientists is remarkable.

Several alternative crops were more economical than spring wheat in northern Kazakhstan thanks to low wheat prices. Wheat nonetheless dominates in the cropping system even more than before the transition (Table 6).

The total cultivated area in Kazakhstan decreased dramatically (in 2001, it was only 48% of the area sown in 1990) due to the dramatic changes in farm size and the removal of governmental control, and to the liberalization of input and output prices. Wheat area decreased by 23%, which led to further increases in the wheat portion of the total cultivated area, from 40% in 1990 to 64.6% in 2001. The barley area was contracted by half, but its share in the cropping system remained the same. The area under other small grains (millet, rye, oats, and buckwheat) decreased four-five times. Farmers in Kazakhstan stick

Table 6. Change in cropping system and crop ranking as affected by the transition to a market economy in Kazakhstan.

	1990			2001	
Crop ranking	000 ha	% of sown area	Crop ranking	000 ha	% of sown area
1. Wheat	14,070	40.0	1. Wheat	10,850	64.6
2. Perennial forage	4,568	13.0	2. Perennial forage	2,222	13.2
3. Barley	3,660	10.4	3. Barley	1,751	10.4
4. Annual grasses	3,498	9.9	4. Oilseeds	347	2.1
5. Maize for forage	2,282	6.5	5. Annual grasses	267	1.6
6. Millet (proso)	781	2.2	6. Oats	183	1.1
7. Rye	769	2.2	7. Millet	115	0.7
8. Oats	382	1.1	8. Maize (forage)	72	0.4
9. Oilseeds	266	0.8	9. Buckwheat	57	0.3
10. Buckwheat	218	0.6	10. Rye	44	0.3
11. Pulses	159	0.4	11. Pulses	24	0.1

to one crop because of inertia and despite low wheat prices several years in a row, in contrast to farmers in western countries who readily switch to crops with market demand.

Oilseeds are the only crops whose sown area increased during transition along with reduction of total cultivated area. This increase was achieved thanks to two crops: safflower and sunflower. Pulses were the least attractive crops in the past and this has worsened. Certainly pulses are not for large farms as there are problems with losses during harvest. But on small areas farmers can achieve good yields and generate good profits.

The share of perennial grasses remained at the same level. Perennial grasses include some alfalfa under irrigation but mostly it is crested wheat grass sown first of all on light textured soils for strip cropping to protect wheat from wind erosion. Annual grasses and maize for silage both proved to be uneconomical and their production was stopped very quickly.

Certainly, alternative crops will not replace wheat on a large scale, but they may be a good source of income for small farmers. Most alternative crops require special field activities which are not feasible on large farms. Wider adoption of food legumes may contribute to increase production of plant protein for the population of Central Asia, which is specially important for the poor.

Conclusions

1. Wheat is the main dryland crop in Central Asia, occupying 65% of sown dryland area. Considerable share of dryland is covered by summer fallow (10-30% of crop rotation area).
2. Wheat area in the drylands decreased dramatically during the transition period, but considerably less than that of other crops, which resulted in greater predominance of wheat in cropping systems.
3. Summer fallow is traditionally recognized as an integral part of dryland systems in Central Asia, but recent research shows that summer fallow may be replaced with cereal grains, food legumes, and forages.
4. The wheat or summer fallow area may be partially replaced by alternative crops that are more profitable than wheat under current market prices. They will not replace wheat on a large scale but may be an important source of income for small farmers and provide more plant protein and edible oils for local markets. Introduction of legumes into crop rotations will improve soil fertility for higher yields of consecutive wheat.

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The Impact of Genetics and Genomics on Wheat Quality Improvement

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Abstract

This paper discusses how genetic and genomic tools may be used to understand the genetical and molecular control of cereal quality and to develop tools for its manipulation by conventional and genetic engineering approaches. Comprehensive genetic maps are a first step in the genetical and molecular analysis of traits and these now allow the dissection of the genetical control of complex traits. As an example, data on the genetical control of grain protein content in UK winter wheats is presented. From a series of field trials, several potentially useful new QTLs were identified on chromosomes 2B, 5D, 6A, 6B, and 7A which can be targets for marker-assisted selection. Expressed sequence tags (ESTs) and cDNA microarrays identify candidate genes involved in differences in quality and a means for understanding the molecular control of endosperm development. This paper gives data on the use of micro-arrays for identifying differential expression of genes during early endosperm development. Genetic engineering provides a complementary tool to conventional breeding for cereal quality modification, and the prospects and problems of applying the technology for wheat end-use quality improvement are discussed.

In this millennium, the production of new varieties adapted to novel end-uses will be achieved either by conventional cross breeding, or by genetic modification using isolated, cloned homologous, or heterologous genes. Both methods will rely on a greater understanding of plant genetics, physiology, and metabolism, to identify the genes that mediate plant performance. This will allow a more targeted manipulation of phenotype and will rely heavily on the development of advanced genetic and genomics technologies. Emerging tools will enable the discovery and manipulation of new desirable genetic variation that can be combined into the next generations of crop varieties, designed to meet specific challenges of the new economic and environmental constraints on farming, and the specific requirements of end-users.

Simplistically, the wheat grain can be divided into three constituents: the germ, bran, and endosperm. All three are complex structures made up of different constituents. Eighty percent of the endosperm is made up of starch, and most of the remainder is protein. Generally, the endosperm composition has received most attention with respect to the genetical analysis and manipulation of quality traits, since proportionally, this is, by far, the greatest component. However, the composition of the embryo and the grain coats, the pericarp, and aleurone, is complex and contains a range of constituents whose biochemistry is partially known, but whose genetic control is very poorly understood. This paper describes how advances in genetics and genomics are contributing to our understanding of the genetic and molecular control of cereal quality and methods for its manipulation using conventional breeding and genetic engineering.

From Phenotype to Genotype: Traits to Genes

The first step towards understanding the whole genetics of individual crop plants is to develop comprehensive genetic maps. Good genetic maps based on molecular marker technologies are now available for all major cereal species, including wheat. Presently, the major use of genetic maps is to locate genes of interest so that the maps can be fully annotated with the locations of genes, be it for quality, agronomic performance, disease resistance, adaptability, or any other trait, so that they can be manipulated in a directed manner by marker-assisted selection. Much of the variation for important quality traits in wheat is quantitative in nature and controlled by many genes of small effect acting together, so called QTLs.

QTL analysis in crop species with complex genomes is an important tool that allows the location of multiple loci such as those involved in quality differences. This analysis is complicated in wheat by the complexity of its polyploid genome, with the three genomes interacting in the regulation of one trait. In addition, low levels of polymorphism in molecular markers (Chao et al., 1989), especially in the D genome of wheat, make it very difficult to construct complete genetic maps. To produce complete maps, researchers have in the past resorted to studying very wide crosses, such as that of the ITMI population, to increase the chances of finding polymorphic markers. However, to study quality traits, crosses need to be made between much more closely related varieties to ensure the results are relevant to the modern market.

An example of the application of genetic maps for new gene discovery for end-use quality can be illustrated by our work to identify novel loci and alleles regulating grain protein content in wheat, in order to find genes which could be used to boost protein levels in UK varieties without causing a subsequent loss in yield. In a major study, two parental lines, Avalon and Hobbit Sib, were studied, which represent parentages of UK varieties with hard textured grain, high protein, and good bread-making quality (BMQ); and soft, low protein, suitable for biscuit making, respectively.

Additionally, these varieties differ only in one high-molecular-weight (HMW) glutenin subunit (Hobbit Sib has a null allele at the *Glu-A1* locus, and Avalon produces the subunit 1 band). This suggests that they can offer insight into important factors involved in BMQ other than the major storage proteins. Avalon has also been shown consistently to yield better than would be expected for its high protein content, making it an ideal candidate for investigating yield-independent protein alleles.

A population of 97 recombinant inbred lines (RILs) was produced by single seed descent from the cross between the parents, being at F_7 for this study. The results from two years of field trials were gathered, analyzed, and collated. In 2000, the population was planted out in spaced plant field trials consisting of one-meter row plots of 11 plants of each line, hand-dibbed, in a triplicated block experiment. In 2001, 1 m x 6 m drilled plots of each line were sown out in a triplicated experiment, alongside dibbed rows of all lines. Yield components were measured for all lines (spikelet number, seed weight, grain number per ear, tiller number) in the dibbed rows; in addition, a yield assessment was made from the drilled plots in 2001. Following harvest, grain protein content was measured using near infra red reflectance spectroscopy (NIR) on a Bran and Luebbe Infra-analyser 2000. The protein measurements were calibrated according to calibration samples analyzed by the Dumas method.

For genetic mapping simple sequence repeat (SSR) markers were used. DNA was extracted from the leaves of seedlings of individual lines as described in Magrath et al. (1994). SSRs were analyzed as described in Roder et al. (1998), being run on 5% polyacrylamide gels and visualized by silver staining (Sourdille et al., 1998). Five different groups of microsatellites were used "gwm" (Roder et al., 1998), "gdm" (Pestsova et al., 2000), specifically designed to map to the D genome, "wmc" (Wheat Microsatellite Consortium), psr (M.D. Gale, John Innes Centre, UK) and barc (http://www.scabusa.org). The genetic map was developed using JoinMap (Stam and Van Ooijen, 1995). and QTL analysis on the phenotypic data was carried out using QTL Café (http://web.bham.ac.uk/g.g.seaton/) and MapQTL software (Van Ooijen and Maliepaard, 1996).

In the RIL studies, single marker ANOVA detected a total of 35 markers across 13 chromosomes associated with significant ($P<0.05$) differences in grain protein content (Table 1). Of these, 12 markers showed consistent differences in both years of the study. Increased grain protein content was consistently associated with markers on chromosomes 1A, 2B, 2D, 3B, 5BS/7BS, and 6B, with Avalon contributing the increasing allele, and markers on chromosomes 3A, 6A, and 7A, with Hobbit Sib contributing the increasing allele.

QTL analysis by interval mapping of grain protein content showed significant QTLs on chromosomes 2B and 6B (Avalon contributing increasing effect) and chromosomes 6A and 7A (Hobbit Sib contributing increasing effect). The QTL on chromosome 2B (Figure 1) was located near *Xgwm644* and explained about 15% of the variation, and had significant Lod scores in both years. The QTL on chromosome 6A was located near *Xgwm334* and explained around13% of the variation, and had a significant Lod score in 2002 only. The QTL on chromosome 6B was located near *Xbarc24* and explained around18% of the variation, and had significant Lod scores in both years. The QTL on chromosome 7A was located near *Xbarc108* and explained between 8.8 and 10.3% of variation across the chromosome, and had significant Lod scores in both years.

Additionally, a separate analysis using recombinant substitution lines identified a QTL associated with the *Ha* gene for grain hardness on the short arm of chromosome 5D, with Avalon contributing the allele for increased protein.

Table 1. Marker means analysis of grain protein concentration on the Avalon x Hobbit Sib RIL population over two years. Only significant (P<0.05) consistent year-on-year differences are presented. Where the additive effect is positive, Avalon contributes the increasing allele; where the additive effect is negative, Hobbit Sib contributes the increasing allele.

Year	Chromosome	Marker	Position (cM)	Additive effect (%)	P value
2001	1A	*Xbarc83*	87.9	0.36	0.014
2002	1A	*Xbarc83*	87.9	0.3	0.0086
2001	2B	*Xgwm410*	10.1	0.28	0.0066
2002	2B	*Xgwm410*	10.1	0.21	0.0062
2001	2B	*Xgwm644*	10.9	0.28	0.006
2002	2B	*Xgwm644*	10.9	0.21	0.0069
2001	2B	*Xwmc179.1*	14.7	0.29	0.006
2002	2B	*Xwmc179.1*	14.7	0.21	0.0063
2001	2D	*Xwmc441.3*	124.1	0.29	0.0045
2002	2D	*Xwmc441.3*	124.1	0.17	0.0251
2001	3A	*Xgwm32*	62.8	-0.22	0.0463
2002	3A	*Xgwm32*	62.8	-0.18	0.0216
2001	3B	*Xbarc229*	141.3	0.25	0.0141
2002	3B	*Xbarc229*	141.3	0.17	0.0288
2001	5BS/7BS	*Xgwm537*	90.1	0.27	0.014
2002	5BS/7BS	*Xgwm537*	90.1	0.22	0.0062
2001	6A	*Xgwm334*	140.1	-0.29	0.0056
2002	6A	*Xgwm334*	140.1	-0.25	0.0022
2001	6B	*Xbarc24*	89.6	0.23	0.0452
2002	6B	*Xbarc24*	89.6	0.23	0.0076
2001	7A	*Xwmc9*	114.3	-0.31	0.0029
2002	7A	*Xwmc9*	114.3	-0.2	0.012
2001	7A	*Xbarc108*	115.2	-0.44	0.00007
2002	7A	*Xbarc108*	115.2	-0.29	0.0037

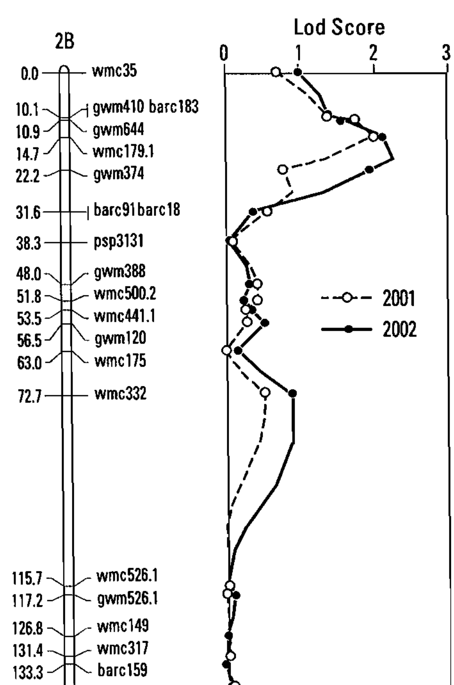

Figure 1. Interval mapping of chromosome 2B for grain protein content. One significant QTL detected (both years).

2001
Lod Score : 2.27
Significance*: 0.03
Peak of QTL: 19.7 cM
Additive effect: +0.2559%
% variation explained: 15.5

2002
Lod Score : 2.01
Significance*: 0.042
Peak of QTL: 14.7 cM
Additive effect: +0.3024%
% variation explained: 10.9

* permutation test, 500 permutations.

This study is the first to provide a complete analysis of grain protein content in UK wheat varieties. It has shown that it is possible to dissect the genetics of a difficult-to-measure and highly-environmentally sensitive character using modern methods of genetic analysis. It has shown that genetic control is complex, and there are no underlying major genes. This is the case of grain texture, where most of the variation is controlled by the major gene *Ha*, found on the short arm of chromosome 5D. Significant QTLs were identified on chromosomes 5D, 2B, and 6B (Avalon contributing increasing effect) and chromosomes 6A and 7A (Hobbit Sib contributing increasing effect) in data from both years. These effects were also relatively large, and, interestingly, dispersed between the parents. So, although Avalon is generally regarded as a high protein wheat, it carries alleles at certain loci for reduced grain protein relative to their homologues from Hobbit Sib, and vice versa. Thus, in this cross, genes for higher levels of grain protein are dispersed between the parents. Transgressive segregation for lines that contain more protein than Avalon is possible from this cross. Diagnostic markers for particular alleles could be sought / designed so that plant breeders could use this as a tool for protein content selection.

Functional Genomics: From Genes to Traits

Following on from mapping, the new science of genomics is enabling the understanding of the relationship between gene structure and function. This is being addressed, firstly, by sequencing whole genomes–for example, Arabidopsis and rice–and, secondly, by the accumulation of libraries of Expressed Sequence Tags (ESTs).

The first crop species to be completely sequenced was rice, and the release of the first draft sequences by groups in China and Syngenta in 2002 suggests that cereals have between 40,000-50,000 genes. Relating these genes to homologues in wheat and barley will be a major goal for cereal geneticists. The full genomic sequencing of wheat, however, is presently not a realistic strategy–mostly because of the high amount of repetitive DNA (80% of the wheat genome is repetitive DNA).

Thus, alternative ways of finding genes and gene sequence information in crop plants are either to clone individual genes of interest or to directly isolate the sequence of genes from their expression, where the sequence information in the messenger RNA can be 'captured' by making ESTs by reverse transcription from the RNA. The latter is easier, and ESTs can provide information on the structure and function of genes, and, through bioinformatics, can be identified by homology with other species, be it plant, animal, or bacterial. Also, isolating RNA from any particular specific tissue–for example, the endosperm–gives a description of what genes are expressed in that tissue. If RNA is isolated from many different tissue types, at several different times of the life cycle, then it is hoped, eventually, that all expressed genes can be captured by the RNA that they produce. However, as in whole genome sequencing, the challenge is then to ascribe function to these genes.

If we are to understand plant circuitry and how to modify seeds for quality attributes, we need to know where and when individual genes and groups of genes are expressed. Another new genomic tool to do this, used in conjunction with ESTs, is DNA microarrays, also known as DNA chips. This is where glass slides each containing the individual signatures of thousands of genes, either identified from sequencing genomic or copy DNA, are produced. Challenging these arrays with fluorescently labelled RNA from any tissue or growth stage will indicate which genes are expressed in that particular tissue, and thus give hints on which to manipulate. By following expression under different growth conditions, the spatial and temporal expression of groups of genes can be worked out, thereby indicating the ongoing metabolic processes and their control. Much of such work is being focused on the developing grain. Libraries are being produced from RNA extracted at different stages of development following anthesis, and expression patterns identified to discover the key metabolic enzymes involved in starch, lipid and protein deposition, and the cell cycle. Figure 2, for example, shows differences in gene expression for genes expressed early in endosperm development in studies carried out by Syngenta in a joint JIC-Syngenta collaboration looking at the control of grain development in wheat. This analysis has identified key genes in the pathways of grain development which can be targets for future genetic manipulation to increase grain size and hence yield.

Genetic Modification and Quality Improvement

Genetic modification allows the introduction of isolated individual genes from any biological source, and offers a huge variety of

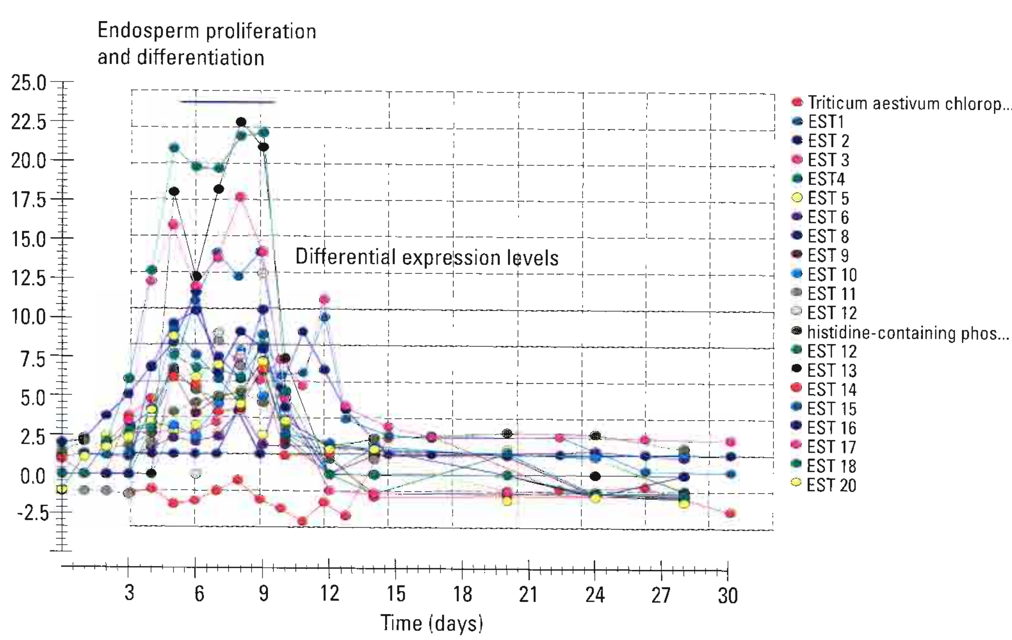

Figure 2. Differential expression of genes involved in endosperm development in wheat.

opportunities for the improvement of quality in cereals or even for the production of entirely novel crops for industrial use. Technologies for the genetic modification of most, if not all, cereal crops are now available, and their application in agriculture has more to do with the economics and politics of genetically modified organisms (GMOs) than biology or technology.

Despite the often negative public attitude to GMOs, particularly in Europe, 2001 saw a worldwide increase (19%) in the growth of GM crops to 52.6 million hectares, over 2000 (James, 2002). Globally the principal crops were soybean, maize, cotton, and oil-seed rape, with an overwhelming predominance of herbicide (glyphosate, glufosinate) resistance, and insect (Bt) resistance. The expectation is that this trend will continue and that, despite current problems, GM wheat and barley will eventually be grown in the UK and other countries, although there are barriers to be overcome in terms of public acceptability. The main issues are first, technology limitations, particularly the need to remove unwanted DNA of herbicide or antibiotic resistance genes; secondly, concerns about food safety, namely the unpredictability of transgene expression; and, thirdly, environmental, the problem of transgene transfer into non-GMO crops. Some of these limitations are technological, and solutions–for example, 'clean-gene' technology–are emerging where marker genes can be separated from the target gene leaving transgenic lines only containing the target genes. We have already demonstrated this in rice using an *Agrobacterium* system and are presently transferring the technology to wheat.

Other limitations require more information on the consequences of transgene insertion on target and non-target gene expression. This information is currently being produced in a number of studies. However, even if these limitations and problems are overcome, consumer choice has to be favorable, and industry has to produce more consumer-oriented transgenic crops than those available at present. It would be better to see the introduction of traits that have more advantages for the consumer in terms of quality, environmental, or health benefits, rather than just agronomic advantages for the producer. Some examples of possible targets in crop plants for quality traits in this respect are shown in Table 2.

Conclusions

In this millennium, genetic and genomics research on our cereal species have the potential to define the total extent of genetic variation for end-use traits, whether exhibiting simple or complex inheritance. This will allow plant breeders and geneticists to synthesize novel gene combinations by marker-assisted-breeding, using high through-put molecular marker systems, to produce 'designer' varieties. Also, there is the capacity to modify metabolic pathways by genetic engineering, leading to novel products and processes for industry. Besides leading to economic prosperity, this research can make an important contribution to world food security through the development of varieties much more resistant to pest and diseases both of major crops such as wheat, and of 'orphan' crops of the less developed world through comparative approaches. Clearly, we have only just started to see the fruits of this genomics revolution, which will lead, hopefully, to the evolution of a new Green Revolution.

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Table 2. Examples of targets for the genetic modification of wheat for quality attributes.

Character	Genes
Nutritional quality for animal feed	Phyt gene encoding phytase to increase phosphorus availability for animal feed
	DapA gene encoding di-hydro-di-picolinate synthase (DHDPS) to increase lysine content
Bread-making quality	High and low molecular- weight glutenin subunits
Industrial applications	Modified starches

The United States as an Economic Participant in World Wheat Production and Trade

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Given the unique focus of this paper relative to the general makeup of the conference proceedings, how it fits into the 1st Central Asian Wheat Conference should be addressed. "Why assess the economics of wheat in the US?" would seem to be a logical place to begin an introduction to this paper. The title seems to suggest there are two components to this question.

The first component is why economics in a conference that is largely focused on agronomic issues? You must recognize that the answer is coming from an agricultural economist, but being objective is still my underlying goal! Obviously, many of the issues facing the wheat industry in the Central Asian region are agronomic in nature. Varietal improvements, weed control, disease pathogens, irrigation techniques, and production management practices are needed to maintain wheat industry competitiveness. There likely will not be much argument from the attendees on this point. However, looking at a broader perspective suggests economic issues are just as essential and are likely closely related to the critical agronomic issues.

Questions on the economic feasibility of recommended production practices, accessing the capital to implement needed changes, market demand for specified quality attributes, relative transportation costs, and cohesive economic policy implementation are also critical to the long-term success of the region's wheat industry. Similar to the agronomic issues, many of these economic considerations are global rather than regional. Regardless of where production is located, it is important to recognize that wheat is an important internationally traded commodity. Therefore, it seems inappropriate to view wheat on a regional basis without considering the region's competitive position in world wheat trade. This global perspective is stressed in a study on the competitiveness of the Kazakhstan wheat sector by Longmire and Moldashev (1999). Thus, an important goal of this presentation is to provide a global perspective on the economics of wheat production and marketing.

Second, why a focus on the US since this is the Central Asian Wheat Conference? Given the need for a global perspective, it would be difficult to conduct a detailed analysis of the wheat industry throughout the world in the time and space allowed. Business economists often take an approach referred to as a "case study." That is, instead of trying to focus on the entire world market, select a specific firm or country and conduct a more detailed review. Since the US is a major participant in the world wheat market, it should make a good case study. Having additional knowledge of a major competitor can provide some useful information. Finally, there is a very practical reason for focusing on the US. The economics of the US wheat market is a subject about which I have some knowledge to share.

As a good economist, I will assume I have convinced everyone there is value in my presentation and move forward. Let's begin by looking at a broad overview of world wheat production and marketing and see where the US and Central Asia fit. Table 1 provides data on world wheat production by the world's major

Table 1. Major participants in world wheat production.

	10-year average		Current (2002/03)	
Participant	Production (MMT)	World share (%)	Production (MMT)	World share (%)
China	106.1	18.6	91.0	16.1
European Union	92.9	16.3	103.1	18.3
Newly Indep. States	70.9	12.4	96.4	17.1
Russia	37.0	6.5	50.6	9.0
Ukraine	16.3	2.9	20.6	3.7
Kazakhstan	10.0	1.8	12.6	2.2
Uzbekistan	2.6	0.5	5.0	0.9
India	65.2	11.4	71.8	12.7
United States	63.0	11.0	44.0	7.8
E. Europe	31.2	5.5	30.6	5.4
Canada	23.7	4.2	15.7	2.8
Australia	19.4	3.4	9.5	1.7
Argentina	13.2	2.3	12.5	2.2

Sources: US Department of Agriculture, *World Agricultural Supply and Demand Estimates;* US Department of Agriculture, *Grain: World Markets and Trade.*

producers. These data are presented by individual country and country groupings. Some countries are grouped because there is a logical economic or historical connection. The European Union, Newly Independent States (NIS) of the Former Soviet Union, and Eastern Europe are the groupings utilized in this presentation. Additionally, data are presented in the context of a 10-year average and the current marketing year. Given that production levels vary substantially from year to year, the longer-term perspective (10-year average) provides some sense of history.

The 2002/03 marketing year data provide a feel for the current situation. Note that China has traditionally been the world's major wheat producer with a 10-year average annual production of 106.1 million metric tons (MMT). China is followed closely by the European Union, with an average of 92.9 MMT. The NIS rank third, although production varies substantially by year. Note that current production for the NIS (96.4 MMT) is well above its 10-year average (70.9 MMT). Within the NIS, Russia, Ukraine, Kazakhstan, and Uzbekistan are the major producers. On average, India and the US have similar levels of wheat production, but India's current crop (71.8 MMT) is well above the US (44.0 MMT).

Eastern Europe is also a major producer, along with Canada, Australia, and Argentina.

Table 2 provides a similar presentation, but emphasizes world trade of wheat. Note that the largest producers are not necessarily the largest exporters. The US has traditionally been the largest wheat exporter, with an average market share of 29%. The current market share for the US is about 23%, suggesting its share has been declining. Canada, toward the bottom of the list of major producers, is the second largest exporter. Australia and Argentina are also relatively small producers that rank high on the list of exporters. Note also that the NIS countries (led by Russia, Kazakhstan, and Ukraine) are major players in current (2002/03) world wheat trade, with market shares ranging from 12.5 to 7.5%.

US Wheat Production

Now that a better sense of the world perspective has been established, let's focus on the case study, namely the US as a major competitor in world wheat trade. The US agricultural economy is well diversified with livestock accounting for a slightly larger share of farm receipts (51% for livestock and livestock products, led by beef cattle and dairy). Farm receipts are defined as the dollars received by farmers from the sale of crops and livestock, and receipts are a common measure of relative economic importance. Within the crops category, field crops account for the bulk of farm receipts. Wheat is the third most important field crop in the US, following corn (maize) and soybeans. Wheat accounts for about 24.1 million hectares of total crop production, which is just under 20% of the total area dedicated to US crop production.

The US has six official classes of wheat. The largest class, hard red winter (HRW) represents about 40% of total US wheat. HRW wheat is used primarily for blending to produce bread flour. HRW is produced primarily in the southern plains, including Texas, Oklahoma, and Kansas. Hard red spring (HRS) is a high-protein bread wheat produced primarily in the northern plains states of Montana, North Dakota, and South Dakota. Soft red winter wheat (SRW) is produced in the mid-western states and southeast region. SRW represents about 20% of US wheat production. Soft white wheat (SW) is grown primarily in the Pacific Northwest states of Washington, Idaho, and Oregon. SW accounts for about 13% of US wheat, and has both winter and spring varieties. Soft wheats (red and white) are used for cookies, crackers, flat breads, and Asian noodles. Durum wheat, also produced in the northern plains, is used for semolina to produce Italian-style pastas. Hard white, a fairly new class, is being produced in small amounts in the Pacific Northwest and southern plains.

Total supply of US wheat is currently averaging about 60 to 70 MMT. About 67% of total supply represents production, with

Table 2. Major participants in world wheat trade.

Participant	10-year average Production (MMT)	10-year average World share (%)	Current (2002/03) Production (MMT)	Current (2002/03) World share (%)
United States	30.5	29.0	23.8	22.6
Canada	18.3	17.4	8.5	8.1
European Union	16.5	15.7	15.5	14.7
Australia	14.4	13.7	8.0	7.6
Argentina	8.6	8.1	7.0	6.7
Newly Indep. States	6.9	6.5	25.7	24.4
Russia	1.1	1.1	12.5	11.9
Kazakhstan	3.7	3.5	5.5	5.2
Ukraine	1.7	1.6	7.5	7.1
E. Europe	3.2	3.0	3.5	3.3
India	1.2	1.1	5.0	4.8

Sources: US Department of Agriculture, *World Agricultural Supply and Demand Estimates*; US Department of Agriculture, *Grain: World Markets and Trade.*

beginning stocks typically representing another 30%. The US has historically been a significant holder of wheat stocks. Imports typically account for about 3% of total US wheat supply, with most wheat imports coming from Canada. Domestic use accounts for about 40 to 50% of total US wheat utilization, with food being the primary domestic use. Seed and feed use account for less than 20% of total domestic use. Feed use varies substantially from year to year, principally determined by the price of other feed grains (primarily maize). Exports account about 35 to 45% of total use, with ending stocks accounting for the remainder.

Economics of US Wheat Production

This initial discussion of wheat production economics in the US focuses on production costs and returns. The first thing to recognize is that costs of production vary substantially, depending on factors such as production practices, land quality, and farm size. Table 3 provides information to show the diversity of costs, depending on region and farm size. The idea is to clearly indicate that any discussion about average or typical production costs must represent a broad generalization. For example, looking at regional differences, per-hectare costs vary from $353.40 in the southern plains to $609.42 in the western region. Many parts of the western region are irrigated, making costs and yields higher. Production costs per kilo are less variable, but still vary from $0.167 in the southeast to $0.133 in the southern plains. A similar pattern exists with regard to farm size. In general, larger farms tend to have lower production costs. However, higher yields for the smallest size category (less than 20 ha) tends to reduce per unit costs relative to the second size category (20 to 160 ha).

With that recognition, lets look at a more detailed breakdown of production cost for what are called mid-cost farms (those farms that do not include the one-fourth of farms with the lowest costs and the one-fourth with the highest costs). This is likely the closest we can get to an average or typical US wheat farm. Table 4 outlines the cost structure for this group of wheat farms based on survey data for the 1998 crop. Three issues need to be highlighted relative to Table 4. First note that US wheat production tends to be capital intensive. Labor (both hired and non-paid) accounts for a very small share of total production costs. Machinery costs, land costs, and chemical inputs account for the bulk of costs. Yields reflect the intensive nature of wheat production, with close to 3 t/ha as the average yield of grain. Finally, returns can be negative when wheat prices are low as was true in 1998. Over the last 10 years, US farm level wheat prices have ranged from a high of $0.167 per kilo (1995/96) to $0.911 per kilo (1999/2000). The US average farm level price was $0.974 per kilo in 1998 (US Department of Agriculture, *Wheat Situation and Outlook Yearbook*). Actual prices received vary substantially by class and location. Government payments are not included in this cost and returns analysis, and such payments may compensate for a significant share of the negative returns.

Wheat from US farms is typically delivered to and sold at a local grain elevator located less than 50

Table 3. US wheat production costs, yields, and costs by location and farm size, 1998.

Category	Total cost per hectare	Total yield (kg/ha)	Unit cost ($/kg)
Region			
Southern Plains	$ 353.40	2649.7	$ 0.133
Western	609.42	4371.3	0.139
Northern Plains	369.14	2333.6	0.158
Southeast	504.28	3026.3	0.167
Farm size (ha)			
Less than 20	$ 494.72	3214.6	$ 0.154
20 to 160	446.72	2773.8	0.161
160 to 325	395.90	2723.6	0.145
More than 325	392.72	2851.4	0.138

Table 4. US wheat production costs for mid-cost farms, 1998.

Item	US $ per hectare	
Gross value		
Wheat grain	289.72	Grain yield = 2925.4 kg/ha
Wheat straw	7.76	Grain price = $0.099/kg
Operating costs:		
Fertilizer	$ 49.72	
Repairs	21.87	
Chemicals	20.66	
Seed	19.94	
Custom hire[a]	18.14	
Fuel/electricity	13.94	
Hired labor	5.91	
Other expenses	5.34	
Total oper. costs	$155.52	
Ownership costs:		
Machinery	$107.04	
Taxes/insurance	9.39	
Land	97.65	
Other costs:		
Unpaid labor	$ 35.41	
Overhead	6.90	
Total costs	$421.91	
Returns per ha[b]	- $124.43	

[a] Custom hire represents payment for work done by others for a specific price per hectare or per kilo.
[b] Returns per hectare are for a single year (1998), when wheat prices were abnormally low. Government payments are not included.
Source: Mir (2002).

kilometers from the farm. Local elevators can be cooperatives or privately owned, and typically provide marketing and storage services to growers. Many local elevators also provide additional services to wheat producers, including seed, fertilizer, fuel, and other inputs. From the local elevator, grain is moved by truck or rail to terminal elevators located on waterways or major rail lines. Terminal elevators usually focus on marketing large volumes of grain, but may provide some storage services. Terminal elevators move grain to export facilities or domestic mills either by barge or multi-car units trains. Some farmers bypass the local elevator and transport grain directly to terminal elevators, export facilities, or domestic mills. Location, competitive conditions, and personal preference generally determine whether a producer will use or bypass the local elevator.

US wheat is generally marketed based on description rather than visual inspection. Description is based on US Department of Agriculture (USDA) grades and additional industry specifications. USDA grades are consistent throughout the US and are based on: 1) test weight (weight per bushel which is a volume measure equaling 35,2391 liters); 2) % defects (heat damaged, foreign material, and shrunken/broken kernels); and 3) % wheat of other classes (contrasting and all other classes). Grade specifications are based on a maximum allowable percentage in each category. Failure to meet the standard in any category means a lower grade is assigned. Industry specifications vary by location, class of wheat, and year. These specifications generally include quality measures like protein content, dockage, and falling number.

Government Programs

US agricultural policy plays a significant role in the economics of wheat production. This is true for the production of all grains, oilseeds, cotton, and several other commodities. The discussion here will focus on farm programs specifically for wheat. Agricultural policy in the US is driven by a major piece of legislation passed every five to seven years typically called the Farm Bill, although the legislation is generally given a more formal name. The 2002 Farm Security and Rural Investment Act was passed in 2002, and covers the period from 2002 to 2007. A new Farm Bill will likely be debated beginning in 2006.

There are three primary domestic programs for wheat. The first is called the Direct Payments (DP) program. Almost all domestic wheat producers are eligible for the DP program. Under current provisions, wheat producers receive a direct payment of $0.019 per kilo times 85% of the producer's program yield on a pre-established acreage base. The program yield is continued from a base established by previous legislation, and is approximately equal to the farm's average annual yield between 1981 and 1985. The farm's acreage base is also established by formula based on previous area planted to wheat. The key point is that the direct payment is not connected to current production, but is fixed by a previously established base.

The second program, called the Counter Cyclical (CC) payment, is designed to make up the remaining difference between a legislated "target" price and the average farm level price received by wheat farmers. The current target price is $0,14 per kilo. Therefore, if the average farm level price and the Direct Payment combined is less than $0.14 per kilo, the CC payment program makes up the difference. Again, both payments are based on 85% of the producer's individual program yield times the acreage base, not the current level of production.

The final payment program for wheat is called the marketing loan program, and is based on the concept of a loan deficiency payment (LDP). The LDP provides a potential payment when the local market price is below the legislated loan rate. The US loan rate is currently $0.10 per kilo, but is adjusted for location. Thus, if the market price for wheat is below the loan rate, the producer can choose to take an LDP payment representing the difference between the market price and the local loan rate. The LDP is based on actual production for the current year. If the market price is above the loan rate, no LDP is authorized. Since the producer chooses when to take the LDP, the size of the LDP is determined by the price difference on the day the producer selects to receive an LDP. Since market prices change daily, the size of the LDP also changes daily. Each of the three payment programs also includes a legislated maximum payment amount per farm, which can be an issue for larger producers (US Department of Agriculture, *Farm Policy: Title I – Commodity Programs*; Vocke).

In addition to the three direct payment programs, wheat producers also benefit from several indirect programs. These program include such things as subsidized all-risk crop insurance, federal research support, transportation infrastructure development, and tax incentives for crop-based fuels.

The final set of programs impacting the economics of US wheat production is the export programs. Several are in place, so just the major programs are addressed here. The US Export Enhancement Program (EEP) is an export subsidy program that can be used for US agricultural products at the discretion of the USDA's top administrator (the Secretary of Agriculture). EEP was used extensively for wheat during the late 1980s and early 1990s, but has not been actively used since 1995.

Two export credit guarantee programs (GSM 102 and 103) provide credit guarantees to buyers of US agricultural products. The two programs are designed to provide short and long-term federal credit guarantees to buyers who may not be able to obtain credit from private sources. There are also several programs designed to fund overseas promotional activities for US agricultural products. The Market Assistance Program (MAP) and Foreign Market Development (FMD) are two examples of export promotion programs. Finally, the US continues to support a concessional sales and donation program commonly called PL 480. This program is designed to provide agricultural commodities to countries in dire need of food assistance (US Department of Agriculture. *Farm Policy: Title III – Trade*).

Conclusions

Issues related to the Central Asian wheat sector are clearly complex, are strongly influenced by economic variables, and cannot be addressed without considering the global nature of wheat production and marketing. A better understanding of the economic variables influencing world wheat production and marketing is critical to the wheat industry in Central Asia. All of the issues facing this region need to be considered in the context of a global market. The United States, along with several other major competitors, has a significant influence on the world wheat market. Hopefully, a better understanding of some of the economic variables influencing the US wheat sector will prove to be a valuable addition to the participants of this conference.

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Modern Trends in Wheat Production in the United States

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Wheat (*Triticum aestivum* L.) is grown in most states in the U.S. mainland. In 2002, 18,600 hectares were planted for an average yield of 2.366 tonnes per hectare. The total value of production was US $5,863,378,000 (USDA-NASS 2002). The primary production regions are the central plains from Texas through North Dakota; the western states of Montana, Colorado, Utah, California and Arizona; the Pacific Northwest; the eastern states of Ohio, Indiana, and Kentucky; the Mississippi River states of Missouri and Arkansas; and the mid-Atlantic states including Georgia and Virginia. Irrigated production is located mainly in California and southern Idaho. The six wheat-marketing classes are generally produced in distinct geographical regions. Hard red winter wheat is produced mainly in Kansas, Nebraska, Colorado, Texas, Oklahoma, and South Dakota and accounted for 38% of total production in 2000-2002. Hard red spring wheat, produced in North Dakota, Minnesota, Montana and the Pacific Northwest, comprised 20% of total production. Soft red winter wheat, produced in the high rainfall regions of the eastern and southern states, followed closely at 20% of total production. Soft white wheat, including club wheat (*Triticum aestivum* L. subsp. *compactum* (Host) Mackey), was produced mainly in the two northern corners of the country, the Pacific Northwest and the states of New York and Michigan. Soft white wheat comprised 15% of the total production. Durum wheat (*Triticum turgidum* L. subsp. *durum* (Desf.) Husn.) was produced in North Dakota and Arizona and represented about 5% of total production. Hard white wheat is a small but growing component of U.S. production and is grown in the same places as hard red wheat (Fig. 1).

Most wheat in the U.S. is grown as a low-input crop. Nitrogen (N) fertilizer is the most common and, frequently, the only input. In the main production states of Colorado, Illinois, Kansas, Missouri, Montana, Nebraska, Ohio, Oklahoma, Texas, and Washington, 86% of winter wheat received N fertilizer at an average rate of 76 kg/ha for the crop year (USDA-NASS, 2003). In 2002, N was also applied to 86% of the spring wheat and 88% of the durum wheat acreage. Phosphate and potash were added at lower rates, to approximately 50% and 20% of total acreage, respectively. Over 90% of spring wheat, including durum, received herbicides targeted at broadleaf weeds, while herbicides were applied to only 38% of the winter wheat crop. Insecticides were also used on a limited basis.

Because of the geographical range in which it is produced, wheat is grown in several different cropping systems in the U.S. Most of the wheat acreage is in the central Great Plains. The climate of the Great Plains is characterized by the extreme changes that typify continental climates worldwide, including severe, windy, dry winters with little snow accumulation, moist springs, and dry summers punctuated by thunderstorms. The predominant wheat cropping system in the Great Plains is the winter wheat-fallow system, which results in two years of moisture storage for a single year's crop. Diseases and weeds are controlled through tillage. Wind- and water-induced soil erosion is common.

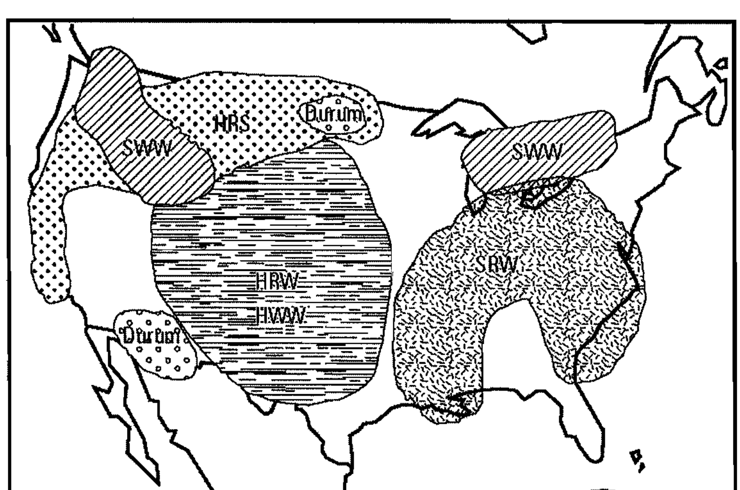

Figure 1. Wheat classes and production zones in the United States.
Note: HRS=Hard Red Spring, SWW=Soft White Winter and Club, SRW=Soft Red Winter, HRW=Hard Red Winter, HWW=Hard White Winter

In other parts of the country, wheat is grown in rotation with other field crops as a primary means of pest control. In the east, wheat is rotated with maize and soybean, the main cash crops. In the mid-Atlantic states and Mississippi River states, double crops of winter wheat followed immediately by soybean in the same growing season are prevalent. In the south, wheat might be rotated with rice, peanut, cotton, or soybean. In the north and Pacific Northwest, winter wheat is rotated with spring barley, spring wheat, legumes or brassicas. In higher moisture areas, spring wheat is produced in rotation with spring barley, food legumes, and brassicas. In dry areas of the Pacific Northwest, as in the Great Plains, winter wheat-fallow systems are common.

Irrigated production is increasing in California and the Pacific Northwest. In irrigated cropping systems, wheat is frequently not the main cash crop and is rotated with potatoes or other vegetables. In the southern Great Plains, winter wheat is grazed in autumn. Wheat is grazed in autumn and early spring, providing a pasture source when other forages are scarce. Grazing does not reduce grain yield much if fertility levels are adequate. To be able to graze the wheat, planting rates are typically increased 50% (Shroyer et al., 1990).

As with most field crops in the U.S., soil erosion is a major management problem in wheat production. In the U.S., total wind- and water-induced soil erosion on cropland dropped 39% between 1982 and 2001. Much of this erosion reduction can be attributed to the increased use of conservation tillage that began under the conservation compliance requirements of the 1985 Farm Bill and the enrollment of highly erodible land in the Federal Conservation Reserve Program, a government program that pays owners to remove highly erodible lands from production. The conservation compliance provisions required that producers develop conservation programs for highly erodible cropland and obtain approval from the United States Department of Agriculture (USDA)-National Resources Conservation Service (NRCS) to maintain eligibility for other USDA program benefits, including price support payments (Zinn, 2001). The U.S. Farm Bill is a compilation of several laws that govern agricultural policy and is renewed approximately every five years. The new 2002 Farm Bill, also known as the Farm Security and Rural Investment Act of 2002, contains more spending for conservation than any agricultural bill in the past.

Research associating grain yield decline with soil erosion has been conducted on wheat in the Pacific Northwest and in the Prairie provinces of Canada. Mean yield decline ranged from 0.028-0.143 mg grain per 1 ha and 1 cm depth of soil loss (Biggelaar et al., 2001). While small annual declines may be easy to ignore, the cumulative effects include production declines, necessary changes in machinery due to changes in soil structure, and off-site costs of declining water and air quality. Even with federal conservation programs, excessive erosion occurred on 42.04 million hectares of cropland in 2001 (USDA-NRCS, 2003a). The above figures are only averages; severe water and wind erosion occurs throughout the wheat producing areas of the U.S., especially where the winter wheat-fallow cropping system remains common.

Conservation tillage and crop residue management are two major components of conservation compliance programs. Conservation methods that minimize tillage leave more residue on the soil surface, reduce soil erosion, and contribute to improved soil structure. However, they also cause other major problems in wheat cropping systems—for example, increased incidence of diseases and pests, rotation restrictions due to residue buildup, and the need for new equipment that can plant successfully into residue. The components of cropping systems are interdependent, and changes in one component affect the others.

In wheat cropping systems throughout the U.S., increased crop residue on the soil surface and lack of rotation choices have increased the severity of production constraints. Examples include increased incidence of Fusarium head blight (causal agent *Fusarium graminearum*), Cephalosporium stripe (causal agent *Hymenula cerealis* Ellis & Everh), common root rots (caused by *Bipolaris sorokiniana* (Sacc.) Shoemaker and *Fusarium pseudograminearum* O'Donnell et. T. Aoki sp. nov.), Hessian fly (*Mayetiola destructor* (Say)) and weedy pests like jointed goat grass (*Aegilops cylindrica* Host) and downy brome (*Bromus tectorum* L.). Solutions to those constraints and other, long-established problems (such as the three wheat rusts, winter injury, flooding and freeze damage) will only be achieved through the combined efforts of breeders, agronomists, pathologists, and economists.

Wheat research is unique among the major crop commodities in the U.S. because there continues to be large, vibrant public sector involvement in wheat cultivar development and production research. In the last census of U.S. crop breeders, approximately 60% of the wheat breeders were in the public sector. By comparison, 93% of the corn breeders were in the private sector (Frey, 1996). Public investments in wheat breeding during the past century have resulted in the development of most cultivars grown by U.S. farmers. Of cultivars released in the 20th century, approximately 60% were developed by state agricultural colleges and experimental stations, USDA, or CIMMYT. A higher percentage of U.S. wheat production may be attributed to publicly developed cultivars if estimates are based on area of production (Kansas 62%, North Dakota 64%, Washington 88%, Nebraska 90%) (USDA-NASS, 2001).

Private breeding companies are active in the soft red winter region of the eastern Midwest, the Pacific Northwest, California, and Kansas. Active cooperation exists between private and public sector breeders with regard to sharing of germplasm, disease screening efforts, and establishing national research priorities. In 1990, approximately half of all agricultural research in the U.S. was funded by the public and half by the private sector. The internal rate of return was 27% for the public sector and 6% for the private. (Makki et al., 1999).

Research Collaboration to Solve Problems

Because resources are limited and problems cross disciplinary boundaries, recent examples of successful research initiatives in wheat cropping systems in the U.S. are collaborative in nature. The remaining part of this paper will highlight four collaborative research projects that include both public and private sector research aimed at solving particular constraints in U.S. wheat cropping systems. They are:

- Solutions to Economic and Environmental Problems (STEEP)
- United States Wheat and Barley Scab Initiative (USWBSI)
- Bringing Genomics to the Wheatfields (MAS-Wheat)
- National Jointed Goatgrass Initiative (JGGI)

Solutions to Economic and Environmental Problems (STEEP)

STEEP was initiated in 1975 as a collaborative project involving scientists and educators from the University of Idaho, Oregon State University, Washington State University, and the USDA-Agricultural Research Service, in cooperation with grower organizations and agricultural support industries and agencies. The focus of STEEP grant funding is to develop profitable cropping systems technologies for controlling cropland soil erosion and protecting environmental quality (Veseth, 2003). STEEP is one of the first multi-institutional, multi-state, and multi-disciplinary research efforts and has functioned as a national model for multi-state, multi-disciplinary efforts among land grant universities, USDA-agencies, grower commodity organizations, conservation districts, and other agricultural support groups and agencies. Each year, STEEP funds research grants for a total of approximately US$ 400,000. The money is awarded to STEEP through a USDA-Cooperative State Research Education and Extension Service special grant. From 1975 to 1990, STEEP-funded research accomplished the following:

- Adapted soil erosion prediction technology for the climate conditions, soils, landscape and production systems unique to the Pacific Northwest.
- Developed and tested many of the conservation options producers are using to meet Farm Bill mandated conservation compliance requirements.
- Documented the impacts of cropland soil erosion on long-term soil productivity, environmental quality, and farm and regional economics.
- Developed technology and prototype equipment for improving residue placement, fertilizer use efficiency, seed placement, and increased producer use of conservation tillage systems.
- Improved understanding of the interactions between crop pests, tillage systems, and crop rotations.
- Bred new crop cultivars with improved pest resistance.
- Developed alternative crops and investigated their production practices.

The following are summaries of two recently completed projects.

Project title: **Managing the Economic Transition to No-Till Farming in the Pacific Northwest**
Investigators: D. Young and H. Wang, Washington State University

The objectives of this study were to identify appropriate economic strategies for farmers in the Pacific Northwest to successfully manage financial risk and to maintain acceptable economic returns during the transition to no-till farming. Key research findings were that farmers who adopted conservation practices usually adopted more than one practice at a time. For example, several farmers who adopted no-till systems also switched from winter wheat-fallow cropping systems to spring wheat in rotation with other spring crops. Farmers used multiple methods of land tenure including those who: 1) rented all their land, 2) owned all their land but were still paying for it, and 3) owned all their land and had fully paid for it. This indicated that land tenure was not a definitive factor in the transition to no-till. Use and ownership of seed drills capable of planting into stubble was the primary risk factor identified. Most farmers custom hired or rented a drill during the first three years of the transition but were able to purchase drills during years 4-6. Farmers paid cash for drills when they were able to minimize risk. They also retained their conventional tillage equipment, which was deemed to be of low cash value. In order to economize, some farmers rented larger tractors needed only for no-till drilling and some bought used drills or shared no-till drills and tractors with relatives or neighbors. Some did custom no-till planting to help pay for drills.

Farmers began with small amounts of acreage in year 1, often 10% or less of their total acreage and increased each year, some to 100% of their land by the fifth year. Adoption of conservation tillage practices and intensified cropping with annual spring crops has resulted in a 44% decrease in winter wheat–fallow cropping systems in North America during the last 30 years. Additional work is underway to assess the risk involved in different no-till drill acquisition sequences for farms of different size, equity structure, and regions. Risk is also being assessed using crop prices and expected yields over time (Young and Wange, 2001).

Project title: **Impact of Direct Seeding on Crop Water Use Efficiency, Soil Physical and Microbial Properties, and Quality of Soil Organic Matter**
Investigators: D. Bezdicek, S. Albrecht, M. Fauci, and J. Hammel, Washington State University, University of Idaho and USDA-ARS

The objectives of this study were to determine crop water use efficiency, seed zone temperature, soil profile winter water storage, and N use efficiency under direct seed and conventional systems and to evaluate transitional soil physical and biological interactions under direct seed systems and the influence of different crop rotations. The quantity and quality of soil organic matter change under direct seed systems, and the significance of sequestering atmospheric carbon dioxide was also a goal of the project. Soil from eight long-term conventional and direct seed sites in Oregon and Washington was evaluated for fractions of soil organic matter. The highest soil organic carbon was found after 70 years of grass-pasture in Oregon, and after 25 years of direct seeding in Washington. The lowest values were recorded after 68 years of conventional wheat-fallow in Oregon. Particulate organic matter carbon was concentrated at the soil surface under grass-pasture and direct seed. This was 33-35% of total surface soil organic carbon in those cropping systems. Substantial shifts in surface particulate organic matter carbon were noted after only three years of direct seeding in Washington. This particulate organic matter fraction is an intermediate nutrient pool with high microbial life and activity and one that contributes positively to the soil physical condition under direct seeding. Conversely, if these soils are tilled, this particulate organic matter carbon fraction is lost very rapidly as was observed when our native prairies were tilled in the early 1900's, indicating that both positive and negative effects of changes in tillage systems occur fairly rapidly (Bezdicek, et al., 2001).

The United States Wheat and Barley Scab Initiative (USWBSI)

The goal of the USWBSI is to develop as quickly as possible effective control measures that minimize the threat of Fusarium head blight (scab) to the producers, processors, and consumers of wheat and barley (USWBSI, 2003). Like STEEP, the scab initiative was initiated in response to changes in crop management that were implemented in order to reduce soil erosion. Unfortunately, reduced tillage resulted in a buildup of crop residue, specifically maize residue, which acted as a host for the scab-causing pathogen.

The disease is caused by the fungus *Fusarium graminearum* Schwabe (teleomorph: *Gibberella zeae*), which is also the causal agent of stalk rot in maize. Inoculum pressure has soared since the widespread adoption of no-till cropping systems in the U.S. corn belt, which leave high amounts of residue on the soil surface. Yield losses are due to shriveled grains, low test weight, and poor germination. The problem is amplified because scab infected grain is usually contaminated with deoxynivalenol (DON) (also known as vomitoxin), a toxic metabolyte produced when the pathogen invades the developing grain kernel. The U.S. Food and Drug

Administration has limited DON to 1 ppm in food products. Scab occurs when continuous moisture is present during anthesis. The most favorable conditions for infection are prolonged periods (48-72 hours) of high humidity and warm temperatures of 24-29 °C (Bai and Shaner, 1994). The disease has been severe in the U.S. corn belt, particularly in the northern region where epidemics have occurred nearly every year since 1990.

Recognizing the multidisciplinary nature of the problem, the initiative is organized into seven research areas: Biotechnology; Chemical and Biological Control; Epidemiology and Disease Management; Food Safety; Toxicology and Utilization; Germplasm Introduction and Enhancement; and Variety Development and Uniform Nurseries. Approximately US$ 5 million in small grant funding is awarded each year to multiple institutions and researchers throughout the United States. Two projects are summarized below:

Project title: **Influence of Corn Residue and Cultivar Susceptibility on the Accuracy of Fusarium Head Blight Risk Assessment Models**
Investigators: E. De Wolf, P. Lipps, L. Madden L., L. Francl, Pennsylvania State University, Ohio State University

The objective of this project was to evaluate the performance of forecasting models for Fusarium head blight of wheat in the United States. Disease forecasting models were developed to predict the probability of a scab epidemic based on environmental variables. Model 1 uses the duration of time that temperature is between 15 and 30 °C and the duration of precipitation for the seven days prior to flowering. In the original development study, model 1 correctly predicted epidemics 78% of non-epidemic years (greater than 10% infection) but predicted only 56% of the epidemic years. Model 2 uses environmental variables observed 7 days prior to flowering and 10 days after flower initiation. For Model 2, the duration of temperature between 15 and 30 °C during the 7-day period prior to flowering plus the duration of temperature between 15 and 30 °C with relative humidity above 90% during the 10-day period after flower initiation are calculated. Model 2 correctly predicted 84% of the cases used to develop the model. Validation experiments indicated that highly susceptible cultivars and fields with high levels of corn residue affected model accuracy. Specifically, a higher percentage of false negatives (failure to predict an epidemic) occurred when either of those two conditions were present (De Wolf et al., 2002).

Project title: **Targeted Saturation Mapping of QFHS.NDSU-3BS Using Wheat ESTs and Synteny with the Rice Genome**
Investigators: S. Liu and J. Anderson, University of Minnesota

The objective of this project was to fine-map the major QTL region for resistance to scab, QFHS.NDSU-3BS, that was identified by Waldron et al. (1999) in a recombinant inbred population of Sumai3 (resistant) by Stoa (susceptible). The best RFLP marker in the 3BS region explained 15.4% of the variation. Five microsatellite (SSR) markers (*Xgwm389*, *Xgwm533*, *XBARC133*, *Xgwm493*, and *XBARC102*) are closely associated with QFHS.NDSU-3BS (Liu and Anderson, 2003). Those markers have been verified by several research groups and are in use in several breeding programs incorporating marker assisted selection for Fusarium head blight resistance. Using synteny between wheat chromosome 3BS and rice chromosome 1S, and wheat deletion lines for chromosome 3BS, 25 sequenced tagged site (STS) markers were located into wheat chromosome bin 3BS 0.78-0.87. One STS marker, XSTS-3B-138, explained 55% of the variation for disease in the Sumai3 / Stoa mapping population. The investigators state that this strategy can be applied for fine-mapping of other traits in cereal crops (Liu and Anderson, 2002).

Bringing Genomics to the Wheatfields—MAS Wheat

The MAS-Wheat project was begun to bridge the gap between basic genomic research and applied plant breeding in wheat. The summary of the second research project for the USWBSI above illustrates some of the opportunities and challenges that arise when genomic research and applied breeding are integrated in wheat. Biotechnology has revolutionized plant breeding efforts by providing tools, such as DNA tags, which can be used in marker-assisted selection (MAS) strategies for cultivar development (Paterson et al., 1991). Limited funding for implementation efforts has delayed the incorporation of these technologies into public wheat breeding programs. The U.S. government has made significant investment into wheat genomic and molecular research through the National Science Foundation and other sources. Projects include the development of 104,846 expressed sequence tags (ESTs) from wheat (Qualset and McGuire, 2003), the construction of wheat bacterial artificial chromosome (BAC) libraries (Lijavetzky et al., 1999), and the assembly of these BACs into physical contigs. The overall goal of the MAS-Wheat project is to transfer new developments in genomics to wheat breeding and production through the combined expertise of genomics researchers, breeders, and wheat end-users.

An integrated network of collaborative public wheat breeding programs has been established that uses MAS to accelerate the transfer of valuable genes into locally adapted cultivars. Two marker development laboratories complement these efforts by transforming RFLP markers into PCR-based markers and by testing new molecular markers based on single nucleotide polymorphisms. Specific objectives are to: a) enhance market demand for major classes of U.S. wheat through end-use quality improvements; b) reduce pesticide use in wheat production through improved host plant resistance; c) strengthen MAS as a cultivar improvement tool by enhancing current DNA markers; and d) enhance public awareness of the potential of biotechnology for providing a stable, safe food supply.

At present 11 laboratories and breeding programs throughout the U.S. are collaborating on the project. The goal is to use MAS to integrate genes for six quality and nine pest resistance traits into adapted winter and spring wheat breeding lines (Table 1). Now in its second year, the project has created a web site with tested protocols for MAS in wheat: http://maswheat.ucdavis.edu/. The project is funded by a grant from the USDA-CSREES Initiative for Future Agriculture and Food Systems grant program. Funding is approximately US $4 million for the four-year duration of the grant.

Two of the most widely introgressed traits are the QFHS.NDSU-3BS segment for resistance to Fusarium head blight (additional details for the method are at http://maswheat.ucdavis.edu/protocols/FHB/index.htm) and a chromosome segment named HGPC (for high grain protein content). That gene was originally transferred from *Triticum turgidum* ssp. *dicoccoides* into durum wheat (Joppa and Cantrell, 1990). It was subsequently transferred into hexaploid wheat in the hard red spring wheat genotypes Glupro and ND683 (Mesfin et al., 1999). Research on durum wheat indicated that the gene did not have negative effects on yield or other quality parameters but did increase protein content. It is located on chromosome 6BS, between the *Nor* region and the centromere. MAS tools for HPGC include RFLPs, microsatellites, and two STS-Caps markers (Khan et al., 2000) (http://maswheat.ucdavis.edu/protocols/HGPC/index.htm). A closely linked STS marker has recently been developed (J. Dubcovsky, personal communication). Laboratories involved in the project are using a combination of markers to verify that the gene is present.

The National Jointed Goatgrass Initiative (JGGI)

Wild relatives of wheat have long been a valuable source of new genes for disease resistance and quality traits that have been exploited by wheat geneticists (e.g., the HPGC segment from *T. turgidum* ssp. *dicoccoides* described above). Wild relatives of wheat have also become noxious weeds in wheat cropping systems. Jointed goatgrass (*Aegilops cylindrica* Host) is a tetraploid

Table 1. Selected traits and markers used for marker-assisted selection of wheat (Bringing Genomics to the Wheatfields).

Trait	Alleles (underline indicates PCR-based marker)	CA	CO	ID	IN	KS	ND	NE	NY	MN	MT	WA
Quality												
Grain protein content	Nor(CAPS) - Xgwm193-6B	x	x			x	x	x		x	x	x
Gluten strength	HMW-GS: Glu-A1, B1, D1 & LMW-GS: Xpsp2999, Xpsp3000	x		x			x			x		x
Semolina color	Yp, Xwg380 and Xcdo347	x					x					
Water absorption	Ha: pinB-D1b,c, pinB-Am1a, XksuG53-3A and Pentosan: Xbcd508-1B			x	x				x	x	x	
Starch properties	GBSS-4A & GBSS-7A null waxy mutations	x					x		x			
Preharvest sprouting	Xgwm550-1A, Xmwg900b, Xcdo795, XksuG9, Xbcd944	x			x				x			x
Disease and pest resistance												
Leaf rust	Lr21, Lr39, Lr40, Lr37, Lr47 and Lr T. timopheevi	x			x	x		x		x	x	
Stripe rust	Yr5, Yr8, Yr15, Yr17,YrHTAP	x		x								x
Fusarium head blight	QTL.3B: Xgwm533 - Xgwm493 and QTL.3A: Xgwm2 - Xgwm674				x	x	x	x	x	x		
Eyespot	Pch1: Ep-Dib isozyme band & Pch2: Xwg380 and Xcdo347				x				x			x
Barley yellow dwarf virus	Bdv2: Xpsr680 and Xpsr687	x	x	x	x	x		x	x	x		x
Wheat streak mosaic virus	Wsm1: STS J15		x			x		x			x	
Wheat spindle streak mosaic virus	Wss1: Xbcd1095 and Xcdo373				x				x			
Russian wheat aphid	Dn2: XksuA1* & Dn4: Xabc156 - Xksud14*	x	x					x				
Hessian fly	H9: RAPD 9-1 and 9.2 & H13: RAPD 13-1				x				x			x

possessing the C and D genomes of the Triticeae (Fig. 2). Wheat possesses the A, B, and D genomes, and hybrids between wheat and jointed goatgrass occur in nature (Hanavan et al., 2002). Because of similarities in genetics and biology, selective herbicides are not effective for controlling jointed goatgrass in wheat. Jointed goatgrass is present throughout most of the mainland U.S. but has been declared a noxious weed in Arizona, California, Colorado, Idaho, New Mexico, Oregon, and Washington (USDA-NRCS, 2003b). Jointed goatgrass infests 5 million acres across 14 western and Midwestern states. The recent trend towards conservation tillage systems has allowed jointed goatgrass to proliferate because the rate of establishment of jointed goatgrass seed lying on the soil surface is about 96%, compared to 30% for winter wheat (White, 2003).

In 1994, the JGGI, an integrated, multi-disciplinary effort involving 11 states and over 35 state and federal scientists, was initiated with a USDA-CSREES special grant. Its goal is to ensure that producers have the best and most recent information possible to successfully manage jointed goatgrass in winter wheat. The project takes a systems approach to research and includes the identification of best management practices that include crop competition, crop rotations, seed prevention, herbicide resistant crops, and gene flow analysis. Technology transfer is facilitated through a web site, extension presentations, and bulletins. Control of jointed goatgrass requires a combination of chemical and cultural methods. Research sponsored by the initiative has developed the following list of cultural control methods:

- Use crop rotation with three years between winter grain crops
- Plant certified goatgrass-free seed
- Delay seeding in autumn
- Plant tall, fast-growing winter wheat cultivars at above-normal seeding rates in narrow rows
- Maintain healthy wheat–band-apply fertilizer to it
- Prevent new seed production in fallow, roadsides, and waste areas
- Adjust combines
- Cover trucks during grain transport
- Do not transport contaminated straw
- Grind contaminated grain before using as feed
- Deep-plow every five years
- Burn fields to kill goatgrass seeds on the surface

Unfortunately, the latter two methods are not compatible with best soil erosion reduction and air quality practices.

In addition to cultural control, herbicide resistant wheat is being developed. The two most widely used genes confer resistance to imazamox (BEYOND™) herbicide. The resistance is commercialized in the U.S. as CLEARFIELD™ wheat; resistance to glyphosate (ROUNDUP™) herbicide, is commercialized as ROUNDUP READY™ wheat. BASF (then American Cyanamid) owns the patent for CLEARFIELD™ wheat developed through chemical mutagenesis. The original germplasm source was the French cultivar Fidel, mutagenized with sodium azide to create an altered acetohydroxyacid synthase (AHAS) (also referred to as acetolactate synthase (ALS)-enzyme) (Newhouse et al., 1993). That mutant resulted in resistance to imidazolinone herbicides. The CLEARFIELD™ system is comprised of herbicide tolerant wheat varieties; BEYOND™ (imazamox) herbicide, and a stewardship agreement with growers that ensures the use of best management practices for system sustainability. The stewardship agreement is crucial for limiting the development of herbicide resistant weeds. Resistance to ALS-inhibiting herbicides has occurred frequently, and more weed species are resistant to ALS-inhibiting herbicides than to any other herbicide group (Tranel and Wright, 2002). Hanson et al. (2002) recommend adding a fallow year and alternating CLEARFIELD™ and non-resistant wheat cultivars. Clearly, multiple control methods both chemical and cultural, will still be required to manage goat grass. CLEARFIELD™ cultivars will be available from public breeding programs in Colorado, Oregon, and Idaho in 2003.

Figure 2. Line drawing of jointed goatgrass (*Aegilops cylindrica* Host) seed head.
Photo from: Hitchcock, A.S. (rev. A. Chase). 1950. Manual of the grasses of the United States. USDA Misc. Publ. No. 200. Washington, D.C.

The ROUNDUP READY™ system confers resistance to glyphosate (*N*-phosphonomethyl glycine), a compound that binds to and blocks the activity of 5-enol-pyruvylshikimate-3-phosphate synthase (EPSPS). The ROUNDUP READY™ mutation produces an altered form of EPSPS and is transferred into crop plants via genetic engineering (Padgette et al., 1995). Several private and public researchers are incorporating glyphosate resistance into wheat in cooperation with the Monsanto Company (St. Louis, Missouri). Although production of ROUNDUP READY™ wheat cultivars is technically simple because the selection mechanism is a herbicide treatment, deployment of ROUNDUP READY™ wheat has been delayed because of concern about consumer acceptance of genetically modified wheat. US Wheat Associates, an export market development organization based in Portland, Oregon, surveyed wheat importers in Japan, South Asia, China, Taiwan, and Korea. It reported that 100% of the respondents in Japan, China, and Korea stated that under no circumstances would they buy GM wheat, regardless of whether or not their governments provide regulatory approval; 82% of respondents from Taiwan also refused to buy GM wheat. European buyers echoed similar concerns (WORC, 2003), though they focus on consumer acceptance rather than safety issues.

Herbicide resistant weeds are a growing problem in ROUNDUP READY™ cropping systems throughout the world. Problem weeds include rigid ryegrass (*Lolium rigidum)*, Italian ryegrass (*Lolium multiflorum)*, goosegrass (*Eleusine indica)*, and horseweed (*Conyza canadensis)*. Non-resistant Italian ryegrass is an increasing problem in conservation tillage wheat cropping systems in the U.S. Glyphosate resistant Italian ryegrass has only been reported in California. Glyphosate resistant horseweed has been reported in seven states in the eastern U.S. where ROUNDUP READY™ corn and soybeans are prevalent (HRAC, 2003). Herbicide resistant wheat will be an important tool to manage noxious grassy weeds in wheat cropping systems but must be used in conjunction with other cultural and chemical weed management practices.

Conclusions

Recently, collaborative multidisciplinary research has functioned well in the U.S. to address cropping system problems in wheat. Because most wheat variety development and agronomic research is in the public sector, federal grants have funded much of the research. Federal programs have also been instrumental in the adoption of conservation methods in wheat cropping systems. The best examples of collaborative research involve growers in the decision-making process and have an active, well-funded outreach goal aimed at disseminating research findings. Challenges to the wheat cropping systems in the U.S. continue to exist. The long-term sustainability of the wheat-fallow cropping system is not clear, and conservation methods that leave additional crop residue on the surface have created new challenges. Continued collaborative efforts are required to: 1) ensure the environmental and economic health of wheat production in the U.S.; 2) include genetic solutions to production risks, diseases, and pests; 3) increase the use of minimum tillage methods to control soil erosion; 4) develop and market alternative rotation crops; and 5) develop equipment for low-input agriculture.

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Winter Wheat Breeding and International Cooperation in Kyrgyzstan

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The main food crop in Kyrgyzstan is wheat. During the last century its cropping area has grown from 250,000 to 500,000 ha. In 2002 wheat was planted on 502,000 ha and average yield was 2.6 t/ha. Due to different soil and climatic conditions, three types of wheat are grown: winter, spring, and facultative. In 2002 the winter wheat area was 330,000 ha, of which 220,000 ha under irrigation were cultivated with varieties Intensivnaya, Kiyal, and Bezostaya, and 110,000 ha were rainfed. Spring wheat occupied about 170,000 ha.

Wheat breeding work has been conducted in the country since 1935 on the basis of Kyrgyz State Breeding Station, which was transformed into the Kyrgyz Research Institute of Farming (KRIF) in 1956. Within this period national breeders developed more than 30 wheat varieties. The genetic yield potential of the varieties developed increased from 2.5 to 10.0 t/ha and higher.

As Figure 1 shows, the yield potential of the intensive varieties (Lutescens 46, Bermet, Kyzyl -Dan, Lutescens 42) increased during the 1990s. This is associated with high yielding varieties developed using wide crosses (spelta material with dwarf stature and best varieties from CIS and abroad). The work was led by M.G. Tovstik. Highly valuable materials named Kyrgyzstan Dwarfs were placed in the Vavilov Institute collection. The materials were used as the basis for developing a number of highly productive winter wheat varieties that occupied large areas and produced record on-farm yields. However, the current situation in agriculture requires further breeding of new varieties with resistance to biotic and abiotic stresses and high quality grain.

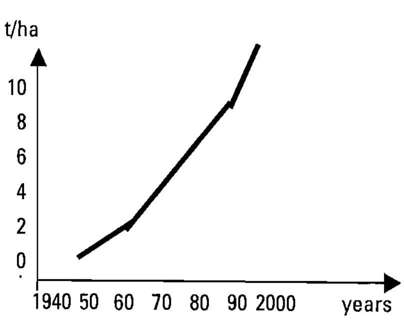

Figure 1. Yield potential of varieties of Kyrgyz selection (Advanced Yield Trial data).

In this context, in 1996 a joint CIMMYT/ICARDA research effort was initiated under the leadership of H.-J. Braun and A. Morgounov. Diverse soil climatic areas of the country with elevation from 500 to 2000 masl and different temperatures require development of varieties with yield potential of 9 to 10 t/ha, resistance to diseases, and superior grain quality. For rainfed areas varieties with early and early-intermediate maturity, plus heat and drought tolerance are required. In breeding varieties with desirable traits, traditional methods are applied: hybridization with targeted selection and multi-locational testing of the selected material.

The main parental material of winter, facultative, and spring bread wheat and winter durum wheat is represented by germplasm from Vavilov Institute (VIR), CIMMYT, and ICARDA, as well as germplasm of local origin (Table 1).

According to Table 1, in recent years VIR has not provided the germplasm, and in this regard the role of international centers in wheat breeding diversity enrichment has become very important. Breeding research is conducted at KRIF's experiment station. Selection begins in the F_2-F_6 for valuable agronomic traits, resistance to diseases, heat and drought tolerance, vegetative period length, and grain quality. Currently, 12 varieties of Kyrgyz selection are cultivated in the country. Table 2 presents characteristics of the released varieties.

Despite the fact that varieties Intensivnaya, Eritrospermum 13, and Bermet were released long ago, they still occupy large areas in the country. In recent years new varieties Kiyal, Adyr, and Tilek have been involved in the production system. When crop management recommendations are followed properly, these varieties are capable of yielding up to 8-9 t/ha. The new varieties do not lodge, are relatively

Table 1. Parental breeding materials used for crosses in Kyrgyzstan.

Years	Sources (%) Local selection	CIMMYT-ICARDA	VIR	CIS region
1990-1995	40	-	40	20
1996-2000	50	20	20	10
2001-2003	50	40	-	10

resistant to diseases, particularly yellow rust, and have good bread making quality (Table 3).

Presently, national breeders have available a range of new high yielding varieties bred in Kyrgyzstan. Annually in various breeding nurseries, about 18,000 entries are studied under irrigated and 6,000 entries under rainfed conditions. Also about 1,000 entries are now being tested in multi-locational yield trials. In 2000 a joint research project with ICARDA (A. Yahouyaui) on yellow rust resistance in wheat was initiated. Experiments are conducted in three ecological zones of Kyrgyzstan: Issyk-kul, Naryn, and Chu oblasts (provinces). Within this period about 2,000 winter wheat entries were evaluated for resistance to pathogens. In those three ecological zones a special nursery containing 100 winter wheat genotypes from various parts of the world were investigated, and 15 genotypes were selected for yellow rust resistance. In 2002 through CIMMYT-ICARDA project, a total of 3,184 entries were studied, including 2,438, 553, and 57 in Chu, Issyk-kul, and Naryn regions, respectively. By the initiative of CIMMYT representative, Dr. Morgounov, the International Advanced Yield Trial (AYT) was established and 29 varieties were planted in the 2002-03 season. Brief characteristics of the best varieties are given in Table 4.

CIMMYT together with KRIF established an on-farm yield trial of the released and promising varieties to promote new varieties in private farms (Table 5).

As Table 5 shows, the highest yields were produced by Adyr, Djamin, Tilek, and Dostuk, which beat the local check Intensivnaya.

Multi-locational Yield Trial. At the Issyk-kul Experiment Station (elevation: >1600 masl) 16 nurseries including a total of 533 entries provided through the CIMMYT-CARDA project were tested. In 2003, 170 lines were selected and planted to achieve the yield. The multi-locational yield trial was conducted following AYT rules (Table 6).

Table 2. Characteristics of Kyrgyz-bred wheat varieties for irrigated agriculture.

Variety	Year of release	Plant height (cm)	Yield (t/ha)	Date of heading	Resistance to yellow rust
Intensivnaya	1978	90	6,1	08.05	MS
Frunzenskaya-60	1982	95	5,7	10.05	MS
Eritrospermum-15	1991	70	6,4	13.05	MS
Eritrospermum -80	1980	80	6,1	15.05	MR
Eritrospermum -760	1998	95	6,5	13.05	MR
Kyzyl dan	1998	85	5,9	15.05	MS
Bermet	1998	80	6,7	18.05	MS
Adyr	2001	100	6,0	15.05	MR
Dostuk	2001	90	6,5	06.05	S
Ttilek	2001	80	7,5	12.05	MS
(durum)	1996	90	6,1	19.05	MS
Kyial	2001	110	6,0	09.05	MS

Table 3. Grain quality parameters of wheat varieties released in Kyrgyzstan.

Variety	Protein (%)	Gluten (%)	Bread volume (cm^3)	Bread making score
Adyr	13.4	33.0	780	4.2
Intensivnaya	13.1	31.8	760	4.1
Frunzenskaya-60	13.3	32.6	770	4.0
Tilek	13.3	32.4	770	4.0
Kiyal	13.2	29.0	770	4.0
Dostuk	13.1	28.8	760	3.8

Table 4. Characteristics of the best varieties from CIMMYT-ICARDA germplasm, AYT, 2001-02.

Name	Date of heading	YR resistance	Plant height (cm)	Yield (t/ha)	To check (t/ha)	Growth habit
			Irrigated			
Eritrospermum-13 (check)	23.05	MR	99	5.1	-	W
SBVD 18	16.05	MR	106	6.2	+0.3	W
SPN/NAC/ATTILLA	19.05	MR	105	6.2	+0.3	F
LEN/1158-57APRL	11.05	MR	98	6.3	+0.4	F
ERYT.155/90	18.05	MR	80	6.2	+0.3	F
			Rainfed			
Adyr (check)	11.05	MR	121	5.1	-	W
AGRI/INAC/ATTILLA	23.05	MR	90	5.5	+1.4	F
GUN91/MNCH	20.05	MR	100	6.0	+1.9	F

Table 5. On-farm winter wheat yield, yield trials, 2000-01.

Variety	Yield (t/ha)	Yield surplus (compared to check)
Intensivnaya (check)	7.0	-
Lutescence-42	7.3	0.3
Tilek	8.1	1.1
Kiyal	7.5	0.5
Dostuk	7.9	0.9
Adyr	8.9	1.9
Djamin	8.7	1.7

Table 6. Results of a multi-locational yield trial at the Issyk-kul Station, 2001-02.

Variety	Yield (t/ha)	Yield surplus (t/ha)	1000-kernel weight (g)
Bezostaya-1 (check)	7.0	-	50.6
Eritrospermum	8.4	1.4	46.6
Tilek	8.6	1.6	46.8
Djamin	8.4	1.4	49.2
Line-10	8.4	1.4	49.0
Assyl	8.6	1.6	51.7
Almira	8.8	1.8	48.8
Adyr	8.1	1.1	49.0

According to Table 6, new winter wheat varieties considerably outyielded the check under Issyk-kul conditions (from 1,1 to 1,8 t/ha). At the Naryn Experiment Station (elevation: 2200 masl) 193 spring wheat entries of CIMMYT-ICARDA germplasm compiling 4 nurseries were tested. The best entries yielded from 4.3 to 6.4 t/ha, exceeding the check Kazakhstanskaya 10 by 1.2 to 2.4 t/ha. Fifteen entries were selected. The new variety of facultative wheat Djamin resulting from the joint international efforts produced the highest yield under irrigated conditions in Naryn highlands, outyielding the check by 1.9 t/ha (Table 7).

CIMMYT, in collaboration with KRIF, initiated research on bed planting of wheat at the KRIF experiment station near Bishkek.

Early seed production is being conducted for the following seven varieties: Adyr, Djamin, Tilek, Kairak, Assyl, Intensivnaya, and Bezostaya 1. In the last two years 560 tons of super-elite seed were produced and provided to seed farms.

In 2001-2002 four varieties of winter and facultative wheat were submitted to the State Variety Testing Yield Trial, of which two varieties of winter wheat (Kairak, Asyl) and two of facultative wheat (Djamin, Almira) were developed on the basis of national and international cooperation. Concurrently, these varieties are being tested for DUS and will be officially patented (Table 8).

Table 7. Characteristics of promising variety Djamin (Naryn, 2200 masl, spring wheat), 2002.

Variety	Plant height (cm)	1000-kernel weight (g)	Yield (t/ha)	Yield advantage (t/ha)
Kazakhstanskaya -10 (check)	41.0	49.8	4.1	-
Djamin	74.6	59.8	6.0	1.9

Table 8. Main agronomic and biological parameters of the new wheat varieties.

	Varieties			
Parameters	Asyl	Kairak	Djamin	Almira
Yield (t/ha)	8.6	7.2	8.4	8.8
Vegetation (days)	240	255	238	243
Plant height (cm)	93	110	97	76
Productive tillers per plant (no.)	3.7	2.0	3.8	4.0
Lodging tolerance score	5	4.5	4.8	5.0
1000-kernel weight (g)	46.7	45.0	42.6	39.1
Test weight (h/l)	835	820	799	831
Gluten content (%)	26.1	27.6	26.3	26.4
Protein content (%)	14.1	13.9	12.7	14.1
GDI (gluten deformation index)	82	80	85	85

Conclusions

1. As the result of multi-year targeted breeding in KRIF, about 30 winter, facultative, and spring wheat varieties were developed for different climatic zones of Kyrgyzstan.
2. Breeding utilizes traditional methods: intraspecific and interspecific crosses with successive individual selection, thorough generation-by-generation study, and multi-locational testing of selected promising lines.
3. About 60% of the cropping area in the country is occupied by the varieties Intensivnaya, Eritrospermum 13, and Bermet, which were developed in the 1990s. In recent years new varieties such as Kiyal, Adyr, and Tilek have been widely cultivated. Their yield potential varies between 8-9 t/ha.
4. Through the CIMMYT-ICARDA project, 46 nurseries were received and tested. About 10,000 entries were evaluated in total.
5. Research on resistance to yellow rust in wheat has been conducted in collaboration with ICARDA since 2003.
6. Through the CIMMYT-ICARDA project, multi-locational yield trials were established in three zones: Chu, Issyk-kul, and Naryn.
7. The Institute invests much effort in early seed production and multiplication of released wheat varieties.
8. In 2002 four new winter and facultative wheat varieties were submitted to the State Variety Testing Yield Trial, of which two winter wheat varieties (Kairak, Asyl) and two facultative ones (Djamin, Mira) were developed on the basis of national and international cooperation.

Breeding Winter Wheat for Different Adaptation Types in Multifunctional Agricultural Production

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With the introduction of the sustainability concept considerable changes have taken place in agriculture. In the previous period of Hungarian wheat production the main point considered was yield increase, to supply the population with enough food. Besides this important task, new priorities have been raised nowadays due to increasing concern for environmental protection and healthy food production. These new priorities, which have led to the agricultural sector developing a more multifunctional character, are based on new social demands in relation to food production, where the essential criteria are to provide nutritious foodstuffs free of dangerous substances and to use environment-friendly technologies which ensure sustainability.

Great emphasis is placed on maintaining the ecological equilibrium in the agroecological environment. This purpose is served by the division of agroecological areas into three groups:

- Areas suitable for agricultural production;
- Ecologically sensitive areas where environmental protection takes precedence over agricultural production;
- Areas removed from agricultural production.

In market-oriented agriculture, wheat production should be located primarily in areas in the first group, where farmers generally sow wheat varieties suitable for use with high input technologies. However, the population of ecologically sensitive areas would like to maintain agricultural activities using low input, environmently friendly technologies that are less likely to harm the environment.

Wheat breeders carry out research and develop new germplasm adapted for high and low input cropping systems and different agroecological environments. Breeding aims can be divided into two groups. The first includes traits which have equal weight in selecting for various types of adaptation in winter wheat. For example, tolerance to extreme climatic effects in winter is essential if winter wheat is to be successfully grown under any technological conditions. In the present study a comparison was made between the frost tolerance of non-intensive and that of high yielding, intensive types of varieties adapted to different cropping systems and grown in Hungary over the last 50 years. Besides stress resistance priorities, yield and quality parameters belong to the other group of traits. While maximizing these traits is the main endeavor in high input technological systems, achieving stability in yield quantity and quality is given priority in low input environments.

Materials and Methods

The frost tolerance of the most important wheat varieties registered in Hungary over the last 50 years was tested in the greenhouse of the Agricultural Research Institute of the Hungarian Academy of Sciences in Martonvásár using the method developed by Tischner et al. (1997). After germination (three days in complete darkness at a day/night temperature of 20°/12°C and a 12-hour day), wheat seeds with intact rootlets were planted in a 4:1 mixture of earth and sand in wooden boxes, the internal dimensions of which were 38x26x11 cm. The seeds were planted at a depth of 3.5–4.0 cm. Each box consisted of nine rows with 20 plants to a row. The varieties were planted in four replications, 20 plants per replication. After planting, the boxes were kept at room temperature for a day, after which they were transferred to an autumn-winter type growth chamber (Conviron PGV-36), where they were kept for six weeks. During this period, the temperature, light intensity and duration of illumination were gradually reduced, with a weekly change of program to simulate autumn conditions in the field. Every week the temperature was decreased by 1–2 °C and the daylength by 15–45 minutes. Within each weekly program, temperature fluctuation, light intensity and daylength were the same each day. The daily temperature fluctuation followed the daily temperature changes ocurring in nature.

The preliminary growth stage was followed by two-phase hardening period. The plants were exposed to the first phase in the autumn-winter chamber, where daily temperature fluctuated between +3 °C and –3 °C, with a 21-hour daylength and a photosynthetic photon flux density (PPFD) of 190 µmol.m^{-2}.s^{-1}. This phase lasted a week. The second phase lasted four days and took place in a frost tolerance testing chamber (Conviron C-812) immediately prior to freezing. The temperature was a constant –4°C with no illumination.

Freezing was carried out in the frost tolerance testing chamber set up in the phytotron specifically for this purpose. Temperature was gradually decreased (by 1 °C every hour). Freezing took place at –15 °C for 24 hours. Following the frost treatment, the plants were kept in the freezing chamber at +0.5 °C for 2 days. After thawing, the boxes were transferred to growth benches (Conviron GB-48). The plants were grown for a further 3 weeks at a day/night temperature of 17/16 °C, with a 14-hour daylength and a PPFD of 125 µmol.m^{-2}.s^{-1}. At the end of the third week, surviving plants exhibiting renewed growth were clearly distinguishable from those that died. Freezing results are given as a percentage of plant number prior to freezing. Experimental data were evaluated using single-factor analysis of variance. Differences between means were tested using least significant differences (LSD) (P=0.05, 0.01 and 0.001).

Lines in generations F_6–F_7 were tested in two cropping environments in Martonvásár in two seasons, 2000/2001 and 2001/2002. The technological difference between the high and low input environments was given by the quantity of mineral fertilizer applied. The plots in the high input environment were fertilized with 150 kg nitrogen, 80 kg phosphorus and 80 kg potassium active agents per hectare. In the low input environment no mineral fertilizer was applied, but, as in the high input environment, the forecrop was peas and herbicide was used to control weeds.

The grain yield of the lines was used for analysis. Wet gluten content and gluten index were tested according to standards ICC 137/1 and ICC 155, respectively. Grain hardness was measured using the SKCS 4100 instrument, based on AACC 55-31, the falling number based on ISO 3093-1982, and rheological quality with a Brabender farinograph, according to MSZ 6369-6:1988 standard. Statistical analysis of the summarized data was carried out using the hierarchical cluster analysis module of the SPSS for Windows 11.0 program package.

Results

Frost tolerance is an important trait in both high and low input cropping environments. In the present study, changes in the frost tolerance of newly registered wheat varieties and of those grown most widely in Hungary over the last 50 years were studied under greenhouse conditions. Varieties registered and grown prior to 1975 were chiefly of Soviet or South European origin and included only a small number of western European and Hungarian varieties. The average survival percentage of this group of varieties was 61.6% (Table 1). During this period, great differences were observed between the frost tolerance levels of various groups of varieties.

The most rapid increases in yield in Hungarian wheat production were witnessed from the mid 1970s to the end of the 1980s. During this time, intensive type, high yielding southern European and Hungarian varieties were grown most widely, and most Soviet varieties lost ground, leading to a non-significant reduction in the mean frost tolerance of varieties registered between 1975 and 1990 compared to that of the less intensive varieties grown in the previous period.

The number of registered varieties increased after 1990. Due to the reduced application of chemicals in commercial wheat production, preference was again given to less intensive varieties. The average frost tolerance of these varieties and of those registered most recently has increased non-significantly compared with both the previous periods, and the survival percentage is now close to 70%.

Regardless of this trend, frost-sensitive and frost-tolerant varieties were found among both the old, non-intensive type of wheats and the intensive varieties. Over the last decade, the average level of frost tolerance has non-significantly increased despite a substantial increase in the number of varieties. If the frost tolerance of varieties successfully grown over the last 50 years is examined, it can be seen that the vast majority had good tolerance. These varieties include Bezostaya 1, Yubileinaya 50,

Table 1. Average frost survival in the greenhouse of wheat varieties registered in different periods in Hungary; Martonvasar, 2003.

Period of registration	Survival (%)	No. of varieties
Before 1975	61.6	22
1975 – 1990	54.3	33
1991 – 2002	68.2	35
$LSD_{5\%}$	10.0	

Martonvásári 4, Martonvásári 15, and Martonvásári 23. However, two important varieties in Hungarian wheat production, Bankúti 1201 and GK Öthalom, had an intermediate level of frost tolerance, which represents the minimum requirement for frost survival breeding under central European conditions.

The greatest differences in frost tolerance were observed when the varieties were grouped according to where they were bred. Varieties registered in Hungary, but bred in countries to the south or west of Hungary, had lower frost tolerance on average than those bred in Hungary or the Soviet Union. Even within Hungary, the varieties could be grouped on the basis of frost tolerance according to the breeding institute. As is clear from the data in Table 2, among the varieties grown in Hungary, those with the best frost tolerance originated in eastern Europe, chiefly from the ex-Soviet Union. These were followed by varieties bred in Martonvásár. The least frost-resistant varieties were those bred in southern Europe, widely grown in Hungary mainly in the 70s and 80s. The average frost tolerance of varieties from western Europe was significantly better than that of southern European varieties, but lower than that of Bánkúti 1201, a variety grown in Hungary for 30 years, with a moderate level of frost tolerance.

Table 2. Average frost tolerance of wheat varieties registered in Hungary and grouped according to site of origin.

Breeding location	Survival percentage	No. of varieties
Western Europe	41.1%	6
Southern Europe	23.7%	14
Eastern Europe	86.3%	8
Hungary	69.9%	60
Martonvásár	75.4%	41
Not Martonvásár	58.2%	19
$LSD_{5\%}$	10.0%	

The yield performance and quality traits of advanced lines in the F_6–F_7 generations (Table 3) were tested at two technological levels, in high and low input environments in Martonvásár for two years. The effect of the two technologies is well reflected in the fact that the average yield of lines in the fertilized experiment was 4.52 t/ha, averaged over two years, while in the unfertilized, low input environment, this figure was 4.27 t/ha, only 5.5% lower. Among the quality traits, the mean gluten content was 36.8% in the high input experiment, 2.0% more than under low input conditions. The rheological value was higher in the low input environment.

Breeding lines were then grouped according to yield performance and quality traits on the basis of cluster analysis on growing site data. The grouping was carried out using the Ward method, based on the Euclidean squared distances.

In the cluster analysis the lines were grouped according to their performance in high input, low input, and both cropping environments (Figures 1, 2, and 3). It is clear from the results that the performance of the lines differed considerably in the high and low input environments. At the same time, it can be seen that analysis based on the average performance in both environments gave results similar to those obtained for the low input environment, since a number of groups formed in the joint cluster analysis were also to be found in the analysis of the low input technology. For instance, lines 04-02, 07-02, and 12-02 formed a group in both the low input analysis and the joint analysis. Lines 09-02, 14-02, and 06-02, and lines 11-02 and 15-02 also formed groups in both analyses.

Conclusions

According to a survey carried out by Braun et al. (1998), the most important breeding aims for the next few years in breeding programs responsible for 90% of the winter or facultative wheat-growing areas of the world will be an increase in yield potential and the

Table 3. Average performance of F_6–F_7 lines in different cropping systems, Martonvásár, 2001–2002.

Environment	Yield (t/ha)	Gluten content (%)	Farinograph value	Gluten index	Falling number (sec)
High input	4.52	36.8	72.5	75.0	396
Low input	4.27	34.8	79.1	80.2	393

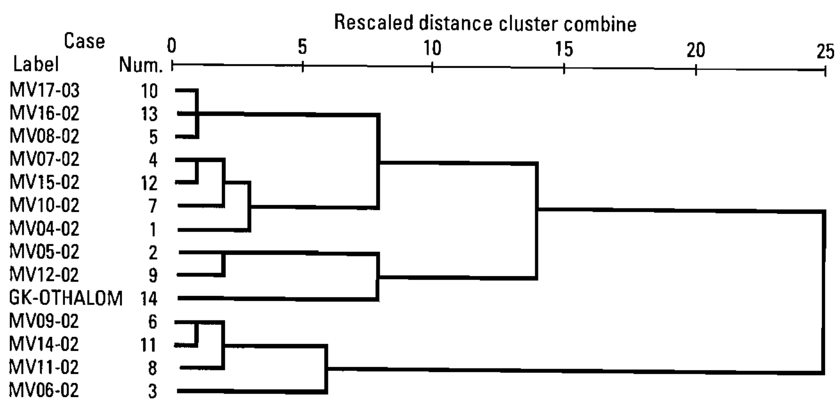

Figure 1. Grouping of lines in a high input environment.

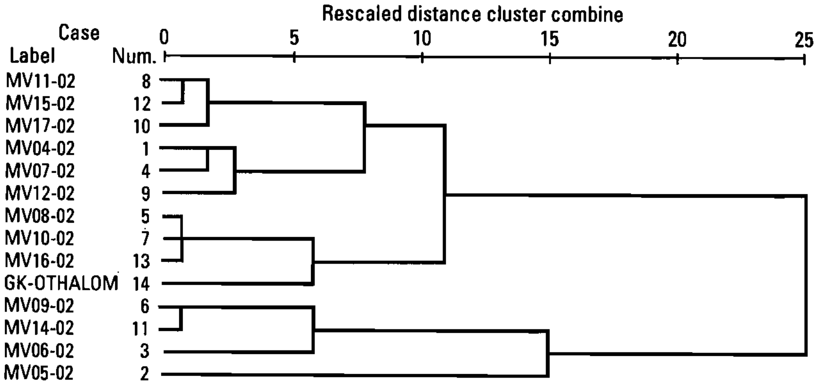

Figure 2. Grouping of lines in a low input environment.

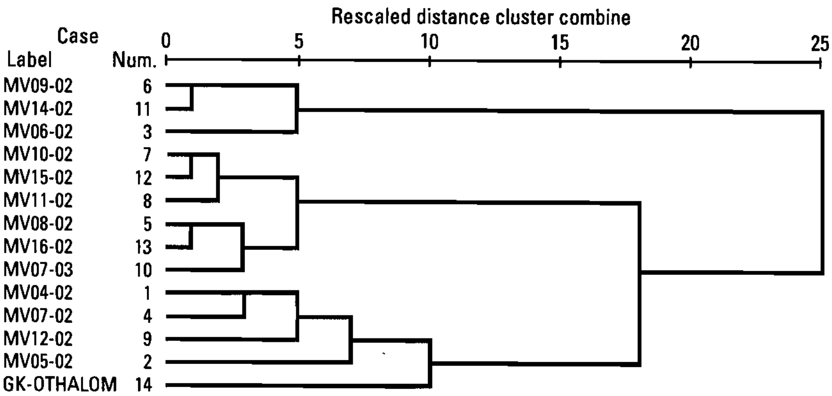

Figure 3. Grouping of lines: average of two locations.

improvement of traits involved in yield stability. Among the wheat diseases, leaf rust (*Puccinia recondita*), *Fusarium* spp., and *Septoria* spp. will be given priority, while winter hardiness and drought tolerance are the major goals in abiotic stress research. Breeding for N and P use efficiency and the development of varieties with stable quality across environments will gain greater importance. The results of the present survey also indicate that yield performance continues to be of importance in wheat breeding, though it will be necessary to improve traits involved in yield stability if further yield increases are to be achieved. The improvement of yield stability is of special importance in a low input environment, where the technological system only allows the use of a limited amount of pesticide, and crops are exposed to many unfavorable conditions.

For many years experiments have been underway in Martonvásár in the field and phytotron on the selection of different adaptation types for various cropping systems. The breeding aims can be divided into two groups in this respect. The first includes traits which have equal weight in selection for various types of winter wheat adaptation in central European environments, such as tolerance to abiotic stress, which is an important selection criterion in any technological system. Tolerance to extreme climatic effects in winter is essential if winter wheat is to be successfully grown under any technological conditions. The steppe-type varieties which were widely grown before intensive, high-yielding wheat varieties were introduced have the best adaptation to low input technologies and also have the best frost tolerance. The Martonvásár breeding program has made great use of these varieties and a similar level of frost tolerance has been achieved in some varieties. These include the old non-intensive variety Martonvásári 4. Martonvásári 5, Martonvásári 9 and Martonvásári 12, which have the same pedigree, also belong to this group. Varieties selected over the last 15 years have a smaller proportion of steppe-type Soviet varieties in their pedigrees. Nevertheless, the frost tolerance of Mv Pálma, Mv Vilma, Mv Optima, Mv Mezofold, Mv Palotás, Mambo, Mv Marsall, and Mv Emese is similar to that of Bezostaya 1.

Prior to the 1990s high rates of mineral fertilizer were applied in Hungarian wheat production. Due to the steep rise in energy costs over the last decade, the amount of fertilizer dropped by some 70%, and is still not increasing to any great extent. In many regions of the country there has been a change from high input to low input cropping technologies. This trend is reflected in the new varieties: average plant height has become taller, yield potential has not increased, and technological quality depends more on genotype than on a high level of fertilizers. Among the fungal diseases, powdery mildew is less important today than 20 years ago in high input cropping environments. Selection of genotypes with different types of adaptability is required to suit the environmental conditions in production regions with different agroecological potential. In addition to varieties with wide adaptability, the development of varieties with special adaptability to low input technologies should be given priority under the present changed cropping conditions.

Calderini and Slafer (1999) consider that the increase in yield potential is particularly pronounced in high-yielding environments with large technical inputs. This trend was associated with a decline in yield stability in the case of modern high-yielding varieties. Under less favourable environments, such as low input cropping systems, the selection of genotypes for yield and quality stability has primary importance.

One of the most vulnerable points of low input technologies is that the technological quality, particularly the protein content and protein quality, may also decline together with the yield. It is essential to select genotypes whose yield and technological quality are more stable than average in a low input environment. In France, for example, the variety Renan is recommended for this purpose in low input wheat production (Charmet, 2003, pers. comm.). It should be noted, however, that there are considerable differences between low input and organic farming technologies, for they are based on quite different concepts.

One important characteristic of wheat varieties suitable for production in a low input environment is the more efficient use of nitrogen and other nutrients. Significant differences can be demonstrated among the different varieties and in genotype x environment interactions for dry matter and nitrogen accumulation. The nitrogen grain filling rate and duration exhibited greater variability than the dry matter grain filling rate (Robert et al. 2001). The investigation of these traits and of their interaction with the environment are of enhanced importance in selection for stable technological quality.

In summary it can be stated that germplasm research for sustainable wheat production has undergone a significant development in recent years. Considerable progress has been witnessed in breeding, especially with the selection of winter wheat varieties with high protein content, which can be used to grow better quality wheat with less fertilizer than in previous years. The development of wheat varieties with abiotic and biotic resistance, selected for various technological systems, will contribute to the development of germplasm with special adaptation type and to that of environment-friendly technologies.

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Photosynthetic Basis of Wheat Improvement

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In the 20th century, the Green Revolution produced a vast number of crop varieties with higher grain yields through conventional breeding and won a temporary victory in man's war against hunger (Borlaug, 2001). However, to meet the needs of the 8.3 billion people projected to live on this planet by the end of 2025, both conventional breeding and the application of recombinant DNA technologies will be required to genetically improve food crops (Miflin, 2000; Somerville, 2000; Chrispeels, 2000; Herrera-Estrella, 2000; Berenbaum, 2001; Ellstrand, 2001; Prakash, 2001; Penna, 2001; Koornneef and Stam, 2001).

At present breeding is undergoing transformation from an extensive to an intensive stage whose aim has shifted from increasing spike size, harvest index, and number of functional units in size and volume to optimizing the function of productive processes (i.e., the complex plant metabolic processes that result in productivity). Photosynthesis is the most important metabolic process relative to crop productivity, as it contributes about 85% of the dry matter accumulated in cereal crops such as wheat and rice (Nichiporovich, 1982; Mokronosov, 1983; Evans, 1998). Manipulation of these processes to increase photosynthetic capacity in plants is difficult, but the only way to improve crops in the near future (Figure 1).

Plants utilize the conventional C_3 pathway for carbon fixation. Many agronomically important species such as wheat and rice suffer from O_2 inhibition of photosynthesis and the associated photorespiration; as a result, they exhibit lower photosynthetic efficiency, especially under high light, high temperature, and drought conditions. This is due to the dual function of the key photosynthetic enzyme, ribulose 1,5-bisphosphate carboxylase/oxygenase (Rubisco). Photosynthesis is more efficient in C_4 plants, which have special features that allow them to capture extra CO_2. Current atmospheric CO_2 levels (0.036%) limit photosynthesis in C_3 plants. Furthermore, photorespiration reduces net carbon gain and productivity of C_3 plants by as much as 40%. A plant that carries out C_4 photosynthesis in a single cell, i.e. without Kranz anatomy, was recently discovered (Voznesenskaya et al., 2001). Single-cell C_4 photosynthesis could help boost the productivity of the world's important C_3 food crops, such as rice and wheat. Changing a C_3 plant into a C_4 plant may be simpler if the two different cell types seen in Kranz anatomy do not need to be engineered (Edwards et al., 2001).

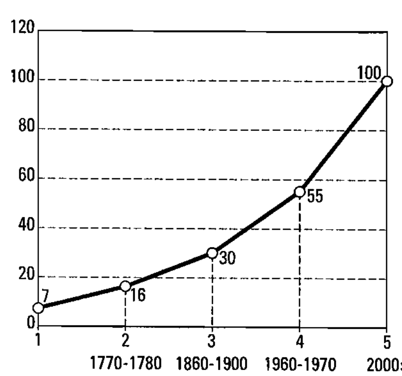

Figure 1. Wheat grain yield increases as a criterion of progress in agriculture.

1 = medieval; 3 = crop-rotation system of agriculture; 2 = introduction of legumes in crop rotations; 3 = use of mineral nutrition; 4 = Green Revolution semi-dwarf wheat; 5 = increased photosynthetic capacity. 7-100 = wheat grain yield, 10^{-1} t/ha.

Analytical methods for cataloguing the global effects of metabolic engineering on metabolites, enzyme activities, and fluxes are also revealing. Genes encoding C_4 photosynthesis enzymes in C_3 crops (e.g., rice) have been successfully introduced (Ku et al., 2000, 2001). Transgenic rice expressing maize C_4 photosynthesis enzymes exhibited higher photosynthetic capacity, better adaptation to stress conditions, and higher grain yield.

Genetic modification of photosynthesis in wheat

Wheat, one of three most important cereal crops (maize, rice, wheat) in the world, is the main food crop cultivated in Kazakhstan, and biotechnology provides great promise for its metabolic engineering. Kazakhstan has very similar climatic conditions as the USA including problems of global climate change, rising atmospheric CO_2, and increased drought. One half of Kazakhstan's territory consists of arid and semi-arid areas that cover the largest extension of crop and rangelands (300 million hectares) in Central Asia. Wheat acreage in Kazakhstan is about 12 million hectares but total wheat harvest is only about 16 million tons per year; that translates into an average yield of just 1.3 t/ha. Unfavourable environments limit wheat improvement in Kazakhstan where 17 abiotic and biotic stresses occur. Increased drought and non-rational uses of land worsen the situation even more, with 50% of carbon in soil being lost.

Increasing wheat productivity in Kazakhstan requires the development of modern plant physiology and biotechnologies, and conversion of ideas and recent achievements of plant metabolic physiology and molecular genetics into breeding, which have progressed rapidly in the USA and other developed countries. Solutions to improve crop yields, protection, and safety are difficult to come by and must have a solid scientific basis. For example, the USA is known worldwide as a country with a very progressive and effective agricultural system. A combination of economic, technological, and scientific advances enhances its crop yields by approximately 1% per year. This increase is the result of the coordinated integration of advances in crop science, plant physiology, genetics, agronomy, and agricultural engineering, plus increasing amounts of atmospheric carbon dioxide.

The most important metabolic process—photosynthesis—is used by plants to generate food from the energy of sunlight and carbon dioxide in the air. We (Photosynthesis Laboratory, Institute of Plant Physiology, Genetics and Bioengineering – the only one in Kazakhstan doing photosynthesis research) have studied photosynthesis for many years, including the effects of environmental stresses and potential global climate changes, with studies ranging from the cellular to the whole plant level underlying diversity in structure and function for wheat breeding optimization. We have been investigating the interaction between primary energetic processes in photosystems and chloroplasts, high CO_2-fixation capacity in leaves and high crop productivity, developmental changes in productive processes and the role of organs in accumulating and redistributing biomass, as well as special photosynthetic metabolism traits (C_3, C_3-C_4, C_4) in wheat and its relatives.

The main objectives of our integrated multiple-year research are (1) to determine the most important photosynthetic processes that need to be optimized by intensive crop breeding; (2) to create a conceptual model of a highly productive optimal photosynthetic wheat plant type (OPWPT); and (3) to develop methods for increasing the capacity of the photosynthetic apparatus, thus advancing wheat improvement.

Materials and Methods

Wheat species, cultivars, isolines, somaclonal varieties, heterotic hybrids, wild relatives (*Aegilops*), C_3-C_4 wheat-sorghum intermediates, and drought resistant C_4-sorghum were used as control materials in studying how to improve photosynthetic capacity and grain yield potential in wheat for increased drought and desertification.

The main photosynthetic traits have been identified using chlorophyll fluorescence, photochemical, polarographic, CO_2-gas-exchange, quality genetics, and biotechnological methods. Conventional breeding methods have been used: hybrid and diallel analysis, correlation analysis of photosynthetic characters and productivity indices, determination of combining ability, and inheritance of physiological parameters (Sidorenko/Kershanskaya et al., 1990; Kershanskaya, 2000a, b, c).

Results

An integral complex approach has been used to study interactions between maximum crop productivity and photosynthetic processes at different levels of the photosynthetic apparatus: from photosystem and chloroplast to leaf and whole plant. This is the basis of wheat production in favorable and marginal environments and of a new effective approach to wheat improvement through molecular genetic manipulation of photosynthesis. As a result we formulated the concept of an OPWPT. The most important photosynthetic processes need to be optimized for intensive wheat breeding. The interaction between primary energetic photosynthetic processes in photosystem and chloroplast, high CO_2-fixation in leaves, and high crop production were determined, as well as developmental changes in productive processes and the role of organs in biomass accumulation and redistribution. Special characters of photosynthetic metabolism in lines C_3, C_3-C_4, C_4, in wheat and its related species responded differently to drought (Kershanskaya, 2001a, b, c, 2002a, b).

Thus, it is possible to develop high yielding wheat varieties with high activity in all the primary redox-oxidative energetic photosynthesis processes, including activity of photosystem II (PSII) reaction centers, Hill reaction, coupling and saturated electron transport in the electron transport chain (ETC), and oxygen exude in chloroplasts (Figure 2).

Productive wheat lines were characterized by high (up to 100% of standard cultivars or parent lines) non-cyclic activity of ATP synthesis, an increase (about 20%) in cyclic chloroplast photophosphorylation, and tighter coupling (to 0.79) of primary photosynthetic processes in the chloroplast membrane. Differences between productive contrast lines were greatest at the end of the vegetative and grain-filling stages.

Highly productive wheat lines with a small number of chloroplasts and highly effective photosystem II reaction centers and chloroplast ETC were found. This proved the existence of unique active chloroplasts that are necessary to activate the productive photosynthetic apparatus at more complex levels (leaf, plant).

We found higher chlorophyll content (to 45%) in productive lines. It is important to underline quality content of pigments and the chlorophyll-protein association, which we found tend to increase chlorophyll content. This may be associated with high activity of PSII reaction centers, and decreased chlorophyll content may be correlated with a decrease in the size of the light harvesting complex (LHC) of PSII.

As a result of experiments, a natural model of OPWTP has been identified: wheat heterotic hybrids. These lines have more active real and potential rates of CO_2-assimilation per leaf unit (25-30% more than the parents) that have a strong positive correlation with carboxylase activity of Rubisco in leaves. A high rate of photosynthetic CO_2-assimilation (30%) in leaves was found to be associated with intensive flux of C from leaf to spike (35-200%). This made it possible to increase daily biomass and biological yields. Thus hybrids with high rates of photosynthetic assimilation produce high biological and grain yields.

Heterotic hybrids are characterized by high leaf-forming rates and low leaf drying, which increases their photosynthetic potential up to 33% during plant development and up to 79% during reproductive phases.

In wheat heterotic hybrids, high photosynthetic activity at all levels of the photosynthetic apparatus is organized to provide a large spike with assimilates. As a result of the dynamic balance between the demands for assimilates of a large spike (sink) and the capacity of the photosynthetic apparatus to fulfil it (source), higher quantities can be handled without straining source-sink relationships in a highly productive plant. Source-sink relations of a highly productive, photosynthetically optimal wheat plant type are represented as follows:

$$\underline{E}_1 \Rightarrow \underline{P}_1$$
$$E \Leftarrow P,$$

while in varieties with large spikes and unimproved photosynthetic capacity, photosynthesis limits productive processes as follows:

$$E \Rightarrow P,$$

where = epigenetic pressure on photosynthesis (growth, development, assimilate supply), and = photosynthetic apparatus.

The inheritance of photosynthetic parameters in progeny of wheat heterotic hybrids has shown that a high level of photochemical activity in chloroplasts is dominant. High number of chloroplasts per cell or

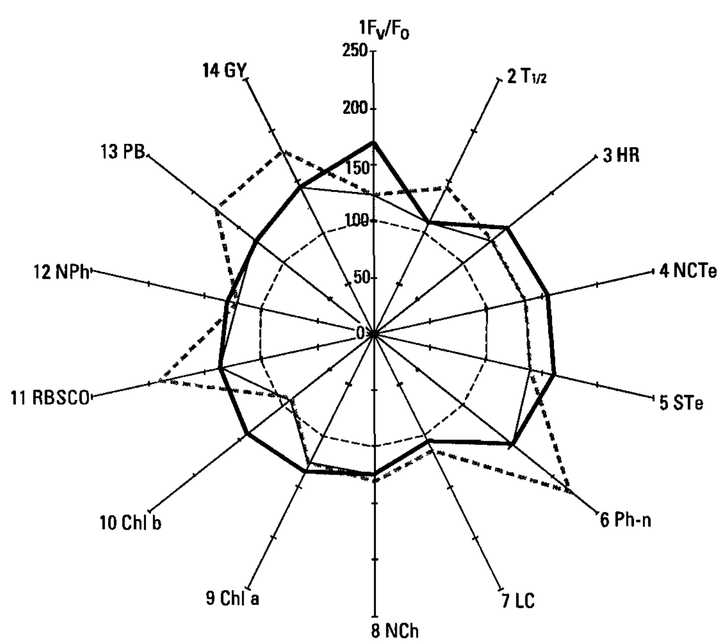

Figure 2. Primary photosynthetic processes, photosynthetic rate, and yield in the optimal photosynthetic wheat plant type.

Wheat heterotic hybrids in % in relation to parents (100%) and potential diversity of functional and structural photosynthetic parameters for increasing yield. 1 F_v/F_0 = quantum efficiency of variable fluorescence; 2 $T_{1/2}$ = time of $_{1/2}$ fluorescence decay; 3 HR = Hill reaction; 4 NCTe = non-cyclic electron transport; 5 STe = saturated electron transport; 6 Ph-n = photophosphorylation; 7 LC = coupling of electron transport and photophosphorylation; 8 NCl = number of chloroplasts in cell; 9 Chl a = chlorophyll a content in leaf; 10 Chl b = chlorophyll b content in leaf; 11 RBSCO = Rubisco activity; 12 NPh = photosynthetic rate; 13 PB = plant biomass; 14 GY = grain yield.

tissue unit is controlled by recessive genes. Genetic variations of photosynthetic rate are conferred by a polygenic (usually recessive genes) nuclear system having additive effects. Leaf area is conferred by polygenic effects of the subdominant type. In highly productive heterotic hybrids, leaf area is controlled by recessive genes as a rule. Genetic analysis of the main photosynthetic indices in wheat heterotic hybrids was based on dispersion, combining ability, and correlation analysis.

Thus, for breeding optimization, the description of a highly productive OPWPT includes major photosynthetic characters at different levels of the photosynthetic apparatus, as follows: (1) at the photosystems level: increased activity of a hypothetical PSII reaction center; (2) at the chloroplast level: activation of primary light-energy transformation processes, a high degree of ETC redox processes with ATP synthesis, increased cyclic and, more importantly, non-cyclic photophosphorylation, tight coupling of primary energetic processes, and increased functional activity in single chloroplast; (3) at the foliar level: activation of key CO_2-assimilation processes (Rubisco carboxylase activity) and CO_2-fixation rate in leaves at the same time as organic carbon flux from flag leaf to spike at grain-filling increases, a+b chlorophyll content and a:b ratio increases; and (4) in the whole plant: compact leaf area, optimal photosynthetic potential and its redistribution in the upper part of shoot during the reproductive period, increased biomass, high photosynthetic "source" required for forming large spike "sink", redistribution of assimilates to spike.

The OPWPT with high grain yield allowed us to apply photosynthetic technologies in breeding wheat varieties with high photosynthetic capacity. As a result 30 photosynthetic tests and 11 photosynthetic test-systems on high productivity have been characterized (Kershanskaya et al., 1998).

A wide range of local and potential breeding materials with contrasting productivity and stress resistance levels were screened, and varieties with wide diversity of photosynthetic function and structure indices were identified. As a result, materials from our own core collection were combined with 200 highly photosynthetically active wheat genotypes and used in breeding.

Four types of wheat production processes were identified for favourable and marginal environments in southeastern Kazakhstan. Results of studies of the introduced wheat lines' morphophysiology and their economically valuable traits have been disseminated as recommendations and included in applications for patents for their use in different local environments and for breeding. Two new cultivars with improved photosynthetic capacity and high grain yield, Bayandy and PPK-6, developed using a complex of high photosynthetic characters, passed the State Examination.

Conclusions

Based on our results, we developed a scheme illustrating the optimal photosynthetic processes that represent the main thesis of the OPWPT (Figure 3). The main thesis of the OPWPT concept was demonstrated by the following:

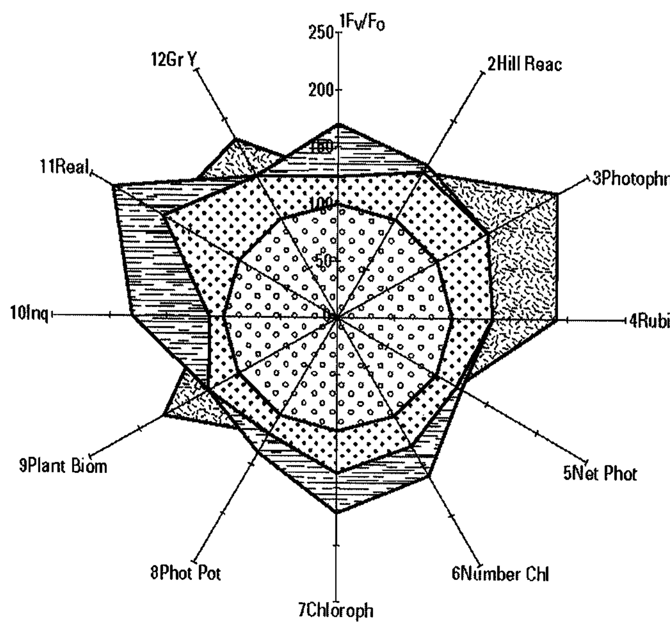

Figure 3. Photosynthetic basis for optimizing productive processes in wheat.

Photosynthetic characters in % of standard cultivar (100%); light violet figure = high-productive photosynthetic type; the whole figure = optimal photosynthetic wheat plant type. Levels of photosynthetic organization: radii 1-3 = chloroplast level; 4-7 = leaf level; 8-12 = plant level. Radius description: 1 F_v/F_0 = maximum quantum efficiency of photosystem II; 2 Hill Reac = Hill reaction; 3 Photophn = photophosphorylation; 5 Net Phot = photosynthetic CO_2-assimilation rate; 6 Number Chl = number of chloroplasts in flag leaf; 7 Chloroph = 0+b content in flag leaf; 8 Phot Pot = plant leaf photosynthetic potential; 9 Plant Biom = plant biomass; 10 Inq = spike demand for assimilates; 11 Real = development of spike demand for assimilates; 12 Gr Y = grain yield. 1-5 = intensive photosynthetic characters; 6-9 = extensive photosynthetic characters; 9-12 = characters for biomass conversion into grain yield. Potential diversity of photosynthetic characters represented.

- The potential for developing soft wheat lines with an integrated chain of compatible photosynthetic processes, from photosystems to whole plant and crop production, was confirmed. The level of energy and redox potentials of active primary photosynthetic reactions determine high CO_2-assimilation activity and regulate structure-functional optimization of productive processes in leaf and plant, which can thus respond to large spike demand for assimilates in high yielding wheat varieties.
  The reproductive type of production process was established, as well as the role of organs in the upper part of shoot (flag leaf, stem after spike, spike components) in high biomass accumulation in OPWPT.
- The best combination of extensive (structure) and intensive (function) parameters of photosynthetic activity was determined. The potential range of functional and structural diversity in the OPWPT's photosynthetic characters was established, as well as probable combinations for high productivity. Activity of photosynthetic processes at the "lowest" levels of organization (photosystem, chloroplast) could not be determined at higher levels of the photosynthetic apparatus (leaf, plant).
- This confirms the relatively independent (discrete) character of expression and inheritance of photosynthetic indices that determine their different interactions and relations.
- In summary, high photosynthetic productivity is determined both by high autonomy of photosynthetic structures at the lower levels of the photosynthetic apparatus organisation (photosystem, chloroplast, leaf) and by the complex system of integrated photosynthetic processes in the whole plant.

The OPWPT can be used to identify photosynthetic characters that could be genetically modified to further increasing wheat productivity (Kershanskaya, 2000b, 2001a, b, c, 2002a, b), for example, in a C_3 wheat plant, photosynthetic enzymes could be modified by molecular metabolic engineering.

Creating a "C_3-C_4 intermediate wheat" would have many advantages for Kazakhstan because C_4 plants are especially successful in hot or arid areas and in soils with high salt content. The agricultural regions of Kazakhstan include large arid zones and salty areas with increased desertification, unknown atmospheric CO_2 balance and, possibly, a global missing sink, and soil carbon losses of 35-50%. A promising advance in wheat improvement would be to genetically modify the photosynthetic process by introducing C_4 photosynthesis genes into wheat, thus creating "C_3-C_4 intermediate wheat" with C_4 DNA.

To use photosynthetic research and technology to fulfil the needs of humanity in the near future, it may be useful to focus on the following:

- Photosynthetic basis of wheat production processes and crop improvement.
- Adaptation of the photosynthetic apparatus to tolerate increased drought, in view of global desertification.
- Global climate change and "missing sink" for elevated atmospheric CO_2.
- Genetic modification of photosynthesis.

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Adaptive Breeding of Winter Bread Wheat in Krasnodar

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Northern Caucasia is one of the major winter wheat producing regions of Russia, with a wheat area of 4-4.5 million ha. In the Krasnodar Region winter wheat occupies more than one million hectares; regional production in 2002 exceeded 5 million tons, and average yield was 5.1 t ha^{-1}. Virtually all of the sowing area is occupied by varieties bred by KLRIA, which are widely grown in the regions and republics of Northern Caucasia, and also in the states of Transcaucasia and Middle Asia.

During more than 80 years breeding efforts, 185 wheat and triticale varieties have been developed in the Institute, 97 of them in the last 20 years. In 2003, 34 varieties were included in the State Register of the Russian Federation and released into production, among them the famous Bezostaya 1 developed by academician Pavel P. Lukyanenko. Its introduction into commercial production in the 1960s and 1970s caused wheat production to double; Bezostaya 1 also responded well in many winter wheat sowing countries of the world. W.E. Kronstad (1995) lists Bezostaya 1 among the most important sources of germplasm, on which many modern wheat varieties have been based.

Materials and Methods

Composite bridge crossing is our basic breeding technique, which includes various types of crosses: intraspecific, interspecific and intergeneric. Use of chromosome and genome substituted lines makes it possible to widen wheat's adaptative potential, and well adapted native material helps to maintain it.

Results and Discussion

Wheat breeding advances and application of new technologies have contributed to constant yield growth. In the last century, winter wheat yields increased almost five times. In the last 50 years of the previous century, winter wheat yields in the Region tripled, from an average of 1.48 t ha^{-1} (1951-1955) to 4.4 t ha^{-1} at the end of the century, and 4.96 t ha^{-1} in 2001-2002 (Figure 1). Annually, yield has increased by 2-2.5% thanks to breeding advances. Breeding has become increasingly important in recent years due to the multi-level adaptive system developed in our Institute and applied in the Region.

All the varieties developed at KLRIA and grown in Kuban in the last 100 years were included in a trial conducted on the occasion of Pavel P. Lukyanenko's 100[th] anniversary. The varieties were grown on moderately fertile soil after fallow with a pre-sowing application of $N_{10}P_{20}$ and N_{35}.

Varieties grown in the first half of the 20[th] century (from Sedouska to Novoukrainka 83) under modern agro-ecological conditions and moderate levels of soil nutrient availability produce from 3 to 4 t ha^{-1}. Their harvest index does not exceed 25% (Table 1).

The revolutionary modification of growth habit in the variety Bezostaya 1 and its derivatives increased yield potential by 1.5-1.7 t ha^{-1}, to 5.89 t ha^{-1} on average. Medium height varieties developed and grown during the last 20 years show even higher yield potential, averaging more than 7.77 t ha^{-1}; protein yield per hectare has almost doubled.

Semidwarf varieties, which we classified as a separate group, made the most efficient use of environmental resources and intensification techniques. Their yield potential averaged 8.55 t ha^{-1}, protein yield per hectare more than one ton, and a harvest index of 45-50%.

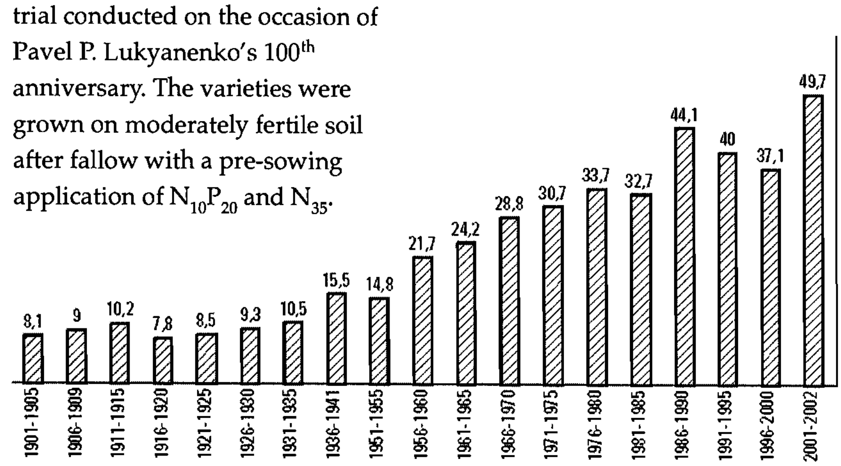

Figure 1. Winter wheat yields in the Krasnodar Region in the 20[th] century.

Table 1. Winter wheat yield increases in the 20th century as a result of plant breeding; mean values of three yield trials, 2001-2002.

Variety	Years grown	Yield (t/ha)	Genes for plant height reduction	Harvest index (%)
Sedouska, Kosobryukhovka and others (folk selection)	1901-1935	4.19	-	25
Kruglic 393, Novoukrainka 83	1935-1955	4.6	-	28
Bezostaya 4, Bezostaya 1, Avrora, Kavkaz, Krasnodarskaya 39	1955-1975	5.89	Rht_9	35
Krasnodarskaya 46, Krasnodarskaya 57, Severokubanka, Kolos 80, Pavlovka, Olimpiya	1976-1990	6.9	Rht_9	36
Istok, Krasnodarskaya 70, Soratnitza, Rufa, Ejka, Polovchanka, Zimorodok, Kupava, Delta, Lira	1991-2002	7.77	Rht_8, Rht_9	39
Yuna, Nika Kubani, Bat'ko, Ofeliya, Starshina	1991-2002	8.2	Rht_1, Rht_9	43
Spartanka, Skifyanka, Kroshka, Pobeda 50, Tanya, Vostorg	1991-2002	8.55	Rht_{11}, Rht_9	48

show greater leaf area index due to the increased number of tillers. This positively affects yield.

Comparative yield analysis of varieties grown in the Krasnodar Region at various periods of this century shows that the above-ground biomass yield of Spartanka has increased by 24% and its grain yield by 143%, compared to local variety Krymka. A variety becomes outdated not only because of increased disease and pest severity but also due to lagging behind changing growing conditions.

Breeding for morphological trait modification (xeromorphic parameters, stay-green and others) was the basis for improving physiological parameters of a wheat plant showing good adaptation ability. Based on this approach we increased germination capacity, water-holding capacity, xeromorphic parameters, chlorophyll content, and drought tolerance of the wheat plant as a whole. It became possible to develop drought tolerant varieties with big spikes, such as Kupava, Krasnodarskaya 99, and Vita.

Yield component analysis shows that Karlic 1 as a source of dwarfness was the genetic basis for improving the productivity of varieties carrying the *Rht1* gene. Karlic 1 had a high level of productive tillering and formed on average 2.4 thousand kernels per square meter, more than its parent Bezostaya 1.

Variety Karlic 1 had had good combining abaility in increasing the number of kernels per unit area in new varieties which was critical for yield improvement. In addition, number of kernels per unit area in with varieties carrying gene *Rht11* increased due mainly to productive tillering increase and in those with *Rht1*, due mostly to higher number of kernels per spike. Tiller leaf area of the wheat plant decreased at the same time as the length of the stem. This reduced the plant's competitive ability for assimilates and light and induced profound tillering (Bespalova, 1998).

Study of high yield production traits showed that the assimilation area and its activity period are most important (Repca and Petr, 1984). We have developed short-stem varieties with reduced area of two upper leaves of one tiller, which

Analysis of breeding achievements shows an increase in the spike's portion of overall plant height (from 5.6 to 10.6%), increase in number of spikelets and their productivity (from 15/3.9 to 18/1), number of kernels per spike (from 23 to 35), and number of spikes per unit area. Varieties with similar yield levels may differ significantly in their yield components (Table 2).

Upon analyzing the results of our semidwarf wheat breeding, of Krasnodar's breeding efforts in general, and of other successful long-term breeding programs, it becomes clear that new varieties can be continuously developed if environment-adapted breeding materials are included in composite bridge crossing. In breeding semidwarf varieties, where it was necessary to introduce dwarfing genes into well-adapted germplasm, backcrossing to one highly adapted recurrent parent could not solve this

Table 2. Yield component alteration caused by breeding efforts (mean of five years).

Variety	Spike length (cm)	Number of spikelets per spike, including sterile ones	Number of kernels per spike	Grain weight per spike (g)	TKW (g)	Number of spikes per m^2	Two upper leaves area
Krymka	8.0	16/3.6	23	0.93	33.6	357	1.41
Sedouska	7.8	15/3.9	24	0.90	33.2	350	1.43
Novoukrainka 83	8.8	17/1.8	27	1.01	37.1	444	1.71
Bezostaya 1	9.1	19/1.5	34	0.31	44.2	486	1.96
Kupava	9.5	18/1	35	1.55	44.8	522	2.36
Spartanka	9.0	17/0.8	29	1.14	42.2	781	2.32

problem. The best results were achieved through inclusion into hybridization of medium height varieties related to Bezostaya 1, either locally bred (Kavkas, Pavlovka) or originating from similar environments (Mironovskaya 50, Rostovchanka, NS Rannyaya 2, Obrij). Thus, Bezostaya 1's genetic background enriched by adaptability factors selected in other similar environments formed the basis for developing highly adaptive semidwarf varieties (Figure 2).

Breeding history indicates that adaptability level usually conforms to the breeding and agricultural situation in general; therefore, to improve adaptability we use the latest breeding achievements that have proved highly valid across a wide range of environments and years.

To improve specific traits responsible for adaptability we include in our crosses lines carrying translocations or chromosome substitutions from wild relatives that were developed in our Biotechnology Laboratory. Varieties Zhirovka, Fisht, and Vostorg were developed in this way.

Our department is engaged in bread and durum wheat and triticale breeding. This contributes to widening adaptability potential through integration of adaptability systems of bread and durum wheats, rye and wild relatives with the help of "bridge triticale" and application of tetraploid components.

The development and widespread production of varieties Polovchanka, Knyazhna, and Krasota proved the effectiveness of using "bridge triticale" for transferring genetic material from rye and durum wheat. The above mentioned varieties show good performance in adverse growing conditions (Timofeev *et al.*, 2001).

Our variety Fisht is an example of how adaptability can be increased through use of lines carrying translocations from wild relatives. It is a semidwarf variety that is resistant to lodging, two rust species, powdery mildew, Septoria diseases, and viruses. Virus resistance and slow autumn seedling growth allow us to recommend this variety for early sowing (12 days earlier than usual) and, therefore, to extend the optimum sowing period. This is particularly important for poorly equipped farms.

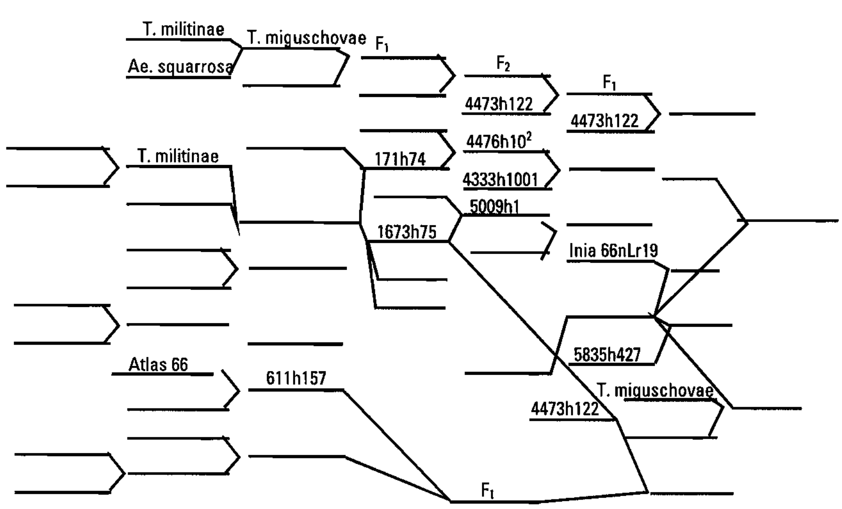

Figure 2. Pedigree of varieties carrying the *Rht11* gene.

Winter-hardiness and, especially, frost-hardiness are very important features for general adaptability in our region. Most varieties included in the State Register surpass Bezostaya 1 in frost-hardiness. Varieties Zimorodoc, Yubilejnaya 100, PalPich, Pobeda 50, Kroshka, Umanka, Millenium, Bat'ko, Soratnitza, Moskvich, Liga, Doca, and Vita show the highest level of frost-hardiness.

Winter vegetation often occurs in our region. Under such conditions the highest yields are produced by varieties that are photoperiod insensitive, have a short vernalization period, and can recover from dormancy at low above-zero temperatures. In breeding such varieties we have to sacrifice frost-hardiness in favor of these adaptation factors.

Our new truly facultative variety Lastochka produces good yields when sown in autumn and surpasses spring wheat varieties when sown in spring. The facultative varieties produce good yields both when sown in autumn on optimum dates and during February and spring thaws. Such varieties can be used as safety nets. Our varieties with different vernalization periods and photoperiodic sensitivity can adapt to any winter conditions.

Varieties developed in our Institute show various types of responses to different agricultural practices. Regression analysis shows that to achieve 7 to 10 t ha^{-1} grain yield, it is necessary to use semidwarf varieties that show the maximum economic response to agro-technological practices (Kroshka, Pobeda 50, Nika Kubani). To increase yields of wheat sown after non-fallow crops in intensive and moderately intensive systems, we recommend using varieties such as Kupava, Umanka, Selyanka, and Russa, among others.

Varieties whose yield is not affected by decreased nutrient availability play a great role in increasing grain production. In this respect, Knyazhna, Lira, and Polovchanka are the most prominent varieties. Though they do not yield well in intensive growing systems, these varieties become leaders when late sown in extensive systems.

A variety's role increases significantly in minimum- and zero-tillage systems. Varieties that have strong root systems and tolerance to compacted soil show better performance. Zimorodok stands out when no fertilizers are applied, while Krasota and Starshina are more effective in moderately intensive and intensive growing systems.

Breeding varieties with complex resistance to biotic stresses is a great challenge. Our studies prove that wheat can be safely protected from disease by breaking apart pathogens and hosts in time and space. This has become possible due to the use of a great number of our varieties with genetically diverse resistance and their mosaic arrangement. Frequent change in varieties lets us control the reproduction process of specific pathogens or races.

Krasnodar Region is noted for its wide range of winter wheat growing conditions, not only soil, climate and weather factors being among them, but also a vast range of agro-technological factors. No single variety can produce sustainable grain yields under all these conditions, even if it has high adaptation capacity. It has been estimated that a farm producing wheat on 4,000 ha can obtain an additional 2,500-4,000 tons of grain if it uses a correctly compiled set of 6-7 varieties.

Our own studies, the State Breeding Achievements Testing and Protection Committee's data, and the results of adaptation trials all contribute to compiling a variety's passport, based on which we work out a varietal arrangement scheme for each area, region, and farm. This forms a kind of mosaic where each section is occupied by a particular variety. Alternate cropping of resistant and susceptible varieties hinders pathogen multiplication and spread, thus preventing epidemics. Regular varietal replacement is aimed at achieving the same result.

An effective breeding program and our new variety policy led to the development of a multiple and miscellaneous variety stock. Immunologists say that a variety cannot be successful if it is popular. In order to avert such a fate for our varieties we rejected macro-varieties or varietal monopolies. None of our varieties covers more than 15% of a sowing area.

If needed, we can quickly make corrections in the varietal arrangement schemes and replace a variety quickly. This approach has helped us not only to stabilize total grain yield but also to improve phytosanitary conditions, for example, when there was a change in the brown rust population in Northern Caucasia. According to the data of the All-Russian Research Institute of Plant Protection, in the early 1990s, when Spartanka and, later, Una covered more than half of the sowing area, aggressive brown rust races became dominant and quickly reproduced. A gradual shift to heterogeneous varietal structures led to stabilization within the brown rust pathogen population, which has been in balance since 2000 (Table 3).

Due to effective breeding a variety's role has changed. Sets of mutually interchangeable varieties with high adaptation capacity, specific variety destination, and diverse variety schemes contribute to increasing the adaptability of the culture as a whole and stabilizing grain production.

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Table 3. Change in race stock in the Northern-Caucasian brown rust population.

Race	Race occurrence frequency (%)				
	1991	1993	1998	2000	2002
77	54.4	15.0	7.0	5.2	6.7
25	34.6	59.5	9.0	1.8	4.5
62	2.6	17.2	9.0	4.3	3.0
15	2.6	5.0	25.0	7.0	1.1
52	2.9	2.7	10.0	5.2	3.6
5	0	0	3.0	2.6	0.8
28	0	0	2.0	3.5	4.8
2	0	0	2.9	5.2	5.0
16	0	0	1.8	7.0	5.8
33	0	0	0	7.0	6.2
124	0	0	0	6.0	0.8
179	0	0	0	5.2	3.3
others	2.9	0.6	30.9	4.0	55.2

Wheat Breeding and Seed Production in Different Ecological Zones of Tajikistan

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The republic of Tajikistan is a mountainous country whose territory extends over 143.01 thousand km^2. Mountains occupy 93% of this territory, and only 7% is arable land. The altitudes where research took place ranged from 900 up to 2200 m above sea level. Grain production increase remains the main problem of agricultural development in Tajikistan, where wheat is the main crop, as it is in many countries of the world. It is grown in both valleys and highlands of Tajikistan. Presently, the area under wheat production occupies 174-180 thousand ha. Average yield is 2.0-2.5 t/ha under irrigation and 0.8-1.5 t/ha under rainfed conditions. This is not enough for Tajikistan to be self sufficient in wheat. Although there is huge potential for increasing national wheat yields, every year about 300-400 thousand tons of grain are imported. The goal is to produce an average of 1.3-1.5 mln tons of grain per year in the country through the development and introduction of high yielding varieties with good quality. Wheat breeding in Tajikistan has a long history. Local wheat varieties such as Surhak, Safedak, Irodi, Bobilo, Mualimko, Sio-suh, Lailak-bogary, Sargurak, Hazoni surh, Hazoni saored, and Kal-husha were developed through selection and improvement.

Wheat breeding started in Tajikistan in 1932, when I.G. Suhobrus began collecting and studying local populations and varieties, as well as germplasm from the Vavilov Institute (VIR). Individual and bulk selection methods were applied in the first period of breeding. The following varieties were released out of the selected germplasm: Surhak 194, Surhak 1288, Surhak 257, Surhak 1414, Surhak 5688, and Irod 1006. However, these varieties had several disadvantages: they had a tendency to lodge and were susceptible to fungal and smut diseases. Therefore, a synthetic approach was used in the second breeding period, which produced bread wheat varieties Surhak 262, Tajikskaya 16, Ferugneium 67, and Tajikskaya 13, plus durum wheat varieties Vatan, Baht, and Sham.

The results of multiyear breeding showed that the most adapted varieties are spring types sown in autumn, representing facultative wheat. In addition to all the positive traits and characteristics, these varieties should possess increased levels of cold hardiness. In Tajikistan, drastic temperature decreases to minus 25 °C can be observed with a small snow cover in intermediate and high mountainous regions. In relation to this, a new method of original germplasm development was applied in wheat breeding using the impact of natural experimental conditions on biologically winter varieties. This method was used to develop the variety Navruz. It was developed through transformation of winter variety (Mironovskaya 50) into spring ones. The authors of this variety were scientists Karamhudoev I. and A.F. Lashkareva. Forty wheat varieties were submitted to the State Variety Testing Commission, out of which 11 bread and 3 durum wheat varieties were released. At present bread wheat cultivars Navruz and Tajikskaya 13, and durum wheat cultivars Vatan and Vahsh are involved in production.

In comparison to local varieties, modern cultivars have several advantages: they have higher yield and the best grain quality. However, in recent years the released variety Navruz failed to meet production requirements. In years with high humidity Navruz became susceptible to fungal diseases and, especially, to yellow rust. In the past few years, we developed bread wheat varieties that are more resistant and high yielding: Somony (Tajikistan), Tacikar, Norman, (Tajikistan-Mexico), and durum wheat varieties: Sham, President (Tajikistan). These varieties are under official state testing. Bread wheats that have been released and are cultivated in Tajikistan also include varieties from Kazakhstan, Uzbekistan, Odessa, and the collections at CIMMYT and ICARDA.

Field experiments were carried out in 1995-2000 in the fields of Tajik Scientific-Production Corporation (SPC) "Zemledelie", Gissar county; the preceding crops were maize and cotton. Soil is a dark serozem with humus content of 1.0-1.2%. The plot area was 0.6-1.2 m^2 in the collection nursery and 16 m^2 in advanced and elite yield trials with three repetitions. Standard varieties were sown every 20 m without repetition in the collection nursery, while in the other nurseries they were sown at the beginning and the end of the experiment. Fertilization was done in the spring using carbamid at a rate of N60. Irrigation was carried out 1-2 times per vegetation period at a rate of rate of 800-1.200 m^3/ha. Observation and biometrical analyses were carried out according to the methodology of Vavilov Institute (VIR) Wheat Department.

Results and Discussion

The development of varieties characterized by high and stable yield potential in different environmental conditions is the main task of breeding. Collaborative breeding and multilocational trials of varieties and released lines were carried out on the basis of the cooperative project GTZ-CIMMYT and Tajik SPC "Zemledelie" in 1999-2000. Survey results showed that during the year the yellow and leaf rust resistance of the released varieties and breeding lines varied depending on soil and climatic conditions. Yellow rust reached the maximum severity level only in some years (in 1952, 1958, 1966, 1997, 1998 and in 2003) under favorable conditions for disease development.

Climatic conditions were different during the test three years. In 1997 the amount of precipitation was 574.1 mm, close to the multiyear average. However, most of this precipitation (366.1 mm) occurred in spring during the period of spike formation as well as grain maturity. In 1998, the precipitation level was higher than the multiyear average by 286.3 mm. In spring during the period of spike formation it was higher by 102.8 mm. As a result of this and the increase in relative humidity, grain crops, including several susceptible wheat varieties, were affected by yellow rust. A rust epidemic in 1997-1998 spread to all areas and regions of Tajikistan. Firstly, imported varieties were affected: several from Krasnodar, Odessa, Uzbekistan, Kazakhstan, plus several varieties from CIMMYT and ICARDA, as well as our released varieties.

In the last few years, yellow rust has become the most serious wheat disease. For instance, in 2001 the degree of yellow rust infection was 20% on released variety "Navruz" and breeding lines CHAM 6 / / 1D13/1/MLT, PTZ NISKA /1556-170. Leaf rust affected varieties "Kaus", "Attila" and PTZ-NISKA/ UTI-1556-170 and Steklovidnaya 24 with up to 30% infection (Table 1).

In 2002, in different environmental conditions, the resistance was different. The degree of yellow rust infection on the variety "Navruz" was 30% in SPC "Zemledelie", 80% at Kulyab Experiment Station and Faizabad zone, and only 0 to 10% of infection was observed in Vahksh and Soviet regions. The following varieties remained resistant in all zones: Jagger (Kansas, USA); KAUZ (Mexico); Tacikar, Norman (Tajikistan-Mexico) GENE; (USA) CHAM 6//1D13.1//MLT (TCI), GRK/ESDA/LIRA; NWT /3/ TAST / SPRW // TAW1239 (TCI) and Bezostaya 1. The degree of infection varied from 0 to 20%. The varieties were infected by disease differently in different ecological zones - from 20 to 80% (Table 2).

The best results on productivity of wheat varieties were obtained at SPC "Zemledelie," where the average yield of the varieties and lines was 3.9 t/ha. In other zones

Table 1. Productivity, disease resistance, and other traits in elite yield trials, SPC "Zemledelie," 2001.

Variety/line	Country	Heading date	Rust (%) Yellow	Leaf	Yield (t/ha)	1000 grain weight	Height (cm)
NAVRUZ (LOCAL CHECK)	TAJ	24.04	20	20	4.10	34.0	98.8
SHARORA	TAJ	26.04	30	20	3.87	33.0	89.6
STEKLOVIDNAYA- 24	KAZ	7.05	10	30	3.91	35.2	98.2
KARLYGACH	KAZ	7.05	20	30	3.81	28.8	114.6
JAGER	KS	28.04	10	10	3.92	27.3	93.0
KAUZ	MX	21.04	0	40	3.87	27.1	81.0
ATTILA	MX	20.04	0	30	4.64	29.8	82..4
SULTAN	TCI	9.05	10	10	4.20	21.8	94.0
TACIKAR	TAJ-MX	24.04	0	20	4.26	32.1	98.6
NORMAN	TAJ-MX	24.04	0	20	4.46	30.3	111.6
ZANDER-12	TCI	8.05	0	20	4.23	31.5	113.4
ZASTAVA	RUS	30.04	10	0	4.09	25.8	96.8
MADZEN	USA	10.05	0	10	2.80	21.4	83.6
GENE	USA	7.05	0	15	3.10	27.5	72.6
ROL /3/ PGFNII	TCI	30.04	0	10	3.20	25.6	96.6
CHAM 6 //1D/13.1/MLT	TCI	30.04	20	0	4.11	29.4	104.2
PTZ NISKA/UT1556-170	OSU-CIT	30.04	20	20	4.00	28.3	89.0
PTZ NISKA / UT 1556-170	OSU-CIT	30.04	15	30	4.35	28.1	91.6
JUP / U / CLLF /3/ 114	MX-OR	30.04	10	10	4.19	28.0	95.6
SOMONY	TAJ	23.04	10	10	4.63	34.6	87.6

yields were: Kulyab Experiment Station - 3.1 t/ha; Vahsh station - 2.9 t/ha; Sovet station - 1.4 t/ha. Yields of 4.3 to 4.6 t/ha were produced by varieties Attila, Somony, Norman, Tacikar, ZANDER-12, and PTZ NISKA / 1556-170, which exceeded the standard variety Navruz by 0.3-0.6 t/ha. In Vahksh zone the was no significant difference between yields of the varieties. In Kulyab Experiment Station, the best yield was produced by Norman and ZANDER-12. The yield advantage compared to the local check was 2.2-2.7 t/ha. The was no big difference in the Soviet region except for varieties Zastava, ZCL/3/PGFN//CH067/SON64 (Turkey), and CHAM 6/1 D 13/ 1/ MLT, which out-yielded the check by 0.7-0.9 t/ha or by 53.8-69.3%.

In 2001, the best results from multilocational trials were demonstrated by varieties Norman, ZANDER-12, and CHAM 6// 1D13.1/MLT, which yielded 0.6 t/ha or 22 % more than the check Navruz (Table 3). In 2002 at SPC "Zemledelie" the best yield was shown by varieties Jagger, Norman, Attila, ZANDER-12, CHAM 6// 1D13.1/MLT, Zastava, Kinaci, VORONA/D 2402, GRK / ESDA / LIRA, NWT /3/ TAST / SPRW/ TAW//1239, and NORKAN // TJB406/892/MON exceeding the check Navruz by 0.9-1.3 t/ha.

In Vahsh zone the best yield obtained was by varieties Karlgach, ZANDER-12 , CHAM 6//1D13.1/ MLT, Kinaci, and AGRI/NAC// KAUZ, which yielded 4.7-5.0 t/ha, which was more than in the standard variety Navruz by 0.4-0.7. In Kulyab Experiment Station most varieties showed good results. In Faizabad zone the best results obtained were by varieties Steklovidnaya-24, Jägger, Attila, Tacikar, Norman, 1,27.6275, PARTIZANKA NISKA / 1556-170, NORKAN//TJB406/892, NWT/3/ TAST/SPRW/TAW//1239, and GRK//ESDA/LIRA. The standard variety Navruz was exceeded in yield by the mentioned varieties by 1.9-3.4 t/ha, or 70-125%. In the Soviet region the only one significant difference in yield was shown by the variety Tacikar. Its yield was higher than the yield of the check by 0.4 t/ha (Table 4).

Table 2. Reaction of winter wheat varieties and lines to yellow and leaf rusts in different zones of Tajikistan, 2002.

Variety/line	Country of origin	Sharora		Vahksh		Kulyab		Faizabad	
		YR	LR	YR	LR	YR	LR	YR	LR
NAVRUZ (CHECK)	TAJ	30	20	10	0	80	0	80	20
SHARORA	TAJ	80	0	40	0	100	0	80	0
STEKLOVIDNAYA 24	KAZ	40	30	5	0	60	0	30	60
KARLYGAH	KAZ	30	20	5	5	50	0	20	30
JAGGER	KS	5	0	0	0	10	0	20	10
KAUZ	MX	20	0	0	0	10	0	10	0
ATTILA	MX	15	0	0	0	5	0	40	80
SULTON	TIR-MX	20	0	10	0	10	0	70	0
TACIKAR	TAJ-MEX	5	0	0	0	0	0	20	10
NORMAN	TAJ-MEX	10	0	0	0	5	0	0	10
ZANDER-12	TCI	0	0	10	0	5	0	0	60
ZASTAVA	YKR	20	0	0	0	80	0	70	0
GENE	USA	0	0	0	0	0	0	5	0
CHAM 6	TCI	0	0	5	0	5	0	5	0
PTZ NISKA/UT 1556-170	OSU-CIT	10	0	5	0	10	0	50	30
PTZ NISKA / UT 1556-170	OSU-CIT	10	0	0	5	50	0	50	35
KINASI	MX-TCI	5	0	0	0	60	0	5	0
VORONA / HD 2402	MX-TCI	0	0	0	0	0	0	10	80
1.27.6275	IR	15	0	0	0	0	0	15	40
NORKAN	OR-CIT	10	0	0	0	0	0	15	50
AGRI / NAC	MX-TCI	40	0	0	0	50	0	40	0
LOV -26	SERI TCI	30	0	0	0	10	0	80	0
GRK // ESDA	MX-CIT	10	0	0	0	10	0	10	0
GUN-91	TCI	20	0	0	0	0	0	35	60
NWT /3/ TAST	TCI	15	0	5	0	10	0	0	0
BEZOSTAYA	RUS	5	0	0	0	30	0	20	0

Table 3. Yield of wheat varieties and lines in different ecological zones of Tajikistan, 2001.

Variety/ line	Country of origin	Yield (t/ha)				
		Sharora	Vahksh	Kulyab	Sovetskyi	Average
NAVRUZ (CHECK)	TAJ	4.1	3.7	1.8	1.3	2.7
SHARORA	TAJ	3.9	2.8	3.1	1.4	2.8
STEKLOVIDNAYA 24	KAZ	3.9	1.6	2.7	1.5	2.4
KARLYGACH	KAZ	3.8	3.1	2.9	1.4	2.8
JAGGER	KS	3.9	2.8	2.7	1.4	2.7
KAUZ	MX	3.9	2.3	3.1	1.5	2.7
ATTILA	MX	4.6	2.6	3.2	1.3	2.9
SULTON	TUR-MX	4.2	3.1	2.7	0.8	2.7
TACIKAR	TAJ-MEX	4.3	2.9	3.1	1.6	3.0
NORMAN	TAJ-MEX	4.5	3.1	4.5	1.2	3.3
ZANDER-12	TCI	4.2	3.5	4.1	1.5	3.2
ZASTAVA	YKR	4.1	3.0	3.4	2.0	3.1
MADZEN	USA	2.8	3.1	2.9	1.2	2.5
GENE	USA	3.1	2.6	3.6	1.6	2.7
ZCL/3/PGFW//CN	TCI	3.2	3.3	3.2	2.0	2.9
CHAM 6	TCI	4.1	2.9	3.7	2.3	3.2
PTZ/ NISKA / UT 1556-170	OSU-CIT	4.0	2.6	3.8	1.4	2.9
PTZ NISKA / UT 1556-170	OSU-CIT	4.3	2.8	3.5	1.4	3.0
JUP/4/CLLF/3/1114	MX-OR	4.2	2.9	1.7	1.1	2.5
SOMONY	Taj	4.6	2.8	2.3	1.0	2.7
AVERAGE		3.98	2.87	3.1	1.35	2.83

Table 4. Yield of wheat varieties and lines in different ecological zones of Tajikistan, 2002.

Variety/line	Country of origin	Yield (t/ha) Sharora	Vahksh	Kulyab	Sovetskyi	Faizabad	Average
NAVRUZ (CHECK)	TAJ	3.1	4.3	3.5	3.6	2.7	3.4
SHARORA	TAJ	2.0	4.0	2.1	3.7	2.9	2.9
STEKLOVIDNAYA 24	KAZ	2.6	4.2	3.5	3.1	5.7	3.8
KARLYGACH	KAZ	3.2	4.8	3.8	2.4	4.6	3.8
JAGGER	KS	4.4	4.3	4.3	3.5	6.1	4.5
KAUZ	MX	3.4	4.3	4.8	3.4	3.8	3.9
ATTILA	MX	3.6	4.5	4.9	3.6	5.7	4.5
SULTON	TIR-MX	2.7	4.3	3.9	2.7	1.2	3.0
TACIKAR	TAJ-MEX	3.7	4.0	4.0	4.0	4.2	4.0
NORMAN	TAJ-MEX	3.7	4.2	4.3	3.6	5.3	4.2
ZANDER-12	TCI	3.7	5.01	4.4	2.1	3.9	3.8
ZASTAVBA	YKR	4.1	4.7	3.3	3.0	4.8	4.0
GENE	USA	3.4	4.7	3.5	3.6	-	3.8
CHAM 6	TCI	4.1	5.0	4.2	3.2	-	4.1
PTZ/ NISKA/UT 1556-170	OSU-CIT	3.1	4.2	3.2	3.4	5.9	4.0
PTZ NISKA/UT 1556-170	OSU-CIT	3.4	4.0	3.8	2.7	6.0	4.0
KINACI	MX-TCI	4.2	4.7	4.3	3.6	-	4.2
VORONA/HD2402	MX-TCI	4.3	4.2	4.4	3.0	-	4.5
1.27.6275/CF1770	IR	3.4	4.5	4.6	4.1	4.7	4.3
NORKAN/TJB406	OR-CIT	4.0	4.5	4.4	3.5	5.9	4.5
AGRI/NAC//KAUZ	MX-CIT	3.4	4.7	4.1	2.9	3.8	3.8
L026//LFN/SD	TCI	3.6	4.2	4.4	2.7	3.1	3.6
GRK//ESDA/LIRA	MX-CIT	4.5	3.8	4.2	2.6	4.6	3.9
GUN91//885KL.113	TCI	3.7	4.2	4.5	2.8	4.5	3.9
NWT/3/TA3T/SPRW	TCI	4.6	4.7	3.8	2.1	5.3	4.1

Conclusions

Among CIMMYT and ICARDA lines/varieties, Jagger (Kansas, USA), Attila (Mexico), Norman (Tajikistan-Mexico), NWT/3/TAST/SPRW//TAW12 (TCI), NORKAN//TJB/406/892/MON (CIT), CHAM6//1D13/1/MLT (TCI), VORONA/HD2402 (MX-CIT), and 27/6275/CF1770//VEE/CNB (Iran) demonstrated a yield of up to 4.2-4.5 t/ha, or 0.8-1.1 t/ha higher than the yield of the standard variety Navruz. Varieties Jagger, NORKAN//TJB/406/892/VON, and GRK//ESDA/LIRA (MX-TCI) were resistant to fungal diseases (yellow and leaf rusts). Several of the selected lines resistant to yellow and leaf rusts and showing high grain productivity and test weight were included in hybridization in 2001-2002. The line NWT/3/TAST/SPRW//TAW12 (TCI) was submitted to the official state testing in 2002 under the name Ormon and the line PYN/BAU under the name Alex.

Breeding Grain Crops in Myronivka Wheat Institute: Achievements and New Directions

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During 90 years of breeding activity, 160 cultivars of 18 crops have been developed in Myronivka. In 2002, of those 160 cultivars, 52 (37 included in the Register of Plant Varieties of Ukraine) were officially recognized for cultivation in CIS: winter wheat, 24 cultivars (including 14 in Ukraine), spring wheat: 3 (3), triticale: 7 (5), winter barley: 4 (4), spring barley: 4 (4), millet: 2 (2), Sudan grass: 4 (2), clover: 3 (3), and alfalfa: 1. For the first time 13 new cultivars–including 7 winter bread wheats (Myronivska 65, Myronivska 66, Myrhad, Kryzhynka, Myronivska 67, Kyivska 8, and early-maturing Myronivska); 1 spring bread wheat (Kolektyvna 3); 1 spring barley (Askold); 2 winter triticales (ADM 11 and Tandem); and 2 clover (Myronivsky 5 and Mriya) were included in the Register of Ukraine during 2000-2002. In 2003 three new cultivars (Westa, Columbia, and Podolyanka) were introduced in the Register of Ukraine. Winter wheat cultivars Remeslivna and Myronivska 35; spring bread wheat Isolda; and spring barley Soborny are candidates for inclusion in the Register.

Materials and Methods

The following breeding methods are being applied: intravarietal and intrastrain selection using artificially created limiting factors; intervarietal hybridization, including forms with different type of development among themselves; mutagenesis using fixed materials (varieties and lines) and hybrid populations (F_1-F_3); wide hybridization, first of all, between species of *Triticum aestivum* and *T. durum*, and with other crops (wheat, triticale, barley, and rye).

The most significant results have been achieved by using recombination, mutation, and hybrid mutation variability. Most new cultivars were developed on the basis of hybrid populations: Myronivska 65 (Myronivska 61 x Myronivska 27), Myronivska 66 (Lutescens 9922 x Erythrospermum 10071), Myronivska 67 (Myronivska 27 x Myronivska 61), Kryzhynka (Myronivska 27 x Myronivska 28), Myrhad (Hadm 5355-80 x Arkos), Westa [(Myronivska 27 x Hadm. 42555-83) x Myronivska 61], and Myronivska 35 (Lutescens 14511 x Myronivska 27). All spring bread wheat cultivars were also developed through hybridization: Kolektyvna 3 - F_3 [(F_4 Red River 68 x Inia 66) x (F_3 WAH-56 x Selkirk)] x Kharkivska 2; and Elegia Myronivska [Maris Dove (spring) x Myronivska 40 (winter)]. The cultivar Podolyanka was developed by treating winter wheat cv. Donetska 48 with N-nitrosodimethylurea (0.001%). Kyivska 9 (mutant of cultivar Albatross Odesky) is currently undergoing state testing. Based on hybrid-mutation variability, we developed the first cultivar Expromt (TXGH 2875 x Trakia + DAB 0,05 %), from which cv. Columbia was subsequently selected. Smuglyanka and Vesnyanka are undergoing state testing. The new cultivar Kyivska 8 was selected from a population developed by crossing Rostovchanka x Myronivska 61 and treating the F_1 generation with gamma rays. Selection of hard spring wheat is organized within the full conventional scheme (beginning in 1994). Wheat cv. Isolda was developed through intraspecific selection from accession Leucurum 806 h2/1 (from the Volga region of Russia).

It is important to evaluate yield potential and grain quality under conditions of highly intensive production, such conditions as we had in eastern Poland in 2000-2002. There, under favorable weather conditions of 2000, we produced the highest harvest: Myronivska 65 and Myrhad yielded 10.2-10.3 t/ha in 1 ha of sowing area. By selecting for quality traits, we also succeeded in improving wheat quality. Of cultivars introduced into the Register in 2000-2001, 85% were classified in the group of strong and valuable wheat, whereas in 1991-1999 only one cultivar had comparable quality (10% of all cultivars registered at that time).

The problem of winter hardiness was essentially improved; thus the number of winter-hardy cultivars introduced into the Register of Ukraine from 2001 to 2003 reached

86% vs. 62% from 1991 to 1999. In general, of the Myronivka cultivars introduced into the Register of Ukraine in 2000-2003, 50% have resistance to 4-6 diseases, compared to only 10% of cultivars introduced during 1990-1999. We also developed winter and spring bread winter cultivars resistant to pre-harvest sprouting in the spike as well as to shattering during maturing-harvesting, and winter wheat cultivars belonging to different groups of maturity.

Conclusions

Conventional breeding has not reached the limits of its resources in either direction. Advanced activities in programs such as frost hardiness, grain quality, and immunity are carried by research teams. The broad ecological testing that allows to isolate selection lines (including new candidates for release) with improved adaptation to abiotic and biotic stress factors is obvious necessary. New parent lines of wheat with a complex agronomic traits were obtained by applying biotechnology methods. New bread wheat lines carrying introgressions were singled out. A range of wheat-barley and triticale-barley hybrids was developed, as well as wheat-rye amphydiploids with essentially new architectonics, high yield potential, and tolerance to environmental stress factors.

Cereal Breeding and Seed Production in Turkmenistan

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Turkmenistan is an ancient center of wheat production. Arid climatic conditions with drastic temperature changes between winter and summer have created unique conditions contributing to a large diversity of local wheat varieties. These local varieties maybe characterized by a range of valuable traits including: drought and heat resistance; dense none-shattering spikes with hard glumes; broad adaptation to diverse growing conditions; low and stable yield; and excellent bread-making grain characteristics.

In the 1970s, local wheat varieties that had become ineffective due to low yield potential (<2.5 t/ha), lodging, rust susceptibility and poor responsiveness to inputs were displaced with modern, improved varieties. For this reason the state program "Grain" accepted in 1992 and associated with achievement of the independence by Turkmenistan, was designed to provide grain for food to the domestic population, based on a broad diversity of local and introduced varieties, and improved crop management practices.

The strategy of "Grain" implies improvement of crop management systems and the release of new varieties with yield potential of 4-5 t/ha. This revolutionary "jump" in yield will be realized only with improvements in wheat breeding and seed production, including: utilization of the local genepool bank as the source for breeding variability; introduction and use of foreign germplasm; and, development of new, highly productive wheat varieties, which combine positive traits from both local and introduced varieties.

Modern wheat breeding began in Turkmen in 1925. However, many interruptions during the period 1925 to 1991 resulted in a loss of connection between generations of scientists and their breeding materials. This, of course, negatively affected the results of breeding. Nevertheless, during the period several varieties were developed in Turkmenistan, including: Turtsikum 57, Meridionalle, Turtsikum M-1, Turkmenskaya, Duye dish, Meridionale 390, Meridionale 449, Eritrosperum 1371, Melyantuye (Shubin, 1955; Zhukovskiy, 1957). Turkmen local wheats were frequently used as parents for many famous Soviet wheat varieties such as: Eritrosperum 841 (P.N. Konstantinov), Kzyl-Shark (Uzbekistan), and Krasnaya Zvezda (Kyrgizstan). The following varieties were created through conventional breeding in 1957-1967: Iolotanskaya-5, Iolotanskaya-28 (B. Durdyev, 1970); in 1970-1975 varieties Tedzhenskaya-5, Tedzhenskaya-60 and Gyaurs-1 (Gelenov, Chesnova, 1985).

To our regret, the majority of the above mentioned local wheat varieties were lost to the breeding programs due to numerous reorganizations. Implementation of current country grain production improvement strategy began with the restoration of these lost local wheat varieties, as supported by the 1992 "Ak bugday restoration" Government Decree. Fortunately, these valuable genetic resources had been maintained by farmers, and now 24 collected accessions have been defined as the country's main wheat genepool. These landraces represent complex populations incorporating 5-11 botanical varieties (Table 1). They are biological, not merely mechanical mixtures, as suggested by the results of our research that indicates extraction of pure varieties from these diverse populations resulted in yield reduction and poorer grain quality.

Out of the all studied local varieties the ecotype of Ak bugday Tahtabazarskyi, which was a combination of botanical varieties, was the closest to the original Ak bugday (Table 1) since it consisted of botanical varieties Meridionale, Barbarossa and Ferrugineu, while the rest of ecotype incorporated 2-3 botanical varieties. It was concluded that the local Turkmen germplasm can be used as parental material. However, in 1996 a white grain genotype with gluten content of 28-30%, protein content of 14% and not less than 5.0 t/ha yield potential was selected from Halachskyi ecotype of Ak bugday.

The accession identified as Ak Bugday Halachskyi further named "Turkmen-bashy" has been released throughout the entire country. Turkmen breeders have developed accelerated methods of breeding resulting in highly productive and broadly adapted to local conditions new wheat varieties. Evaluation of breeding material is carried out using "The model of the new variety" scheme with projected agronomic traits (Table 2).

The testing of the material follows the scheme:

1. Introduction nursery:
2. Introduction nursery and elite international nurseries:
3. Preliminary yield trials and yield trials.

Methodology of SVT (State Variety Testing) and recommendations of TACIS, CIMMYT and ICARDA are used.

Based on the projected trait parameters of "The new variety model", out of more than 3000 assessments in the period of 1995-1999, 3 short stem intensive wheat varieties were identified: Bitarp, Garagum and Guncha (Table 3). The data of the AYT (1997-1999) indicates that the highest yielding variety was Bitarp. Yield increases in new varieties ranges from 5 to 10 %. Of special interest were the facultative wheats with short vernalization period.

From 2000 to 2002 the collaboration with international centers CIMMYT, TURKEY / CIMMYT / ICARDA, and ICARDA was extended. As a total, 28 international and local nurseries were involved in the research. Total number of varieties screened was 5651 out of which 1445 were

Table 1. Botanical variety classification of local wheat landraces in the Turkmen national collection.

Accession name	Origin	Botanical variety
Ak bugday (K-35525)	Kara-Kala -92	Merildionale
Karyshyk (K-35517)	Kara-Kala -92	Tursicum, Ferrugineum
Guzluyk (K-35388)	Kara-Kala -92	Greacum
Ak bugday Babadayhanskyi	Etr. Myatizhi	Greacum, Erythrospermum
Ak bugday Halachskyi	Etr. Halach	Greacum
Ak bugday Halachskyi	State farm M-Kuly	Leucurum
Ak bugday Karakumskyi	State farm Moskva	Erythrospermum
Ak bugday Kaahkinskyi	Kaahkinskyi region	Greacum
Kyzyl bugday (K-35527)	Kara-Kala-92	Erythrospermum, Ferrugineum
Ak bugday Tahtabazarskyi	State farm Dmitrov	Meridonale, Erythrospermum, Turtsicum, Erythroleucon
Kyzyl (K-35515)	Kara-Kala-92	Erythrospermum
Turtsikum-57	Unknown	Tursicum
Kelek bugday	VIR-93	Meridionale
Dya Dish	From Iran	Melyanopus
Turkmenka	VIR-91	Erythrospermum
Ak bugday Maryiskyi	Maryiskyi region	Greacum, Erythroleucon
Ak bugday (K-35513)	VIR-00	Tsaesium, Erythrospermum
Ak bugday (K-35548	VIR-00	Erythrospermum, turcicum
Turtsikum-1 (K-38473)	VIR-00	Turtsicum
Ferrugineum-861	VIR -00	Ferrugineum
Misry bugday (K-13902)	VIR -00	Notabile (Tr. turanicum)
Dya Dish (K-35579)	VIR -00	Notabil (Tr. turanicum)
Femisovn (K-13573)	VIR -00	Fetissovii
Kamchatka (K-23708)	VIR -00	Rubriceps

Table 2. Model of a new variety and traits for renewed (re-selected) promising wheat varieties.

	Parameters for:			
Traits and characteristics	The best released variety	Populations of local varieties	Model of new variety	Reselected varieties
Grain yield, t/ha	5.0-6.0	3.0-4.0	60-80	80-90
Grain weight per spike, g	1.2-1.5	0.8-1.0	1.5-2.0	1.5-2.0
1000 KW, g	40-50	33-40	50-55	38-40
Length of spike	8.2	9-10	8.5	9-12
Height of plant, cm	85-105	110-150	70-80	75-85
Stem hardiness, score	5	3-4	5	5
Spike density	24	16-20	24	19-21
Spike hardiness	mid	High		
Productive tillering	-2.2	2.7	3-4	2.5-3.5
Vegetative period, days	250-320	230-240	210-220	215-220
Winter hardiness, score	7-8	7-8	9	7-8
Drought tolerance	Mid	High	Mid	Mid
Yellow rust, %	1.0-1.2	80 MR	0	5 MR
Brown rust, %	12-15	12-15	0-5MR	0-5 MR
Loose smut, %	«0»	«0»	<1%	<5%
Gluten content	27-35	22-30	35-37	23-30

Table 3. Results from the Advanced Yield Trial (AYT), mean 1997-1999.

	Yield (t/ha)		Vegetation period (days)	
Variety	Actual	Deviation from check	Actual	Deviation from check
Krasnovodopadskaya-25 (check)	5.87	-+0	214	-+0
Guncha	6.08	+2,1	216	+2
Bitarp	6.43	+5,6	210	-4
Garagum	6.24	+3,7	220	+6

selected or 26% of the material (Table 4). Percentage of chosen varieties can indicate usefulness of the material in successive breeding work. Comparative analysis of percentage proportion of studied and selected varieties showed that the following nurseries are the most favorable: FAWWON(20-22%), WWONIR (21-37%), WWONZA-(28%), as well as elite nurseries - EYTIR (up to 30%), EYTRF (up to 48%) and ESWYT (up to 50%). Mainly nurseries of selection, preliminary and competitive trials are formed by these nurseries; the rest of nurseries are used to a lesser extent (from 10-17 %): they enrich the general collection for material conservation purposes and possible use in the successive synthetic wheat breeding.

Evaluation of foreign and local wheat germplasm was carried out for the main agronomic and biological traits such as winter hardiness, early maturity and resistance to rust and loose smut.

The selected varieties had a low infection of leaf rust in two favorable years for disease development (2000-2001) and 2002. The year of 2002 was very favorable for development of yellow rust and powdery mildew. Released varieties, which were planted to in preliminary and advanced yield trials for several years, proved to be the most susceptible to these diseases (Tables 5 and 6).

Assessment of the large amount of germplasm, 2000-2002, allowed the identification of a range of lines matching requirements of the New Variety Model including acceptable levels of winter hardiness, vegetative period duration, plant height, spike length and grain yield (Table 6).

Together with the renewed use of Turkmen landraces and improved germplasm from CIMMYT and ICARDA, our Institute is also involved in the synthesis of valuable breeding traits in identified genotypes by way of crosses. Currently 17 hybrid combination F_1's are being studied now, obtained upon request from CIMMYT-Mexico.

Conclusions

Selection work on local Ak bugday populations in the period of 1993-1999 reconfirmed the suggestion of Turkmenian breeders (in 1950s and 1960s) that local wheats are not mechanical mixtures but

Table 4. Bread wheat, durum wheat, barley and triticale breeding nurseries evaluated, and selections made therefrom, 2000-2002.

	Number of assessments					
	2000		2001		2002	
	Screened	Selected	Screened	Selected	Screened	Selected
Bread Wheat						
Screening nurseries	1234	230	2125	558	1038	305
Yield trials	334	130	403	121	462	101
Total:	1568	360	2583	679	1500	406
Durum wheat						
Screening nurseries	-	-	290	57	425	121
Yield trials	-	-	75	15	39	10
Total:	-	-	365	72	464	131
Barley						
Screening nurseries	595	153	545	118	1024	182
Yield trials	49	8	97	25	111	44
Total:	644	161	642	143	1135	226
Triticale						
Screening nurseries	56	22	340	25	120	36
Yield trials	-	-	-	115	50	22
Total:	56	22	340	140	170	58
In total:	2268	543	3875	1034	3269	821

Table 5. Yield of wheat selections from Advanced Yield Trials.

Name	Grain yield (t/ha) 2000	2001	2002	Mean	Deviation from check (kg/ha)
Krasnovodopadskaya -25 (check)	5.25	5.12	6.99	5.76	-+0
PSK/VEE	6.22	5.77	7.16	6.38	+620
VORONA/CUPE	6.02	5.48	8.09	6.53	+770
88Zong-257	5.64	5.81	8.32	6.59	+830

Table 6. The main agronomic and biological traits of the genotypes identified from AYT, mean for 2000-2002.

Name	Winter hardiness (score)	Date of spike formation	Vegetation period (days)	Height of plant (cm)	Spike length (cm)	1000 KW (g)	Disease infection: Rust YR	LR	Loose smut (%)
Krasnovodopadskaya-25 (check)	8	19.04	210	87.2	9.0	48.5	0	0	0-0
PCK/VEE	7	13.04	201	80.1	9.7	43.5	15MR	5MR	7-30
VORONA/CUPE	8	17.04	206	77.1	10.4	41.0	10MR	20MR	0-5
88Zong-257	7	4.04	196	80.0	10.2	45.5	10MR	20MR	0-0.5

complicated populations or biological communities. They can be used as initial material for improvement of new bread wheat varieties in Turkmenistan.

For the period of collaboration with international selection centers CIMMYT, TURKEY/CIMMYT/ ICARDA, and ICARDA, 1995-2002, 6 prospective lines of bread wheat were selected. Three of these (Bitarp, Guncha and Garagum) are under State Variety Testing Trial since 1999. The remaining 3 lines (VORO/CUPE...., 88ZONG PCK/ VEE...) will be submitted to SYT in autumn 2003.

Analysis of foreign germplasm in different nurseries (1995- 2002) suggests advantages of the following nurseries: FAWWON, EYTIR, EYTRF, WWONSA, WWONIR and ESWYT, where percentage of chosen varieties reaches up to 50%. Germplasm contained in these nurseries performs well and deserves more detailed investigation.

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Developing Varieties Highly Adapted to Siberian Conditions Using Drought Resistant Durum Spring Wheat

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The Altai region is the largest producer of high-quality durum spring wheat in eastern Russia. Plentiful heat and sunshine contributes to growing high quality grain for pasta production that meets international standards.

The climate of the region is highly diverse. There are eight soil-climatic zones located in a territory of 16.8 million hectares, from vast steppe valleys, through forest-steppes to the foothills of Altai and Salair. Moving from west (the border with Kazakhstan) to east, rainfall increases from 250 to 600 mm per year. Rainfall is 140-350 mm during the growing season, and the sum of temperatures above zero (above 10 °C) decreases from 2400 to 1900 °C (Table 1). Droughts and their duration decrease in the opposite direction. It should be noted that drought typically occurs in the spring-summer period (May-June, the first ten days of June) with rains moving to the second half of the growing period (the second and third ten-day periods of July, August, and even September) (Ivanov, 1932). The most severe droughts continue until the end of the growing season; they occur every 10-11 years usually early in each decade (Sennikov and Selaninov, 1972). Soil drought is typically accompanied by dry winds that devastate spring wheat yields at the grain filling stage.

Durum wheat was brought to Western Siberia by migrants from the southern regions of Russia in the late 19th century. A historical analysis reveals that this crop has always been an indicator of the status of the economy and level of farming; in positive periods the cultivated area has increased to 360 thousand hectares, and production of high quality grain was more than 300 thousand tons (1986-1990). In poorer periods the cropping area decreased to 3.0 thousand ha (1941-1945).

Until 1980, seed production was mainly based on varieties developed in the European part of Russia, which did not meet local requirements fully, especially for drought tolerance. The main durum wheat cropping areas were located in the steppe and forest-steppe zones of the region, which, as was mentioned above, are frequently exposed to droughts of varying intensity. In this regard, it has been always a challenge to develop durum wheat varieties with adaptation to soil and air drought and improved grain quality, resistance to diseases and pests, and suitability to mechanical harvesting.

Multi-year research conducted by V. Kuzmin (1965) and Rozov et al. (2003) on yield dynamics and distribution of precipitation during the growth period under conditions of the Altai region has determined that, in contrast to bread wheat, durum wheat has insufficient biological adaptability of seeds and shoots to consume moisture during the initial stages of plant development and develops secondary roots with some delay. The air drought and dry winds are most dangerous from tillering to grain filling and, therefore, may significantly decrease the level of spike fertility and number of grains in the spike (Savitskaya et al., 1980).

These regional features of durum wheat were considered by the authors of this research while identifying initial materials and recombinants in hybrid populations.

Materials and Methods

During the past 30 years, we have studied more than 3500 accessions of the global genepool of *Triticum*

Table 1. Climatic characteristics of the main agricultural zones of the Altai region.

Zones	Arable land (million ha)	Rainfall during growth period (mm)	Number of years with severe lack of moisture	Number of days with air drought in May-June	Sum of temperatures above +10°C
I. Western-Kulundinskaya steppe	2.07	140	80	10-17	2300
II. Western-Kulundinskaya steppe	2.24	170	70	8-15	2250
III. Rubtsovsko-Altai steppe	1.19	200	60	7-11	2200
IV. Forest-steppe of Priboy	1.25	250	40	3-9	2100
V. Foothills of Altai	0,8	300	10	2-3	2000
VI. Foothills of Salair	0,7	310	10	1-3	1900

durum, T. diccocum, T. persicum, and *T. turgidum.* In the beginning the material was represented by germplasm from the All-Russian Research Institute of Plant Industry named after N. Vavilov (VIR), and the best accessions are still being studied in the working collection of the Institute. During the last decade, initial materials were supplied through direct contact with the genetic collections of breeding centers in Russia, Kazakhstan, Ukraine, CIMMYT, and ICARDA.

Initially, an area of less than 1 m^2 was sown in the introduction nursery; it was then extended to 2 m^2 with one replication. Selected accessions and varieties were submitted to the State Variety Testing Commission for multi-locational yield trials sown on 5 m^2 with 4 replications. The material was planted after fallow using planter SSFK-7, and harvested using Hege 125C. The Institute is located near Barnaul City in the moderately dry steppe zone. In addition, some of the material was sown at Kulundinskaya Experiment Station, located in the driest part of the Altai region. During the research process, we assessed productivity, conducted crop vegetation observations, recorded the main stages of plant development, and evaluated resistance to diseases and grain quality. Drought tolerance was estimated on the basis of the Fisher and Mauer formula (1978, cited by Simane et al., 1993:

$$DSI = \left\{1 - \frac{Y}{Y_P}\right\} / \left\{1 - \frac{X}{X_P}\right\}$$

where *DSI* = drought resistance index, Y = yield under stress conditions, Y_p = yield without stress, X = average yield of all varieties under stress, and X_p = average yield of all varieties without stress.

Results and Discussion

Evaluation of the materials showed that the best drought tolerant accessions come from arid zones of Russia and Kazakhstan: Gordeiforme 10, Almaz, Omskiy rubin, Angel, Omskiy korund (Siberian Research Institute of Agriculture, Omsk); Bezenchukskaya 105, Leucurum 163, Gordeiforme 728, Bezenchukskaya 182, Bezenchukskaya stepnaya (Samarskiy Research Institute of Agriculture, Samara); Saratovskaya zolotistaya, Ludmila, NIK (Southeastern Research Institute of Agriculture, Saratov); Svetlana, Elan, Steppe-3 (Research Institute of Agriculture of Voronezh province); Novodonskaya (Northern-Donetsk Agricultural Experiment Station, Rostovskaya province); K-37094, K-37064, Shrtandinskaya-71, Damsinskaya-90 (Kazakh Research Institute of Agriculture, Shortandy, Kazakhstan); Sid-88, Kustanayskaya-30 (Karabalybak Agricultural Experiment Station) and others. Many of these varieties passed an integrated evaluation for drought tolerance and adaptability in 1997-2002 (Table 2). Variety Kharkovskaya-46, which used to occupy around 5.0 million hectares in Russia, Kazakhstan, and Ukraine and was utilized as the initial material for developing many varieties in CIS countries, was studied together with newly introduced varieties. Climatic conditions during the period of research were contrasting, with severe drought in 1997 and 1999. In 2001 and 2002 the weather was favorable and moderately humid.

Analysis of the drought tolerance index (DSI) revealed that the most tolerant variety was Saratovskaya zolotistaya (0.77), but it had the lowest reaction to improved agricultural practices based on mean yield over six years. In our opinion, durum wheat varieties with DSI = 1.07 and high yield potential in both dry and favorable years are most appropriate to the conditions of Western Siberia. Varieties that respond well to improved agricultural practices,

Table 2. Yield (in t/ha) and drought tolerance of spring durum wheat varieties, ARIHCP, 1997-2002.

Variety	Originator	Average	Limits	DSI
Altayka	ARIHCP	2.50	1.34-4.35	1.06
Gordeiforme 53	-//-	2.65	1.28-3.74	1.01
Altaiskaya niva	-//-	2.89	1.59-4.67	1.01
Zarnitsa Altaia	-//-	2.87	1.48-4.26	1.00
Altaiskiy yantar	-//-	3.08	1.52-4.97	1.06
Orenburgskaya 10	Orenburg. RIA	2.95	1.40-4.68	1.07
Angel	Siberian RIA	2.93	1.75-4.87	0.94
Omskiy rubin	-//-	2.81	1.67-4.31	0.92
Ludmila	RIA of South-east	2.75	1.82-4.31	0.88
Saratovskaya zolotistaya	-//-	2.39	1.46-2.95	0.77
Bezenchukskaya 182	Samara RIA	3.02	1.39-5.15	1.12
Bezenchukskiy yantar	-//-	2.60	0.96-4.12	1.17
Voronezhskaya 9	RIA of Central chernozem zone	2.72	1.40-4.46	1.05
Steppe 3	-//-	2.68	1.56-4.47	1.00
Novodonskaya	Northern-Donetsk Agricultural Experiment Station	2.80	1.55-4.43	1.00
Kharkovskaya 46	Ukrainian RI	2.47	1.27-4.23	1.07
Kharkovskaya 51	-//-	2.31	1.67-3.72	0.83
Kharkovskaya 23	-//-	2.72	1.76-4.86	0.97
Sid 88	Karabalybak Agricultural Experiment Station	2.68	1.26-4.25	1.08
Damsinskaya 90	KazRIA	2.69	1.64-4.12	0.92
Krasnokutka 10	Krasnokutskaya Agricultural Experiment Station	2.72	1.41-4.26	1.02
Average		2.72	1.49-4.34	
Limits		2.31-3.08	0.96-5.15	

such as Bezenchukskaya 182, are the most appropriate for breeding for the foothill areas.

Numerous promising lines and commercial varieties were developed using many of the genotypes presented in Table 2. A large collection of durum wheat germplasm from Mediterranean countries, USA, and Canada were assessed as well, though even the best of them were significantly behind Russian, Kazakh, and Ukrainian varieties in terms of drought tolerance. The varieties from genetic collections of ICARDA and CIMMYT responded negatively to day length in our latitudes and had low productivity.

Usage of *T. dicoccum* is widely recognized as promising for strengthening the adaptive potential of durum wheat by incorporating tolerance to water stress. Emmers developed in the Povolzhie region have unique tolerance to all types of Siberian drought (Yanchenko, 2002). Unlike durum wheat, these forms develop higher numbers of primary and secondary roots in the early stages of plant development with high levels of physiological activity (Table 3). Thanks to rapid penetration into the soil, intensive tillering occurs, as well as earlier development of the plant and its reproductive parts. The most productive accessions from the VIR collection were k-7517, k-7530, k-10476, k-6382, k-7849, and k-25516, among others. Currently more than 2.5 thousand lines are being studied at different stages of the breeding process with emmer involvement (35 lines) at the final stages (Rozova et al., 2003). Early-maturing emmer wheats Zabaikalskaya and Kokchetavskaya were successfully used by Siberian breeders for developing highly adaptive durum wheat varieties Raketa (Dergachov, 1967) and Almaz (Savitskaya et al., 1980).

The varieties Gordeiforme-53 and Altaiskaya niva (Figure 1) were developed using line P-274, a derivative from variety Raketa and widely known varieties Kharkovskaya-46 and Kharkovskaya-51. Specific traits of these varieties include high levels of drought tolerance, broad adaptability, resistance to loose smut, and more intensive grain filling at lower temperatures. Altaiskaya niva is also lodging tolerant. It should be mentioned that Altaiskaya niva is a very strong check, difficult to beat not only in dry but also in favorable years. Currently this variety occupies more than 50% of the cropping area in the Altai region. This variety was used for developing higher yielding and better drought tolerant varieties such as Zarnitsa Altaia, Altaiskiy yantar, and Aleyskaya.

Zarnitsa Altaya (Altaiskaya niva x Leucurum 42). The drought tolerance of this variety was derived from its maternal parent. The variety has good response to improved agricultural practices and high lodging tolerance. Leucurum 42 is a derivative of widely known varieties Kharkovskaya 46, Altayka, Bezenchukskaya 105, and Leucurum 163 (Figure 2).

Altaiskiy yantar [(F_1 Gordeiforme 728 x Altaiskaya niva) (F_1 Gordeiforme 728 x Orenburgskaya 10)]. The drought tolerance level of this variety is equal to that of Altaiskaya niva; it can produce up to 6.0 t/ha under optimal agricultural practices. Kharkovskaya 46 and Bezenchukskaya 105 are in its pedigree through Orenburgskaya 10 and Gordeiforme 728.

Aleyskaya [(Altayskaya niva x HT-7)]. Besides high drought tolerance and productivity, this variety has immunity to brown and stem rusts, and is highly resistant to loose smut. The line HT-7 is a result of a complex recombination with durum wheat varieties Shortan-dinskaya 71, Orenburgskaya 2, and

Table 3. Main features of emmer accessions from Povolzhie, as shown by number of roots and seed germination (in sucrose solution).

Number (VIR catalogue)	Average number of primary roots	Number of node roots during tillering	Seed germination (% of check)
Kharkovskaya 46	4.05	1.1	40.9
6249	4.70	3.0	88.0
6382	4.68	3.3	79.4
7350	4.90	3.2	71.6
25516	4.95	2.8	81.6

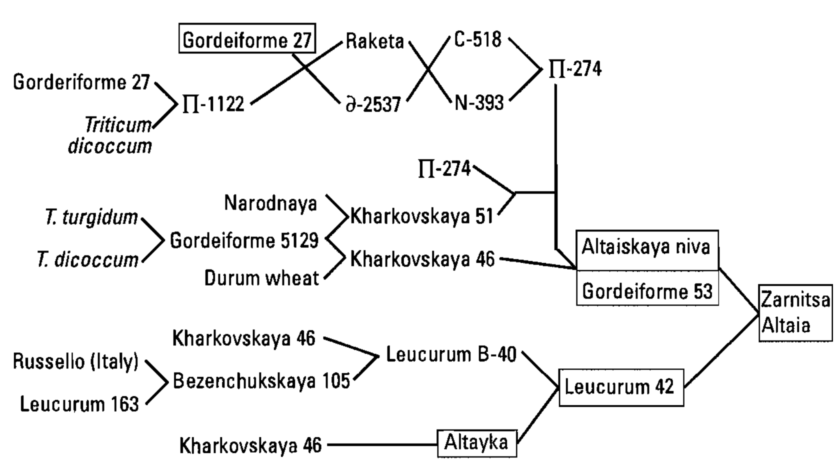

Figure 1. Genealogical history of spring durum wheat varieties developed by Altai RI of Husbandry and Crop Breeding.

T. timopheevii accession k-38555 (Yanchenko et al., 2003).

All the above-mentioned varieties have either good or excellent grain quality, suitable for pasta production.

Remarkable progress has been achieved in the Altai Breeding Center in developing drought tolerant varieties with more extended reaction to climatic conditions in Siberia. We also attempted to analyze the possibility of comparing durum wheat varieties with improved adaptability under high input levels with the same varieties of spring bread wheat and got very good results (Table 4). On average over 14 years, Altaiskaya niva, when sown after fallow and peas, showed an increase of 1.0%; in dry years it was 1.2 and 1.1% and lower, and in humid years it was higher than 1.0%. The productivity of Altaiskaya niva was as high as that of the widespread variety Altaiskaya 50, which occupies more than 1.5 million hectares in Siberia and Kazakhstan.

Table 4. Yields (in t/ha) of improved spring bread and durum wheat varieties Altaiskaya 50 and Altaiskaya niva sown after different crops under optimal sowing conditions, ARIHCP.

	After fallow		After peas	
Year	Altaiskaya 50	Altaiskaya niva	Altaiskaya 50	Altaiskaya niva
1988	2.70	2.19	2.88	2.43
1989	4.20	4.12	3.42	3.25
1990	3.46	3.40	2.93	2.98
1991	3.62	3.65	2.50	2.34
1992	3.40	3.56	3.88	3.96
1993	3.15	3.10	2.92	3.95
1995	2.57	2.96	2.79	3.11
1996	2.81	2.38	2.88	2.62
1997	2.53	2.16	2.15	1.85
1998	2.72	2.95	2.06	2.01
1999	2.61	2.19	1.44	1.26
2000	3.20	3.57	3.21	3.27
2001	3.88	4.53	2.97	4.11
2002	3.75	4.59	3.09	3.92
Average	3.19	3.24	2.79	2.93
Average in dry years	2.66	2.23	2.34	2.04
Average in humid years	3.78	4.06	2.98	3.48

Conclusions

1. In studying a range of durum wheat varieties originated from arid zones of the world, in dry environments of the south of Western Siberia, we found that the most adaptive varieties are those originated from the steppe regions of Russia and Kazakhstan: Gordeiforme 10, Almaz, Omskiy rubin, Angel, Omskiy korund (Siberian Research Institute of Agriculture, Omsk); Bezenchukskaya 105, Leucurum 163, Gordeiforme 728, Bezenchukskaya 182, Bezenchukskaya stepnaya (Samarskiy Research Institute of Agriculture, Samara); Saratovskaya zolotistaya, Ludmila, NIK (Southeastern Research Institute of Agriculture, Saratov); Svetlana, Elan, Steppe-3 (Research Institute of Agriculture of Voronezh province); Novodonskaya (Northern Donetsk Agricultural Experiment Station, Rostovskaya province); K-37094, K-37064, Shrtandinskaya-71, Damsinskaya-90 (Kazakh Research Institute of Agriculture, Shortandy, Kazakhstan); Sid-88, Kustanayskaya-30 (Karabalybak Agricultural Experiment Station).
2. The following emmer genotypes originated from Povolzhye demonstrated unique drought tolerance: k-7517, k-7530, k-10476, k-6382, k-7849, and k-25516. These forms intensively develop primary and secondary roots at earlier stages of plant development with high levels of physiological activity.
3. Screening research and development of new spring durum wheat varieties of Siberian ecotype: Altaiskaya niva, Gordeiforme 53, Zarnitsa Altaya, Altaiskiy rubin, and Aleiskaya showed it was possible to combine in one genotype both high drought tolerance and good response to improved agricultural practices, which creates the necessary prerequisites for wide adaptability.

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Wheat Genetic Resources Activities at ICARDA

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The most valuable part of plant diversity is that which supplies the world's food. Wheat alone provides energy in food to one third of the human population (Harlan, 1992). Archeological and molecular evidence document that wheat was probably domesticated, first, at the diploid and tetraploid levels, from wild ancestors in the western and northern parts of the Near East arc some 10,000 years ago (Harris, 1998; Heun et al., 1997). Hexaploid wheat originated centuries later from a cross of cultivated tetraploid wheat with a goatgrass species, *Aegilops tauschii*. The Near East and the adjacent Central and West Asia and North Africa (CWANA) region are not only the primary center of cultivated wheat origin and diversity, but they are also the home of wheat wild relatives of the *Triticum-Aegilops-Amblyopyrum* complex.

These wild species have been evolving in the harsh, stressful environment of the CWANA region much longer than the wheat domesticates and thus became a rich reservoir of genes for stress tolerance and adaptation to the harsh environment of the region and elsewhere. Since they belong to the primary or secondary gene pool of cultivated durum and bread wheat, useful genes can be transferred to cultivated wheat by distant hybridization. Wheat landraces, particularly those of CWANA origin, represent another important part of the wheat gene pool, because of their adaptation to diverse environments and special characteristics appreciated by the local population. However, both wheat wild relatives and landraces are endangered by rapid genetic erosion in the whole CWANA region and there is an urgent need to conserve the *ex situ* in genebanks and *in situ* in the original habitat.

Materials and Methods

The materials used in this study were wheat genetic resources of different kinds, most of them originally sampled from natural populations of wheat wild relatives or from landraces in farmer's fields. Diverse methods have been used at ICARDA in wheat genetic resource activities, which are described in the following section.

Results

Considering the rapid genetic erosion of natural populations of wheat wild relatives in the center of wheat origin and diversity and replacement of landraces in farmers' fields with improved germplasm, ICARDA gave priority in its collection expeditions and germplasm acquisitions from external donors to these two types of germplasm. As a result, 75% of ICARDA's wheat germplasm holdings are indigenous materials adapted to specific environments and farming systems and shaped by the stressful environment and, in landraces, also by the local farmers. Since its establishment in 1977, ICARDA has assembled, through donations and its own breeding and collection efforts, a total of 35,609 wheat genetic resources holdings in the active collection, including wild relatives and primitive wheats (Table 1). Of these accessions, 93% are also stored in the long-term base collection. Safety duplicates are stored at CIMMYT (15,969 accessions; 46% of the total) or they are duplicated at other major genebanks (13,808 accessions; 40% of the total). According to the agreement with CIMMYT, ICARDA is primarily responsible for wheat wild relatives and durum wheat collections, while CIMMYT's first responsibility is the bread wheat collection. Consequently, ICARDA has recently sent 2000 bread wheat accessions to CIMMYT and, finally, the entire ICARDA bread wheat collection will be duplicated at CIMMYT and held in its active collection of bread wheat. In 1994, ICARDA jointly with other CGIAR centers placed its *ex situ* genebank collections, including wheat, under the auspices of the FAO to be held in trust on the behalf of the global community.

A total of 3603 accessions were collected by ICARDA with NARS partners in 83 collection missions targeted to centers of origin and/or diversity and wheat wild relatives. In the *Aegilops* collection, 59% are new accessions collected by ICARDA and in wild *Triticum* this material represents 27% of the total holdings. Among the major donors to ICARDA wheat germplasm collections were Germplasm

Institute, Bari, Italy; USDA, USA, and the N.I. Vavilov All-Russian Scientific Research Institute of Plant Industry (VIR), St. Petersburg, Russia. However, a valuable part of wheat genetic resources was collected by ICARDA in collaboration with national programs in 76 collection missions to 24 countries, mostly in the CWANA region. This collecting effort yielded a total of 3770 new genebank accessions, of which 2556 are wheat wild relatives. The germplasm acquisition and collection strategy was focused on germplasm indigenous to CWANA region and on that from other countries with Mediterranean climate. As a result, 77% of ICARDA wheat genetic resources holdings originate from CWANA and an additional 9% come from southern Europe and Balkan countries. Landraces represent a major component (60%) of wheat holdings and wheat wild relatives, with 15%, are a significant part of wheat collections held at ICARDA.

Most of the collection missions were targeted to low-rainfall and drought-affected areas of the CWANA region. Table 2 documents that a number of wheat wild relative and landrace accessions were sampled from very dry sites (less than 300 mm annual precipitation). Several wheat wild relative species of goatgrass, such as *Aegilops bicornis, Ae. crassa, Ae. kotschyi, Ae. searsii, Ae. vavilovii*, and *Ae. tauschii* prefer dry environments, since 50% or more of the total were found in dry sites (Table 2). The adaptation of *Ae. tauschii* to drought is of particular interest, since gene transfer from this species to bread wheat is relatively easy. A number of drought-adapted accessions were found in the wild progenitors of wheat, *Triticum urartu* and *Triticum dicoccoides*, which can be crossed with cultivated species, since their chromosomes are similar and 'wild genes can be transferred through chromosome recombination in meiosis. In addition to wild species, many landrace accessions were collected from rainfed sites with annual rainfall below 300 mm. The significant proportion of wheat landraces (26%) originating from dry sites documents again ICARDA's focus on drought in its collection strategy.

A number of natural populations of wild *Triticum* were sampled as single plants; their progenies are held in ICARDA's working collection (Table 3) to be used in genetic diversity studies.

ICARDA's *in situ* conservation activities

Ex situ gene bank collections represent only a fraction of the rich genetic diversity that has accumulated for millennia in the natural populations and farmers' fields. Therefore, the *ex situ* effort has to be complemented by conserving wheat wild relatives and landraces *in situ* in the original habitat in participation with those who manage and utilize it, i.e. farmers, herders and their communities. There are several on-going projects in the CWANA region, in which the *in situ* / on-farm approaches are tested. The current GEF / UNDP project, coordinated by ICARDA in collaboration with IPGRI and

Table 1. ICARDA wheat genetic resources: holdings and distribution.

Germplasm type	ICARDA genebank holdings	Samples distributed to[1]: ICARDA users	External users	Total distribution on request
Wild *Triticum*	1527	2413	3690	6103
Aegilops sp.[2]	3594	10615	8763	19378
Wild relatives subtotal	5121	13028	12453	25481
Durum wheat	19717	6490	23854	30344
Bread wheat	10041	8424	6643	15067
Primitive wheat	729	429	1215	1644
Cultivated wheat subtotal	30487	15343	31712	47055
Grand total	**35608**	**28371**	**44165**	**72536**

[1] Distribution records since 1988.
[2] Including *Amblyopyrum muticum*.

Table 2. Wheat wild relatives and landraces collected by ICARDA in dry sites.

Germplasm type	Accessions collected by ICARDA in <300 mm sites	No. of sites with precipitation data available	% of dry sites (<300 mm)
Aegilops bicornis	11	14	79
Ae. crassa	24	48	50
Ae. kotschyi	37	47	79
Ae. searsii	26	46	57
Ae. tauschii	56	93	60
Ae. vavilovii	54	74	73
Triticum dicoccoides	76	532	14
T. urartu	19	84	23
Other wild relatives	154	1287	12
Wild relatives total	**457**	**2225**	**21**
Durum wheat	82	334	25
Bread wheat	104	374	28
Landraces total	**186**	**708**	**26**

Table 3. Wild *Triticum* single-plant progenies collection.

Species	Populations sampled	Plants sampled
Triticum boeoticum	42	662
T. araraticum	8	74
T. dicoccoides	83	2876
T. urartu	44	987
Total	**177**	**4599**

ACSAD, on agrobiodiversity conservation through sustainable utilization in Jordan, Lebanon, the Palestinian Authority and Syria, is probably the most comprehensive one, being focused on globally important cereal and pulse indigenous gene pool, forage and pasture legume wild species and several fruit tree genera. Wheat wild relatives, particularly wild *Triticum*, are the main target group of the project.

The main task of the project is to identify and test, in participation with local communities and other stakeholders, sustainable options for *in situ* conservation of the target germplasm. These alternatives are ultimately aimed at improving community livelihoods through sustainable utilization of the indigenous agrobiodiversity inherited from generations of their ancestors. The project is conducted in two target areas in each of the four countries (Ajlun and Muwaqqar in Jordan, Baalbak and Aarsal in Lebanon, Hebron and Jennin in Palestine, and Slenfe and Sweida in Syria). The conservation of wheat wild relatives in the Near East center of origin and diversity gave the project highest global importance. The implementation of this project is done through involving local communities, increasing public awareness, enhancing scientific capabilities and the training of NARSs and developing adequate policies.

In cooperation with IPGRI and ACSAD, ICARDA provides assistance to nationally executed project components through coordination, networking and raising awareness, as well as by technical backstopping, capacity building and training and monitoring of the project activities and their impact for lessons learned and adaptive project planning. More information on the project can be found on ICARDA's website http://www.icarda.cgiar.org/Gef.html. The two approaches, *in situ*/on-farm and *ex situ*, to conservation of genetic resources, and agrobiodiversity in general, are complementary. Both are essential for maintaining the rich genetic diversity and providing breeders genes to meet the current and future needs.

Characterization and evaluation

Wheat germplasm has been characterized at ICARDA for a number of agro-morphological descriptors. Most results were published in Durum Wheat Germplasm Catalog (Damania et al., 1991) and in Bread Wheat Germplasm Catalog (Valkoun et al., 1999). The data on *Aegilops* and wild *Triticum* have been compiled and are ready for publishing as a catalog in CD-ROM format. Information on wheat genetic resources held at ICARDA is also available on the internet through the System-wide Information Network on Genetic Resources (SINGER) http://www.singer.cgiar.org.

Taxonomic research conducted at ICARDA resulted in a comprehensive taxonomic publication on wheat wild relatives (van Slageren, 1994). Wheat genetic resources were also characterized by molecular markers and results were published or presented in scientific conferences (Chabane et al., 2000a; Chabane et al., 2000b; Chabane and Valkoun, 2001; Sasanuma et al., 2002). Results of the ecogeographic characterization and maps of geographic distribution of wild relatives were published (Valkoun et al., 1994; Valkoun, 2001a). The most recent maps of geographical distribution of wild *Triticum* spp. and *Ae. speltoides*, *Ae. searsii* and *Ae. tauschii* were presented at the Harlan Symposium (Valkoun et al., 1998). The maps are based on ICARDA's surveys in the collection missions and on the information in the 'Global database of wheat wild relatives' developed by IBPGR in 1990, now upgraded by and maintained at the Genetic Resources Unit of ICARDA. Data were obtained from 52 gene banks on 16,800 entries of wild *Triticum*, *Aegilops* and *Amblyopyrum*, including 13,300 entries with collection site coordinates.

Recent advances in information technology, such as Geographical Information Systems (GIS) and remote sensing technology have increased map resolutions to scales sufficient for detailed climatic characterization of the area of geographical distribution of wild relatives of wheat. The feasibility of such an approach was documented in a study, in which a total of 67 climatic and 4 soil variables were generated for 391 collection sites in Syria, from which ICARDA genebank accessions were collected and geographic coordinates were known (Valkoun et al., 2001). These accessions represented 183 wild *Triticum* and 558 *Aegilops* populations belonging to 4 and 16 species, respectively. The data were subsequently subjected to different statistical analyses, and wheat wild relatives adapted to specific stresses, including drought, were identified.

ICARDA's wheat collection has been widely utilized for research and breeding at the center and worldwide. On request, ICARDA has distributed from its genebank more than 70,000 samples of wheat genetic resources (Table 1), of which more than one third were wheat wild relatives. In-depth evaluation for disease and insect resistance of many wheat genetic resources accessions was done at ICARDA Germplasm Program.

To facilitate the use of wheat wild relatives in conventional breeding programs, a wheat pre-breeding activity started at ICARDA in the 1994/1995 season. Preliminary results of gene introgression from wild diploid progenitors, *T. urartu*, *T. boeoticum*, *Ae. speltoides* and *Ae. tauschii* and tetraploid *T. dicoccoides* are encouraging (Valkoun, 2001b). Crosses with wild diploid *Triticum* spp. yielded high variation in plant and spike morphology. Synthetic hexaploids were produced from crosses of a local durum wheat landrace 'Haurani' with two *Ae. tauschii* accessions. Backcross progenies with desirable agronomic traits, i.e. high spike productivity, short plant stature, earliness, drought tolerance, and high productive tillering, were identified in crosses of durum wheat with wild *Triticum* spp. and in a cross of one of the hexaploid synthetics with a locally adapted bread wheat cv. 'Cham 6'. Resistance to yellow rust was found in durum wheat crosses with the three wild *Triticum* spp. and *Ae. speltoides* and leaf rust resistance was identified in crosses with *T. boeoticum* and *Ae. speltoides*. These results show that wheat progenitors may be a valuable and readily accessible source of new genetic diversity for wheat improvement.

Conclusions

High genetic diversity of wheat genetic resources originating from the CWANA region is rapidly disappearing from the natural habitat, because of several negative processes leading to widespread genetic erosion. *Ex situ* conservation has to be complemented with sustainable projects on *in situ* conservation. The rich genetic diversity of the CWANA wheat wild relatives and landraces has been underutilized in wheat research and breeding, in spite of its high relevance to wheat production systems in the region and elsewhere. ICARDA's wheat genetic resources collections may be a convenient, well-documented source of germplasm, with a particular importance to farming systems in developing countries.

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Achievements of Spring Wheat Breeding in Northern Kazakhstan

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Information on the first wheat plantings in the territory of modern Northern Kazakhstan goes a long time back in history. Wheat was grown 1200-1700 years B.C. during the Andron age. Primitive agriculture collapsed as a result of long-time colonization by Mongols, who imposed their warlike and nomadic life style. Much later, Russian immigrants influenced wheat production, in particular after joining Kazakhstan to Russia. However, current agricultural development started after peasants emigrated from Central Russia to Kazakhstan at the end of the 19th century (Bekmekhanov, 1966).

Significant changes took place after the reclamation of virgin and fallow lands (from 1954 to 1955). Northern Kazakhstan turned into the largest wheat grain producer and supplier to global markets. The area planted to cereals all together totaled 17 million ha, of which spring wheat occupied 12 million ha annually.

Wheat breeding programs in Northern Kazakhstan were initially developed in 1936-1937 through establishment of the first experimental breeding stations (EBS): Karabalyk EBS in Kustanay Province, Shortandy EBS in Akmola Province (Tselinograd Province), and Karaganda EBS in Karaganda Province (Khorikov, 1982).

History of breeding research in Northern Kazakhstan is associated with the name of a talented scientist-breeder, Academician V. Kuzmin, who laid the foundation for practical breeding in Northern Kazakhstan. He identified the main biotic factors influencing growth and development of spring wheat, laid down the basic directions of breeding programs, and determined agronomic types of varieties suitable for specific areas of Northern Kazakhstan. He also stipulated and described as many as 30 main traits and features to be considered in selecting parental material for crossing and screening promising varieties. Kuzmin was the first breeder to select drought-tolerant genotypes based on a number of radicles and introduced the term "radiclity" (*literal translation*). He both studied and applied a principle of using winter wheat in spring wheat breeding as an important source of yield potential and cold tolerance. Based on this principle, he developed varieties Akmolinka-1, Shortandinka, and Snegurka, which were widely released in the country (Kuzmin, 1965; 1978).

In 1971, Kuzmin and his colleagues established the Northern Kazakhstan Breeding Center on Grain Crops and Perennial Grasses (Kazakhstan Research Institute of Grain Farming in Shortandy). This significantly contributed to accelerating and improving breeding programs aimed at developing new improved varieties of spring bread and durum wheat, spring oats, millet, perennial cereals, and legume grasses.

From 1957 to 2002, the Institute developed and released 12 spring bread wheat varieties of the steppe ecological type. These are late maturing varieties: Tselinogradka, Pirotriks 28, Tselinnaya 21, Tselinnaya Yubileinaya, and Eritrosperum 35; medium maturing varieties: Shortandinskaya 25, Tselinnaya 26, Tselinnaya 60, Tselinnaya 3C, and Akmola 2; and semi-early maturing: Tselinnaya 24 and Astana. The varieties bred in Shortandy are being grown in Northern and Eastern Kazakhstan, in Chelyabinsk, Omsk, and Novosibirsk Provinces, and the Altay region of Russia (Table 1).

All the released varieties, except Pirotriks 28, have been included in the list of "superior quality wheat varieties" – improvers. Nonetheless, varieties bred in Northern Kazakhstan have a serious deficiency that negatively affects yields and grain quality: during epidemics they become susceptible to brown and stem rusts and *Septoria*.

Grain production was 16.2 million tons in 2002 and exceeded the record yield of the previous year: 15.9 million tons. Average yield was 1.3 t/ha, compared with 1.4 t/ha in 2001. According to data of the Ministry of Agriculture (Ibraev, 2003), 4 million tons were harvested in three grain-producing provinces of Northern Kazakhstan: Kustanay, Akmola, and Northern-Kazakhstan. One million tons were harvested each in Almaty and

Eastern-Kazakhstan provinces. In 2002, Kazakhstan exported 4.2 million tons of grain to 37 countries. Grain producing farms managed to increase quality of the commodity grain. As much as 90% of exported grain was of 3rd grade that meets the international standards; therefore, the country increased the export volume by 1 million, compared with 2001, when it was 3.3 million tons. The main wheat-importing countries were Iraq (794,000 tons); and Azerbaijan (445,000 tons).

For the first time grain was exported to Africa, up to half a million tons, of which 302,000 were exported to Tunisia. Exports to Central Asian countries rose: to Uzbekistan (182,000 tons); to Kyrgyzstan (191,000 tons); to Tajikistan (325,000 tons); to Turkmenistan (51,000 tons); and to the Baltic countries (Estonia, Latvia, and Lithuania): 244,000 tons. Russia, Turkey, and the Ukraine, being the largest commodity producers, expressed their interest in high-quality bread and durum wheat and procured 278,000, 201,000, and 51,000 tons of 1st and 2nd grade grain, respectively (Ibraev, 2003). Currently, Kazakhstan occupies the 6th position among the grain producing countries (Table 2).

Kazakhstan is the largest grain producer under rainfed conditions, not only in Central Asia but also in the world. Precipitation in Northern Kazakhstan exceeds the global average by 12 times, and 70% of the territory is suitable for agriculture with sufficient soil fertility. In recent years, wheat is being grown on 8.5-9.0 million hectares.

Development of varieties and hybrids adapted to the soil-climatic conditions of Northern Kazakhstan is the main challenge for food security goals in the conditions of a market economy. This includes intensive seed multiplication, variety release, and replacement of old varieties. Dry climate and intense sun radiation, in conjunction with fertile chernozems and chestnut soils, provide the basis for growing high-quality wheat grain with 14-16% protein content, which, in the most favorable years, may reach 17-19%. However, these conditions are extremely difficult for cereal crop production due to short frost-free period and insufficient soil moisture (250-400 mm). Droughts of different intensity occur periodically (two-three times in five years). Thus yield varies from year to year, depending on agricultural inputs and forecrop; the difference may be 30% or more. In the area of chestnut soils and chernozems we identified a positive correlation between the duration of the vegetative period and the yield per unit area. In particular, the highest dependence (correlation coefficient = 0.72) was recorded in dry years, and a bit lower ($r = 0.54$) in optimal years, and almost zero in cold and humid years ($r = 0.13$) (Movchan, 2001).

Table 1. Released spring wheat varieties developed by the Kazakh Research Institute of Grain Farming.

N°	Name of variety	Year of release	Provinces	Originator code	Traits
Spring bread wheat					
1	Akmola 2	1998	1	19	04
2	Astana	1993	1	19	03
3	Karabalykskaya 90	1995	1,8,10,12,13	28	04
4	Karabalykskaya 92	1997	5	24,28	04
5	Karabalykskaya 70	1992	8,12	43	05
6	Kenzhegali	1998	1	2,19	04
7	Pavlodarskaya 93	1999	2,12	30	05
8	Tselinnaya 24	1993	1	19	03
9	Tselinnaya 26	1986	5	19	04
10	Tselinnaya 3c	1996	1,10,13	19	04
11	Tselinnaya Yubileinaya	1988	1,10	19	05
12	Eritrosperum 35	1991	1,8,10,13	28,19	05
Spring durum wheat					
1	Damsinskaya 90	1995	1,5,12,13	19	04
2	Kostanayskaya 52	2000	10	24	04
3	Sid 88	1993	1,8,10,13	28,19	05

Codes:

Provinces of Kazakhstan	**Institutes-originators**
1 – Akmola	2 – Akmola Agricultural University
2 – Aktube	19 – A. Baraev Kazakh Research Institute of Grain Farming
5 – East-Kazakhstan	24 – Karabalyk ERS
8 – Karaganda	28 – Kostanay Research Institute of Agriculture
10 – Kostanay	30 – Pavlodar Research Institute of Agriculture
12 – Pavlodar	43 – Central Kazakhstan Research Institute of Agriculture
13 – North-Kazakhstan	

Trait codes: 03 – semi-early; 04 – medium; 05 – late

Table 2. Grain exports by Kazakhstan in 2002.

Countries-consumers	000 tons
Iran	794.0
Azerbaijan	445.0
Russia	278.0
Ukraine	51.0
Uzbekistan	182.0
Kyrgyzstan	191.0
Tajikistan	235.0
Turkmenistan	51.0
Estonia	156.0
Latvia	35.0
Lithuania	53.0
Turkey	201.0
Jordan	271.0
Afghanistan	85.0
Iraq	98.0
Morocco	87.0
Nigeria	22.0
Sudan	73.0
Tunisia	302.0

Source: The Kazakhstan Ministry of Agriculture.

Table 3 shows the main economic indicators of the most widespread spring bread wheat varieties developed in Northern Kazakhstan (1996-2001). Yield of these varieties is increasing along with the length of the vegetative period (r = 0.92), whereas protein and gluten content is decreasing (r = -0.62, r = -0.88); 1000-kernel weight has increased from 31.7 to 39.2; correlation coefficient is (r = + 0.8). All these varieties are considered "strong" wheat with superior grain quality.

Wheat is the essential crop in cereal production, occupying 50% of the sown area. Modern wheat varieties are very high yielding, but nonetheless require favorable cropping conditions, as their abiotic stress tolerance is insufficient.

The Northern Kazakhstan Breeding Center uses in its breeding programs different varieties and breeding lines from Kazakhstan, Russia, CIMMYT, and ICARDA. Breeding activities include crossing, intraspecific hybridization, and individual selection and screening. There were more than 450,000 accessions of spring bread and durum wheat studied during the specified period. The A. Baraev Research and Production Center conducts joint research with plant protection specialists from the Research Institute of Plant Protection (Almaty) on resistance to *Septoria*, powdery mildew, and brown and stem rusts; and with Bio Centers of Astana and Almaty on development of regenerants of immature embryos and dihaploids from anthers in *in-vitro* conditions. The Center has strengthened its collaboration with international research centers CIMMYT and ICARDA in the areas of breeding and advanced technologies. Also, it is an active member of the Kazakhstan-Siberian Spring Wheat Improvement Network, which aims to enhance bread and durum wheat breeding. Since 1996 almost 15,000 accessions from the CIMMYT collection have been tested to determine their suitability for local breeding programs.

Three new spring wheat varieties, including two bread wheats and one durum wheat, were submitted by the Northern-Kazakhstan Breeding Center to the State Variety Testing Commission in 2002. Spring bread wheat Astana-2 was developed using traditional breeding methods i.e., crossing {[(VIR 264-2 x Tselinnaya Yubileinaya) x Tselinnaya Yubileinaya] x Tselinnaya Yubileinaya} x Tselinnaya Yubileinaya. It is a *Lutescens* botanical variety with white awnless spikes of medium length. The spike has a pyramid shape and medium density. Considering the growing period, this variety is medium maturing similar to the check variety Akmola 2; some years, it is 1-2 days earlier. The yield of this new variety when sown after fallow was 2.6 t/ha, on average, in advanced yield trials (1998 to 2002). This was 0.15 t/ha higher than Akmola 2. The yield advantage of Astana 2 can be explained by more productive tillering (1.9) and grain weight in spike (0.86) compared with 1.7 and 0.83 of Akmola 2, respectively. Astana 2 has a comparative advantage in terms of its resistance to powdery mildew (*Ustilago tritici*) compared with Akmola 2. Considering the main technological indicators, the new variety is at the same level as Akmola 2. General baking score of the new variety is 4.7 (Table 4).

Another new spring bread wheat variety, Bayterek, was developed jointly with the National Biotechnology Center of Kazakhstan (Astana). The variety was developed using haploid method from F_1 cross Lutescens 561/77-5 x VIR 264-2. It is a *Lutescens* botanical variety, with a pyramid-shaped spike of medium length. Bayterek is medium maturing (growing period: 83-87

Table 3. Yield, growing period, and basic technological indicators for spring bread wheat varieties (1996-2001).

Variety	Yield (t/ha)		Growing period (days)		Protein (%)		Test weight (g/l)		1000-kernel weight (g)		Vitreousness (%)		Gluten content (%)		Flour strength		General bakery score	
	Average	Max. Min.	Average	Max. Min.	Average	Max. Min.	Average	Max. Min.	Average	Max. Min.	Average	Max. Min.	Average	Max. Min.	Average	Max. Min.	Average	Max. Min.
Astana	2.03	3.20	75	86	16.0	16.8	792	810	31.8	34.9	70	95	35.0	38.4	450	617	4.5	4.8
		0.41		67		14.7		783		29.4		55		31.2		358		4.3
Tselinnaya 24	2.07	3.62	76	91	15.2	16.2	777	795	31.7	35.1	65	90	31.6	36.4	517	663	4.5	4.7
		0.56		66		14.1		764		28.5		45		28.0		385		4.3
Tselinnaya 3C	2.10	3.48	77	91	14.5	15.8	793	810	35.9	38.5	59	82	29.8	34.0	438	525	4.4	4.7
		0.56		65		13.0		770		33.2		41		27.2		308		3.8
Akmola 2	2.09	3.60	77	91	15.0	16.3	798	810	36.3	38.9	66	90	30.1	33.6	433	492	4.5	4.7
		0.59		67		13.6		778		33.2		43		27.2		391		4.4
Tselinnaya Yubileinaya	2.15	2.83	88	104	14.7	16.4	791	806	34.5	38.0	74	82	28.7	32.8	388	428	4.7	4.8
		1.03		70		13.8		792		32.0		63		24.8		376		4.6
Shortandinskaya 95	2.19	3.32	88	104	15.0	15.7	788	796	39.2	40.1	83	96	28.7	30.0	427	507	4.6	4.7
		1.51		70		14.3		779		38.3		73		27.2		369		4.6

days) and ripens 1-2 days earlier than the check variety Akmola 2. It is highly resistant to lodging and shattering and very drought tolerant. Its susceptibility to powdery mildew (*Ustilago tritici*), stem and brown rust (*Puccinia recondita* and *Puccinia graminis*) is at the same level as the check, and its resistance to *Chaetocnema aridula* Gyll., and *Chaetocnema hortensis* Say is also the same as that of the check. Bayterek is high-yielding. In advanced yield trials, it exceeded the local check Akmola 2 (2.14 t/ha) by 0.19 t/ha. In production trials in 2002 in experimental plots, Bayterek yielded 2.17 t/ha, 0.14 t/ha more than the check. It responds well to improved agricultural practices and inputs. Bayterek's maximum yield was 3.86 t/ha when sown after fallow in 2001. Other parameters are given in Table 4.

A variety of spring durum wheat Damsinskaya Yantarnaya was developed by crossing durum wheat variety Damsinskaya 90 and bread wheat Saratovskaya 210, and subsequent screening of the F_6. Spikes have awns, white in color, and the grain is also white. It is considered as steppe ecological type. The spike is of medium length and pyramid-shaped, which is different from the shape of Damsinskaya 90 spikes. After treatment with phenol, the grain has a lighter color. The growing period is the same as of Damsinskaya 90, 85-92 days. Damsinskaya Yantarnaya is drought tolerant during all growth stages and maintains high productivity. It is resistant to powdery mildew (*Ustilago tritici*), stem and brown rust (*Puccinia recondita* and *Puccinia graminis*), and has medium resistance to Swedish fly (*Oscinella pusilla* Meig) and *Chaetocnema aridula* Gyll., and *Chaetocnema hortensis* Say. In advanced yield trials in 1998-2002, Damsinskaya Yantarnaya yielded 2.84 t/ha, exceeding Damsinskaya 90 by 0.29 t/ha on average. Its yield in production trials was 2.25 t/ha, that is, 0.16 t/ha better than the check. Technological indicators are also better compared to Damsinskaya 90–in particular, there is a noticeable difference in pasta color. Protein content is 17.2%, the same as the check.

The new variety of spring bread wheat Astana was included in the State Register of Breeding Achievements of the Republic of Kazakhstan based on the results of the State Variety Testing Commission in 2003. This new variety Astana was developed using an individual screening from F_2 Lutescens *I-2959 x* Tselinnaya 90. The variety Lutescens I-2959 was developed from winter wheat Ilichovka through seed vernalization. It is a *Lutescens* botanical variety and semi-early maturing. Astana is drought tolerant, has a strong stem, early maturity, and resistance to both *Ustilago tritici* and *Chaetocnema aridula* Gyll.,*Chaetocnema hortensis* Say. It also has good grain quality. Its drought tolerance is based on rapid plant growth and development. During initial growth stage, it has slow plant development and in the second half it develops more quickly, even under severe drought. This allows the variety to escape the May and June drought and to fill the grain better, within a shorter period.

Along with practical breeding targeted towards development of new varieties, researchers are conducting theoretical studies: accelerated breeding using artificial climate; improvement of methods of interspecific and wide hybridization; improved methods for evaluating parental materials

Table 4. Agronomic characteristics of spring wheat varieties included in advanced yield trials after fallow (average for 2000-2002).

Varieties	Growing period (days)	Yield (t/ha) Average	Deviation from check	1000-kernel weight (g)	Test weight (g/l)	Vitreous-ness (%)	Flour strength	Protein (%)	Gluten content (%)	Bread volume per 100 g of flour	Baking score
					Spring bread wheat						
Akmola 2 check	90	2.82	-	34.6	793	76	519	14.8	30.1	770	4.6
Astana 2	87	2.99	+0.17	31.1	787	79	494	15.0	30.0	800	4.7
Astana	85	2.80	-0.02	32.0	784	69	456	15.3	32.8	760	4.7
Tselinnaya !	87	2.75	-0.07	35.8	791	59	435	13.5	28.0	820	4.6
Tselinnaya 24	89	2.86	+0.04	31.8	772	65	532	14.5	29.0	760	4.5
Tselinnaya yubil.	96	2.99	+0.17	34.0	793	66	399	14.5	29.0	870	4.6
Akmola 2 check	88	2.14	-	35.9	803	74	413	13.5	28.4	745	4.6
Bayterek	87	2.33	+1.9	32.4	806	73	315	14.5	30.4	718	4.5

Yield and quality of spring durum wheat Damsinskaya Yantarnaya

Variety, line	Growing period (days)	Yield (t/ha)	Test weight (g/l)	Weight of 1000 grains (g)	Vitreous-ness (%)	Gluten content (%)	Color of pasta (score)	Protein (%)	Carotene (mkg/%)
Damsinskaya 90, st	88	2.51	783	42.4	98	32.6	4.0	17.8	0.418
Damsinskaya yantarnaya	86	2.80	794	42.9	96	32.9	4.2	17.8	0.412

for resistance to powdery mildew, and brown and stem rusts; studying the reactions of varieties with different maturity depending on growing conditions, seed production methods, etc.

In 1991-2002, around 2000 spring bread wheat accessions were evaluated for resistance to powdery mildew, brown and stem rusts, and other intra-stem pests. The following varieties and lines have integrated disease resistance: Tselinnaya 24, Ishimskaya 92, Ishimskaya 98, Karabalykskaya 90, Karabalykskaya 92, Astana, Shortandinskaya 95, Dostyk, Karagandinskaya 70, Akmola 2, Shortandinskaya 195, Lutescens 94, line 161/88, line 207/87-3, and line 9/89-5-21.

The following varieties are resistant to leaf beetle: Tselinnaya 90, Akmola 2, Akmola 40, Dostyk, Shortandinskaya 25, Tselinogradka, Tselinnaya 3C, Tselinnaya Yubileinaya, Kenzhegali, Shortandinka, and other varieties and hybrid lines.

To select material at the initial stages of breeding, researchers of the A. Baraev Research and Production Center initiated studies on the role of gliadin and glutenin in the protein complex formation of gluten with parallel identification of rheological features for predicting physical and technological baking qualities. Glutenin content in wheat grain was found to be higher than content of the other fractions, on average, by 2.6 times, and the sums of easily soluble proteins-albumins and globulins by 1.5 times. It was also found that the glutenin to gliadin correlation varies from 2.10:1.00 to 3.04:1.00 in the studied bread wheat accessions. The high level of this indicator was noted in protein grain fractions of the following varieties: Akmola 2, Tselinnaya Yubileinaya, Akmola 3, and Astana. Astana has consistently shown high protein content throughout the years of research, independently of environmental conditions. The same varieties have high gluten content.

Laboratory and analytical research on drought tolerance of 120 spring wheat varieties and hybrids showed that drought tolerance and yield depend on water availability, leaf water-retaining capacity, and residual water deficit during acceleration of drought effects. The following drought tolerant, high yielding varieties are recommended for use as parents in breeding under conditions of Northern Kazakhstan: Akmola 2, Akmola 40, Tselinnaya 3C, Tselinnaya 24, Damsinskaya 40, and others.

In 2000, breeders and plant physiologists were provided with recommendations for evaluating spring wheat varieties and hybrids for drought tolerance considering plant water regime.

Enhancement of host resistance and improvement of grain quality are the priority objectives of breeding programs in Northern Kazakhstan, which face new and complex challenges. Their success will depend on the theoretical level of breeding efforts and the introduction of new biochemical methods and approaches for discovering the molecular mechanisms of grain quality.

Breeding and genetic research for enhancing the abiotic stress tolerance of newly developed varieties has to be based on prevalence of fixed factors (weather specifics of a year, location, soil treatment, previous crops, fertilizers, seeding times, etc.) over the genotypic influence on grain quality characteristics. Wheat breeding is multi-targeted and oriented towards both domestic and international markets. In this regard, the breeding programs should have a strictly individual character, which means that their purpose should include development of variety-improvers having high mixing capacity for baking needs, pasta (durum wheat), confectionary, and even feed production. Grain production and subsequent processing with such varieties is is based on specific features of grain quality for use as a raw material.

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Development of Widely Adapted Spring Wheat Varieties in the Middle Volga Region

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In Middle Povolzhie there is traditionally a large area of high-quality wheat grain production. Currently, around 1.2 million hectares are sown to spring bread wheat in this region. The areas under winter and spring wheats in Samarskaya province are about 570 thousand ha each, which is approximately 40% of the total area under cereals. Total wheat grain production averaged 708.2 thousand tons in the 1995-1998 period, representing 47% of total cereal production.

The Middle Povolzhie region spans a wide range of natural climatic zones (from the forest zone of Tatarskoe Predkamie with podsolic soils and annual mean precipitation of 650 mm to the steppes of Samarskoe Zavolzhie with southern chernozems and annual mean precipitation of 350 mm). The region is also characterized by unstable weather conditions over and within years. Therefore, the objective is to develop varieties of at least three main types: steppe types for severely dry steppe, semi-intensive types for areas with sufficient natural moisture and minimal agricultural inputs, and intensive types for conditions with optimal agricultural inputs (e.g., irrigation, fertilizers, plant protection, etc.). At the same time, their productivity should be above 4 t/ha. These types are to be suitable for different agro-ecological niches in accordance with integrated environmental stress factors limiting growth and development of spring bread wheat. However, as A. Zhuchenko states (2001), "orientation of breeding programs towards ecological specialization of varieties specifies development of breeding methods that make it possible to combine high potential productivity and ecological resistance at the level of a variety or hybrid." In view of the country's economic situation, there is a greater need at the present time for cereal crop varieties with a broad range of responses to abiotic, biotic, and anthropogenic environmental factors.

Wheat breeders have developed breeding lines adapted to different agro-ecological zones (with different agricultural input levels and practices in different years, as well as varying seeding times during the growing period) thereby increasing general homeo-adaptation (Zhuchenko, 2001). The shuttle breeding method whereby germplasm is tested in contrasting ecological sites has allowed breeders in Australia (Hamblin et al., 1980; Brennan and Sheppard, 1985; Basford and Cooper, 1998), the USA (Brown et al., 1983), South Africa (Marais, 1985) and, in particular, CIMMYT (Rajaram et al., 1984; Rajaram, 1995) to develop varieties combining high productivity and broad adaptability.

It is known that the mean value of a trait and response to environmental factors are under independent genetic control and relatively autonomic (Caligari and Mather, 1975; Connoly and Jinks, 1975; Hill, 1975; Jinks, Jayasekara and Boughey, 1977; Jinks and Pooni, 1982; Dragavtsev et al., 1984; Kilchevskiy and Khotyleva, 1997; Dorn and Schmitt, 1997). We assume there are two overlapping genetic systems. A genetic system of ontoproductive complex determining morphological features and growth rate, and inherited through additive-dominant genes is the core. Another system initiates and corrects ontogenetic and productive processes: the homeo-adaptation genetic system (Sukov, 1995). These two systems overlap in the area of epistatic interactions.

Development of genetic systems on an ecological gradient has made it necessary to establish test sites with different levels of environmental stress. A vector crossing these sites ensures sustainable selection of genotypes in terms of their homeo-adaptation and the development of varieties with a broader range of ecological responses. The establishment of an *ecological (or multi-locational) vector* (a combination of sites in a geographical breeding network that contribute to sustainably selecting highly homeo-adaptive genotypes) is the top priority of ecological shuttle breeding. This was the first step towards establishing the ECADA program in 1995, which deals with breeding spring bread wheat varieties.

In 1995, we identified the following sites for the ecological vector: the experimental fields at Samara Research Institute of Agriculture (RIA), Bezenchuk (hereinafter referred to as *B*); at Ulianovsk RIA (*U*), and at Penza RIA, Lunino (*L*). The yields of two spring bread wheat varieties (L-503 and Ecada-6) in 1995-2001 were within normal distribution at each site; however, there was a clear difference in terms of both absolute values of the trait and variability character (Table 1). Variety Bezenchuk differs by the most intensive combination of ecological factors. Yield potential variation is shifted to the left, to the lowest values, and expresses the most variability. On the extreme right of the ecological vector is Ulianovsk, where wheat production is higher and more stable. Lunino is close to Ulianovsk, but its crop productivity was lower. This means that the ecological vector (EV) goes in the direction of B⇒L-U with limited ability for screening highly homeostatic genotypes. Starting in 1999, a fourth site was added to the EV: an experimental field at Bashkirskiy RIA, Chishmy (*CH*). The results of studying a set of spring bread wheat varieties in 2000-2001 at these four sites are presented in Table 2.

Based on general adaptation (average yield) and the environment's relative differential ability, the EV goes from B⇒CH⇒L⇒U; as per regression of environments on genotypes, the direction is CH⇒B⇒U⇒L; and as per the sum of square deviation from the centroid (SED), it is B⇒U⇒L⇒CH. A correlation and cluster analysis demonstrated that Ulianovsk had the most stable indicators (data correlated by years, and with Bezenchuk and Lunino data in 2001); the most unstable was Chishmy. That is, the location of sites B, L, and U replicates the image of the previous analysis, and CH, located between B and an association of L-U, deviates somewhat from the direction of the main vector. Currently, we are studying possibility of adding a fifth site located in the Tatarskiy RIA experimental field.

The second objective to be reached via multi-locational shuttle breeding was to develop a breeding scheme, including genotypic variability in populations and an algorithm for how breeding materials move through the nurseries. Such analysis is given in Morgounov and Naumov (1987) and Kilchevskiy and Khotylova (1997). We accepted a scheme for the development of spring bread wheat varieties (called ECADA) based on general ideas about the interactions between the genetic system of ontoproductive complex and that of homeo-adaptation (Sukov, 1995), and also on traditional breeding and seed production for the region.

Development of initial material is being carried out independently by each of the four institutions participating in the program. In the first stage, each participant submits 20-40 accessions for multi-locational (ecological) trials of the fourth level (ET-4, one replication; plot size: 9-12 m^2). Multi-locational trials of the third level (ET-3) are established based on materials selected from the previous level (three replications; plot size: 9-12 m^2). Preliminary (ET-2) and competitive (ET-1) trials are established on plots measuring 25-30 m^2 with three-four and four-six replications, respectively. Trap nurseries for brown rust, powdery mildew, common bunt, and septoria were established, and baking quality was evaluated according to the protocol. Since 1995, as many as 525 breeding entries have passed through this program, of which 45 reached first level trials.

Table 1. Characteristics of two varieties, L-503 and Ecada 6, at three EV sites: Besenchuk, Lunino, and Ulianovsk, 1995-2001.

	Parameters in a normal distribution curve per crop yield (t/ha)									
	L-503					Ecada 6				
Site	Av. yield	lim	CV (%)	A	E	Av. yield	Lim	CV (%)	A	E
Bezenchuk	1.88	1.06-4.51	65.5	2.123	4.711	2.09	0.89-5.05	67.1	1.959	4.382
Lunino	2.12	1.09-2.95	37.8	-0.554	-1.402	2.42	1.40-3.63	37.9	0.068	-1.984
Ulianovsk	2.96	1.58-4.60	42.2	0.240	-1.971	3.20	1.61-5.13	46.9	0.087	-2.145

Table 2. Characteristics of four EV sites: Besenchuk, Chishmy, Lunino, and Ulianovsk, 2000-2001.

EV site	Year	Av. yield (t/ha)	Regression coefficient of environment to genotype b_i	Coefficient of differentiation[1]	Relative differentiation of environment[2]	SED[3]
Bezenchuk	2000	0.865	0.53	0.14	83.25	3408
	2001	1.691	0.84	0.25	42.70	833.4
Lunino	2000	2.042	2.09	0.24	36.56	472.8
	2001	4.238	2.13	0.36	17.41	4163
Ulianovsk	2000	2.833	0.96	0.18	25.61	228.8
	2001	3.966	0.89	0.24	18.22	2922
Chishmy	2000	1.448	0.50	0.07	49.95	1442
	2001	2.726	0.06	0.01	26.54	178.2

1 According to Martynov et al. (1993).
2 According to Kilchevskiy and Khotylova (1997).
3 According to Brennan and Sheppard (1985).

The third objective of ecological breeding is establishing a methodology for identifying highly homeostatic genotypes based on phenotype. In other words, this objective can be narrowed down to selection of parameters, which are analyzed during the breeding process based on the ecological vector. The analysis of a large group of statistical parameters demonstrates that evaluation of adaptability is best done according to the methodology of Kilchevskiy and Khotylova (OAC and S^2_{CAC} or S_{GI}).

Selection along the ecological vector has produced positive results in the early stages of breeding. One variety of spring bread wheat, Ecada-6, was developed and submitted to the State Variety Testing Commission (SVTC) (Table 3). This variety is high yielding, widely adapted, resistant to brown rust and powdery mildew, lodging tolerant, and has high grain quality. The results of 2001 trials confirmed a high homeo-adaptation of this new variety. Thus, on average in 39 state variety testing sites located in Central, Central-Chernozem, Northern-Caucasian, and Middle-Volga regions of the Russian Federation, the variety Ecada-6 produced a grain yield of 3.26 t/ha, which is 0.15 t/ha higher than the check. In addition, this variety was the highest yielding across 12 State Variety Testing sites.

Conclusions

1. A program for developing spring bread wheat varieties at ECADA testing sites was established through involvement of five breeding institutions (Samara, Ulianovsk, Penza, Bashkirskiy, and Tatarskiy RIAs).
2. The theoretical background was developed for establishing the ecological vector, as well as the criteria for selecting highly homeo-adaptive varieties.
3. Spring bread wheat variety Ecada-6 was developed and submitted for state trials.

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Table 3. Characteristics of spring bread wheat variety Ecada-6, 1998-2000.

Variety	Line history	Average grain yield (t/ha)*	ΣP**
L-503	standard	1.67	27.5
Ecada 6	krestianka/samsar	1.85	10.5
Ecada 7	krestianka/samsar	1.67	27.5
Ecada 18	ank 4 / ishevskaya	1.87	28.0
Ecada 19	bashkirskaya 20 / simbirka	1.77	44.0
Ecada 20	simbirka / nadejnaya	1.86	40.0
Ecada 21	K-54648 / tselinnaya 20	1.61	49.0
Ecada 23	jemchujina zavoljia/L-1203//kharkovskaya 10	1.82	25.5

* Average yield across all sites of the ecological vector.

** ΣP = a sum of statistical parameters of homeo-adaptation.

Enhancement, Conservation, and Use of Cereal Genetic Resources in Uzbekistan

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Central Asia is a secondary center of bread wheat origin and there is rich diversity concentrated in the region (Vavilov, 1926; Udachin, Shahmedov, 1984). Currently, Uzbekistan implements a legislative policy on PGR conservation and use, including cereals. Wheat is an economically important crop in Uzbekistan. National policy is directed at intensifying work by national research institutes on inspecting the territory, collecting, and including new germplasm into the institute's gene bank, complex study, and identifying valuable trait sources for breeding new cereals cultivars and developing a seed production system. The National Coordinating Council on Cereal Genetic Resources has been established.

New initial materials are constantly required for developing new high-quality cereal cultivars. In this regard, enrichment and preservation of cereal genetic resources is of great importance. Seed collections *ex-situ,* concentrated in research institutions, comprise 21,036 cereal accessions. In the research organization where the basic collection is kept, the role of VIR and national scientists is great. As a result of collecting expeditions and germplasm receipt, mainly from VIR, in UzRIPI the largest cereals collection in Uzbekistan was established, accounting for 13,169 accessions (wheat, 9,277; barley, 2,572; oats, 645; triticale, 675). In the Gallya-Aral branch of the Andijan Research Institute of Cereal and Legume Crops under Irrigated Conditions (ARICGLCIA) the collection includes 8,747 accessions from CIMMYT and ICARDA. The composition of cereals collection includes rare and eroding species, local forms and their wild relatives, as well as introduced accessions used as initial material for breeding new cereal cultivars in the region. The growth of collections in research institutions of the republic is possible due to annual supply with new accessions through collection, exchange and requests to the international centers.

There are 6 quarantine nurseries in the republic. Introduction and Quarantine Nursery of UzRIPI was founded in 1948. Now it is the complex quarantine nursery of republican level where quarantine control and primary valuation of accessions of cereals, grain legumes, fodder, vegetable and non-traditional crops introduced from foreign countries are carried out. The nursery area is 3 ha. Till 1992 annually for quarantine valuation 1,500 to 2,000 accessions of different agricultural crops were submitted. From 1992 more than 10,000 accessions of cereals only were received for quarantine control and primary valuation (Table 1).

In research institutions of Uzbekistan regular re-sowing of the collection is carried out for restoration of seed germination and renewal. Previously, seed of the cereal accessions in the collection were reproduced in UzRIPI every four years. In 1997 a Seed Depository was organized based on which the first Agricultural Crops Genebank was established in the region in 2002. Within the Genebank the seed laboratory was organized in 1999, and is involved in germplasm conservation control. After the reconstruction, storage of germplasm of other crops started.

Considerable effort was invested in documenting the *ex-situ* collections. With the help of international organizations, computers were given to the institutes and staff was trained to maintain PGR documentation. The PGR Documentation Unit was founded in 1999 and is responsible for maintaining the genepool database (Table 2).

Table 1. Cereal accessions received by UzRIPI IQN, 1992-2002.

Year	Number: Accessions	Number: Countries
1992	224	13
1993	480	6
1994	479	14
1995	278	11
1996	1305	11
1997	597	5
1998	1711	9
1999	877	2
2000	969	5
2001	644	1
2002	2519	2
Bcero	**10111**	

In Uzbekistan's research institutions, the study of collection accessions is carried out to identify sources for valuable traits. This study of the genepool is connected with breeding programs. More than 1000 accessions of cereals are assessed annually in UzRIPI. In the Gally-Aral Branch of ARICGLCIA, 8,747 wheat accessions were studied in the last 6 years and sources of valuable traits such as earliness, yield, and resistance to diseases and pests were identified (Table 3).

Annually 300-400 accessions agricultural crops are sent to 20 research institutions; between 100 and 150 of them are cereals. They are used as initial materials for breeding high quality varieties. During the last 10 years, 34 new wheat cultivars were developed and released in Uzbekistan: Grekum 439, Zumrad, Kuk bulak, Marjon, Unumli Bygdai, Dobraya, Krasnovodopadskaya 210, Ok bugdai (Grekum 40), Sanzar 4, Sanzar 6, Sanzar 8, Tezpishar, Ulugbek 600, Sherdor, and Yanbash; hard winter wheat cultivars Alexandrovka, Karlik-85, Lekurum 3, Marvarid, Gulnoz, Zafar, Karshinskiy, Lalmkor, Mavlono, Nutans 799, Temur, Unumli arpa, Khonakokh (Parralelum 59), Dostan; triticales Uzor, Prag serebristiy), Mnogozerniy 2 (bread wheats); Dustlik 85, Tashkent 1, Uspekh (winter oats); Uzbekskiy shirokolistniy (spring oats).

Farmers play an important role in the process of agrobiodiversity preservation and promotion. By planting local landraces, advanced, released, and newly introduced varieties and cultivars and selecting and improving them, farmers save seed material for subsequent reproduction renewal and cereal multiplication. It is necessary to include in collections the diverse materials from farmers and also to recommend to farmers the best accessions from *ex-situ* collections for crop production.

Uzbekistan's scientific institutes collaborate in many ways with international organizations, mainly ICARDA and CIMMYT. Such cooperation has enabled us to develop new projects and support collecting espeditions, obtain new knowledge, supply research institutes with computers, introduce new research methods, exchange germplasm, information, and experience, and improve the professional skills of young staff members by providing new foreign literature.

Public awareness activities on the PGR conservation work in Uzbekistan is conducted through radio, television, and publication of papers on cereals. Technical publications on the activities of international centers with scientific organizations in the region are regularly issued and distributed.

To solve existing problems and expand work on cereals it is necessary to take a number of measures. There is a need to further improve the quality of the collection germplasm and its enrichment with new accessions. It is necessary to continue to conduct a complex inspection of Central Asia territory and collect valuable germplasm.

Accessions in collections of institutes are lost because of the lack of appropriate seed storage conditions. Thus storage facilities

Table 2. The UzRIPI Cereal Genepool Database.

Crop	Parameters	Data amount: Parameters	Data amount: Accessions
Wheat	Morphological data	12	442
	Economically valuable traits	17	3,731
	Resistance to diseases and pests	10	3,892
	Chemical composition	12	3,141
	Physiological characteristics (salt, drought, and heat tolerance)	6	521
Barley	Economically valuable traits	8	209
	Physiological characteristics (salt, drought, and heat tolerance)	6	120
Triticale	Economically valuable traits	20	438
	Total	**91**	**12,494**

Table 3. Study of wheat accessions from CIMMYT and ICARDA in the Gally-Aral Branch of the Andijan Research Institute of Cereal and Grain Legume Crops for Irrigated Conditions.

Parameters	1997	1998	1999	2000	2001	2002	Total
Yield (t/ha)							
• low (1.5-2.5)	67	920	201	1,488	1,260	55	3,961
• middle (2.5-4.0)	110	10,234	401	987	491	475	3,477
• high (>4.0)	33	257	225	275	29	100	919
Resistance to:							
• yellow rust	11	95	74	145	205	25	530
• brown rust	33	118	-	163	128	38	4,809
• both species	5	15	-	28	31	11	90
• drought	56	97	154	207	100	46	660
• heat	-	37	20	184	162	75	478
• cold	13	49	54	69	25	23	233
Total	**200**	**2,200**	**827**	**2,750**	**1780**	**990**	**8,747**

for the working collections in our research institutions need to be updated, and additional funds for work on seed regeneration and restoration are required.

The lack or incomplete description of necessary initial material, insufficient amounts of seed and planting materials, lack of specialists, and insufficient funding are obstacles for effective germplasm use.

In all research institutions it is necessary to carry out documentation of grain crops genetic resources and develop a database on characteristics and conditions of the genepools with the purpose planning conservation and utilization activities, as well as continue publishing joint descriptors, catalogues, and newsletters. It is necessary to create a Uniform Information System on cereals in Uzbekistan that will allow us to systematize the genepool, enhance interrelations with research institutions, and improve the efficiency of their use.

It is necessary to continue training young Uzbek scientists in international training courses and in the international centers on PGR and also through regular English language courses. It is necessary to develop cooperation with the international centers on PGR and the CIS within the framework of an "Agreement on cooperation in the fields of PGR conservation and use." International cooperation and single-minded work will promote conservation and effective use of cereal genetic resources.

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Breeding Spring Wheat Adapted to Conditions in Western Siberia

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Achieving a rapidly growing and stable grain production is the key agricultural objective in western Siberia, where spring bread wheat is the basic grain crop. It is usually cropped under the best agricultural conditions using advanced technologies. However, wheat yields remain low, though with considerable variation over the years. For example, yields reached 5-6 t/ha during favorable humid years of 2001-2002 in intensive systems and agricultural research stations of the Omsk region and decreased to 1 t/ha and lower in drought years of 1998-1999. Moisture deficit in drought years and epiphytotics of fungal diseases in humid years are the main factors limiting spring bread wheat yield.

Breeding is focused primarily on increasing annual wheat yields and improving yield stability. Identifying the right pairs of parents for crosses is essential for solving the problems of adaptive breeding. As a rule breeders keep to three concepts: cultivar, trait, and gene (Boroyevich, 1984; Merezhko, 1994). The last two are most effective. However, it is not always possible to match parent lines on the basis of traits and genes due to the lack of data, i.e., there is usually not enough information on a given genetically conditioned trait and its role in certain regional environments. In this context, trait analogues (BC_4) and near-isogenic lines have a unique role to play in breeding.

Biochemical markers, particularly prolamines (alcohol-soluble fractions of Gramineae grain storage protein in which huge intraspecific polymorphism was revealed; Sozinov, 1985), have opened up big prospects in crop improvement research. A number of researchers have found that specific allelic variants of gliadin blocks are typical of particular agroecological areas (Metakovsky et al., 1987; 1990), and that provides new opportunities for using them in adaptive wheat breeding.

A series of isogenic lines for *Vrn* genes (Stelmakh and Avsenin, 1983) was developed in CIS countries, and Pugsleu's isogenic *Vrn* lines (1973) were used simultaneously. Krupnov and co-authors (1994) produced a large number of lines isogenic for economic and morphological traits in varieties from the Saratov Breeding Centre. Extensive research was conducted on the yield contribution of particular traits, and the varietal model of Volga spring wheats was scientifically grounded. Intensive experiments aimed at producing isogenic lines for morphological traits, plus resistance to leaf rust and powdery mildew, are being carried out at the VIR Genetics Department and the Institute of Cytology and Genetics, SB RAS (Koval et al., 2001).

Analogues and isogenic and alloplasmic lines are usually used as models in various experiments or as breeding materials (donors, prospective varieties). For this purpose NILs and allolines should be convenient to work with under a wide range of field and greenhouse conditions. Results should be easily reproduced and unequivocal (Koval and Shamanin, 1999). Conclusions will be justified not only for the case under study but also for a wide range of phenomena with good correspondence to the aims of this investigation.

There are very strict requirements for spring wheat varieties under conditions in western Siberia (Zykin et al., 2000). Recommendations on the breeding value of certain traits and genes from other regions of Russia are not always applicable to western Siberia, especially in adaptive breeding (Shamanin, 1994). A complete evaluation of analogues and isogenic lines is necessary under certain regional conditions for their more effective use in breeding.

The staff of the Breeding, Genetics, and Seed-Farming Department of Omsk State Agricultural University, in cooperation with the country's breeding-genetic institutions, have been working at solving adaptive and ecological problems of wheat breeding for more than 20 years. These efforts are based on the concept of broadening genetic control to make more effective use of favorable environmental factors and tolerance/resistance to abiotic and biotic stresses, i.e. "genotype predominates over environment" (Zhuchenko, 2001). As a result of complex research we have developed an adaptive breeding methodology, and 17 spring wheat varieties (7 of which have already been included in the State

Registration List of Breeding Achievements) were targeted for use in agricultural production.

Materials and Methods

Our research has been conducted at the Omsk State Agricultural University experiment station since 1979. Forest-steppes and steppes are the main spring wheat cropping areas of the Omsk Region. The first is an area of unstable humidity; the second is drought prone. Considerable variation in total precipitation over a number of years is typical of the region: 250-350 mm, with 180-210 mm during the vegetative period. Dry spells and hot dry winds are frequent. In summer temperature rises to more than 40^{0}C. Average summer temperature is 20-22^{0}C in the steppes and 19-20^{0}C in the forest-steppe zone.

It is warm enough for wheat in most years. Active temperatures (higher than +10^{0}C) on average total 2200^{0}C in the steppes and 1800-2000^{0}C in the forest-steppes. Although summer is not long, there are no frosts for 108-127 days. Timely sown spring wheat ripens till the beginning of the first autumn frosts.

A big advantage of western Siberia is its dry, continental climate, favorable for development of very high-quality grain. Western Siberia is one of the main providers of wheat grain with excellent bread-making properties and economic traits in the country.

The mostly chernozem soils in the steppe and forest-steppe zones of western Siberia are the best for spring wheat in terms of fertility, available nutrients, and reaction to soil solution. However, alkaline soils are found in arable lands, where they sometimes take up 10% or more of the fields. The soil in the trial plots is chernozem of average fertility with low organic matter and weak alkalinity.

Intraspecific and wide hybridization is the basic method used to produce parental materials. Winter wheat varieties from the Ukrainian steppe (ecotype: Chaika, Obry, and others), from Central Asian dryland farming (ecotype: Krasnovodopadskaya 210, Tezpishar, and others), and the best locally bred and foreign varieties are used as parents. Locally bred spring varieties are used as the male parents. Winter wheat seeds are vernalized at 0-1^{0}C before sowing in spring at germination stage. Top-cross is the crossing scheme as a rule. Spring x spring hybridization, simple, saturating, and complex crosses are widely used.

Trials were conducted in environments with different soil moisture levels. Drought conditions were simulated with the help of drying and isolated ground water (Shamanin, 1994), precursories and evaluation in different locations of ecological trials. Experiments on analogues and NILs of Novosibirskaya 67 and Saratovskaya 29 were carried out in 1984-2000. Analogues and NILs of variety N-67 are described in a monograph (Koval et al., 2001) and S-29 analogues in two theses (Shamanin, 1994; Trushchenko, 2002).

Spike metabolite content was determined using Konovalov's methods (1983). Based on these results, analogues and NILs were used in breeding as donors of specific traits and genes. *Triticum dicoccum*, *T. durum*, and *E. elongatum* were used in wide crosses. Studies of electrophoretic gliadin spectra in varieties and populations were conducted using standard methods with some modification (Chernakova, 1999; Chernakova et al., 2000).

Results and Discussion

Analyses of genotypic variability for yield components in plants and hybrids derived from spring x winter wheat crosses showed that the expression of genes with additive effects depends on the type of drought. Genes of locally bred spring genotypes had the greatest effect under early summer drought in western Siberia. Winter wheat genes of Ukrainian steppe and Central Asian dryland farming ecotypes contributed more to variability under summer drought. The entire stock of parental materials used in adaptive breeding was produced by pyramiding genes co-adaptable to different drought types and their blocks.

Analyses of the allelic composition of gliadin-encoding loci in 37 spring bread wheat varieties from the Omsk Region showed the presence of both homogeneous (26) and heterogeneous (11) genotypes. Heterogeneous genotypes were a mixture of two or more biotypes with different alleles of one or several gliadin-encoding loci. Five (Gli-D1) to nine (Gli-A2 and Gli-B2) alleles were found in each locus. Duration of vegetative stage is one of the most important traits determining a genotype's adaptability to certain regional environments. The genotypes belong to three maturity groups: intermediate to early maturity (basically in the pre-taiga zone and northern forest-steppes), intermediate maturity, and intermediate to late maturity (in the southern forest-steppes and steppes). We found an association between allelic composition of gliadin-encoding loci and duration of vegetative stage. This allowed us to hypothesize that the most widely spread alleles are associated with adaptability to specific environments. Genetic models including the most frequently encountered alleles were constructed for each genotypic group: (1) Gli-A1K, B1b, D1a, A2k, B2k, D2k for the intermediate to early maturing genotypes; (2) Gli-A1f, B1e, D1a, A2q, B2o, D2a, or D2e for intermediate maturing genotypes; and (3) Gli-A1f, B1e, D1a, A2k, B2s, D2e for the intermediate to late maturing genotypes.

Grain samples from competitive cultivar tests (CCT) were studied to determine the possible effect of selection on the allelic composition of gliadin-encoding loci. In general CCT genotypes had the same set of gliadin-encoding loci as cultivated varieties, despite having used a wide range of spring and winter parents in hybridization.

Analyses of frequency of allelic variants of gliadin-encoding loci in an artificial spring bread wheat population with numerous re-sowings showed that while frequencies of one allelic group increase from generation to generation, others decrease, and the frequency of still others remains almost unchanged or chaotic. The increase of allelic frequency for A2q and D2e was statistically significant, as was the decrease in the frequency of allele D2a. It should be noted that alleles A2q and D2e are widely spread among local cultivars (20.3% and 33.8%, respectively). Based on these results, it is possible to hypothesize that alleles A2q and D2e are associated with adaptive traits that confer higher seed productivity and lead to more frequent occurrence of plants with this trait in subsequent generations.

We made a comparative analysis of wheat genotypes from areas analogous and non-analogous to the Omsk Region. According to a GIS computer database and the results of investigations carried out by scientists in the State of Maryland in the USA, the Canadian provinces Alberta and Saskatchewan are analogous in natural climatic and soil factors to the southern forest-steppes of the Omsk Region. Mexico was considered non-analogous as we tested accessions from the CIMMYT collection.

Genetic similarity between genotypic groups from Omsk and Canada was calculated based on Nei's formula. Our analysis demonstrated that there was some similarity in the allelic composition of group 1 chromosome loci among the studied groups but not of group 6. On average, the genetic similarity of the Omsk and Canadian genotypes is 0.175. It is a low index that accounts for the genetic distance between the two groups. For example, the genetic similarity between the Omsk and Saratov groups is 0.750, and 0.709 between the Omsk and Cheliabinsk groups.

The alleles most typical of accessions from the CIMMYT collection (Gli-F1a, B11, D1d, A2f, B2c, D2m) are practically not found in varieties cultivated in the Omsk Region. Results of genetic analyses of gliadin-encoding loci indicate the economic inexpedience of direct introduction of spring bread wheat materials from the CIMMYT collection due to their low productivity and sensitivity to unfavorable western Siberian conditions. They are useful only as parental materials in breeding for certain traits.

The obtained results and their theoretical analysis suggest alleles of gliadin-encoding loci may be used as genetic adaptability markers at different stages of wheat breeding, as follows:

1. Allelic identification is performed on a collection nursery to: find matching parent lines for use in hybridization; identify valuable alleles; detect genotypes with rare combinations of allelic loci; and control the purity and authenticity of the collection.
2. F_1 and F_2 lines in the hybrid nursery are analyzed only when making theoretical investigations for genetic analysis.
3. In breeding nurseries (F_3-F_4) it is expedient to analyze the genotype of each spike to be used for establishing a breeding nursery (BS 1) in repeated selection of elite plants in segregating numbers of separate combinations.
4. All breeding lines are analyzed in the control nursery; their genetic formulas are determined; valuable genotypes are identified; and all materials atypical of the region are eliminated.
5. In evaluating CCTs, the genotypes' genetic gliadin formulas should be considered. At this stage their heterogeneity for gliadin-encoding loci should also be studied. In case of heterogeneity it is reasonable to determine the percentage of bytopes in a variety to maintain its purity during seed production.

Data on the role of certain wheat genes, traits, and properties for adaptive breeding were obtained in experiments with NILs of cultivar N-67 conducted in environments with different moisture levels.

Studying the effect of genes with weak photoperiodic sensitivity (*Ppd*) on NILs economic traits demonstrated that genes from different donors reduced the "seedling-heading" period to 2-6 days. Yield performance of early

NILs of N-67 was on the same level as the recurrent parent and even higher under some conditions, mainly due to the large number of productive tillers per square unit. Involving *Ppd* genes makes it possible to increase 1000-grain weight, which is very important for raising technological and qualitative indices.

Isogenic line ANK 17B with genes of weak photoperiodic sensitivity (*Ppd 1-3*) was used as donor in hybridization to reduce the vegetative period of cultivar OmSHI 6 (abbreviated Omsk Agricultural Institute). As a result cultivar Cherniava 13 was produced.

Leaf pubescence is very attractive to breeders as marker trait. Many authors consider that intense pubescence is effective protection against stem-concealed (frit fly) and leaf-eating (cereal stem flee beatles and leech) pests. Our results on hard pubescent leaf with isogenic line ANK-7A showed the trait's positive effect under drought. On average, yield performance under drought was 206 g/m^2 in the initial cultivar (recipient) and 218 g/m^2 in the line, drought tolerance being 46.7 and 50.2 %, respectively. Pubescent leaf contributes to better viability of lateral shoots and has a positive effect on productive tillering (0.2 stem per plant). Grain weight of lateral shoots was 35% of the entire plant grain weight in the N-67 isogenic line under drought, 33%.

Thick pubescent leaf is very important for breeding in combination with other traits for the steppes and forest-steppes of western Siberia. Spring bread wheat Tertsiya, which we developed, has multiple disease resistance and thick pubescent leaf, and is outstanding in its high drought tolerance and yield performance.

Comparative studies of analogues and NILs revealed the effect of awns on spike yield components. Awned lines had higher spikelet grain-filling and more grains per plant. On average, awned analogues had more grains per spikelet (0.1), more grains per spike (1.5), and more grains per plant (1.6) than the recurrent parent. High spike grain-filling correlates closely with drought tolerance under western Siberian conditions. The effect of awns on drought tolerance was 6.8% on average and as high as 20.3% in some lines. It is worth noticing that the awns donor affected the analogues' drought tolerance. If donors were drought tolerant (Krasnaya zvezda, Erythrospermum 841, and two accessions from China), the analogues from them had a greater positive effect on drought tolerance. The awned cultivars (Erythrospermum 59, Zlatozara, and Duet) we developed are distinct in their wide adaptability.

Studying the isogenic line for gene *Hd* (ANK-13) revealed the positive effect of this gene for the regional environment. To determine the degree of spike metabolite content, we pinched spikelets of ANK-13A and the recurrent parent of N-67. Line ANK-13A had a bigger grain size in 1986. The effect of the gene was significant and equal to 3.8 g, which indicates higher spike metabollite transportation in the isoline. Metabolites accumulated in stems and leaves are used more effectively to produce additional yield that is economically valuable. Investigations have revealed the capacity of gene *Hd* to increase metabolite transportation into the spike during cold, humid summers. Based on this, we proposed a way of breeding spring bread wheat with high spike metabolite content (Anonymous, 1990). Precipitation is adequate in some years in western Siberia but, as a rule, there is insufficient sunlight, as was the case in 1986, 1992, and 2002. Wheat crops have a delayed vegetative stage and thus subject to the first summer frosts; for this reason, harvesting frost-affected grains is quite common. Gene *Hd* will be relevant for breeding in such years. By increasing spike metabolite transportation, gene *Hd* contributes to faster grain-filling and earlier maturity in wheat.

Plant height is very important under regional conditions. Research has shown that under drought conditions of western Siberia dwarf and semidwarf plants carrying genes *Rht 1-3* do not compete well with tall varieties, which are more adaptable to the unfavorable regional climate. In 1986-1988, grain weight of dwarf lines ANK-11 and ANK-12A was, on average, 50% and 43% of that of parent, mainly due to their small grain size. Yield of Novosibirskaya 67 was 324 g/m^2, while ANK-12 produced only 246 g/m^2. It should be noted that significant negative effects were observed in dry environments. Drought tolerance of ANK-12 was on average 7.4% lower than that of the parent. Physiological experiments on water regime confirmed that lines carrying the gene *Rht2* had lower indices of water regime. A high genotypic correlation ratio (0.6:0.9) was found between plant height and yield in dry environments. Results also indicate that using dwarfing genes *Rht 1-3* in breeding wheat adapted to western Siberia is ineffective for improving waterlogging tolerance. Short-stemmed accessions from the CIMMYT collection had considerably lower yields, viability, and were far behind local varieties in other traits, especially in drought years.

Thus, based on studies of different analogues and NILS in environments with different moisture levels, we identified traits capable of improving adaptability and specific varietal models for different areas in the region. Analogues and NILs of the ANK series are effectively used in breeding as donors of certain traits. At present, a number of varieties has been produced using these analogues; four of them have been included in the State Cultivar Registration List (i.e. cultivars Tertsiya, Sonata, Duet, and Cherniava 13). All of them are distinct in their combination of economic traits and adaptability to the unfavorable regional environment. Valuable initial materials have been produced for further spring bread wheat breeding in western Siberia.

Analogues of cultivar S-29 that are resistant to diseases and waterlogging have been developed in cooperation with S.F. Koval, ICG, since 1986. Winter wheat Bezostaya 1 was used as donor of waterlogging tolerance. Crossing and further backcrosses have been made at the ICG, SB RAS. Hybrid population F_2 (S-29 x Bezostaya 1) x S-29 (BC_4) was selected and evaluated at Omsk State Agricultural University (OSAU). The best lines (NS-29) were subjected to CCT in 1988-1992. Based on line NS-29-888 selected in Omsk and BSK-21 selected in Novosibirsk (Table 1), new analogues with different genes for leaf rust and powdery mildew resistance (evaluated in the OSAU breeding nurseries) (Table 1) were developed.

It is worth noticing that the more additive traits are introgressed into a drought tolerant recipient (backcrossing), the less likely it is that the drought tolerance level of the initial cultivar will be maintained in the analogues being produced. Analogues with leaf rust resistance genes had considerably lower yields than the recipients in dry 1998. All analogues exceeded the recipient cultivar S-29 due to waterlogging tolerance and leaf rust resistance in more favorable 2000. Evaluation of ecological adaptability showed that S-29 is less responsive to environmental changes than the analogues. Coefficient of linear regression was less than 1 for S-29 (bi=0.49). Analogues with leaf rust resistance genes (NS-888 with *Lr19* and BSK 21 with *Lr9*), whose regression coefficient was more than 1, were outstanding in their response to environmental changes. Introgressed genes for leaf rust resistance had a significant effect on the increase of 1000-grain weight in analogues compared to the recipient.

It is possible to conclude based on evaluation results that BSK-21 with *Lr9* and NS-29-888 with *Lr19* are very promising for use in adaptive breeding. Lines selected on this basis are being subjected to competitive testing. Convergent crosses were carried out to concentrate several genes for leaf rust and powdery mildew resistance in one genotype (in NS-29-888 and BSK-21).

In 1997-2000 we evaluated more than 1000 accessions from CIMMYT's international collection and identified accessions with multiple disease resistance that were involved in hybridization to produce initial breeding materials. Evaluation of the identified accessions under the infectious conditions of the Cheliabinsk Scientific-Research Institute of Agriculture (CSRIA) showed that there were also no races that would overcome their resistance in the southern Urals.

Of the 55 best accessions in 2000, 21 (HRWYT-33, 43, ESWYT-8, HRWSN-31, 34, 35, 117, 128: SAWSN-26, 42, 44, 56, 131, 234, 235, 240, 263, 290; IBWSN-77, 197, 205, 237, 361, 370, and 371) were identified and included in the group of lines resistant to powdery mildew.

Results of laboratory evaluations of 600 samples of accessions resistant to leaf rust (infection type expressed in scores) are presented in Table 2.

In 1998, 60.4% of 197 accessions were resistant to leaf rust under epidemic conditions in the field. Accessions combining leaf rust and powdery mildew resistance (HRWYT-20, 33, 43; HRWSN-17, 31, 34, 35, 117, 128; SAWSN-26, 42, 44, 240, 263, 290; IBWSN-197, 370, and 371) were identified for 1997-2000 collection studies.

Accessions combining leaf rust and powdery mildew resistance

Table 1. Yield performance (t/ha) for analogues of cultivar Saratovskaya 29.

Cultivar/analogue	Origin	1998	1999	2000
Cultivar S-29	Recipient	1.84	2.56	2.38
NS-888	(S.29xB1)xS.29(BC_4)	1.78	2.68	2.88*
NS-888(*Lr19*)	(NS-888xLr19)xNS-888(BC_4)	1.38*	2.34	3.01*
BSK-21	(S.29xB1)xS.29(BC_4)	1.58	2.25	3.04*
BSK 21 (*Lr9*)	(BSK21xLr9)xBSK21(BC_4)	1.41*	1.86*	2.88*
LA 05		0.41	0.27	0.49

* Analogues considerably different from the recipient.

Table 2. Resistance of accessions to leaf rust.

Type of response (score)	Number of accessions	
0	427	71.2
1	12	2.0
2-3	4	0.6
3	7	1.2
4	150	25.0

plus good economic traits are of the greatest interest for breeding. Big spike grain number is typical of accessions HRWSN-117 (23.0-36.7), SAWSN-240 (24.9-41.5), and IBWSN-371 (23.8-35.1). Accessions SAWSN-240 (0.8-1.6 g) and IBWSN-197 (0.7-1.4 g) stood out in grain weight per spike. HRWSN-31 (31.1-39.6 g), SAWSN-44 (27.8-38.7 g), 240 (27.3-38.3), and IBWSN-197 (27.5-45.2) had the biggest grain size.

Our collaboration with CSRIA allowed us to outline aspects of ecological organization in breeding wheat for western Siberia and the southern Urals. The main objective of adaptive breeding (combining high productivity with resistance/ tolerance to biotic and abiotic stresses in the same genotypes) can be achieved only through right ecological organization of the breeding process, i.e., practical breeding aimed at combining different wheat traits, for example, drought tolerance and improved grain carbohydrate-protein content. Some researchers consider this phenomenon as seed enzymatic-micotic impoverishment (SEMI). We demonstrated the potential of such a combination. Erythrospermum 59, widely used in the Cheliabinsk and Omsk Regions, is highly resistant to seed impoverishment (SIR) and drought for the southern Urals typical of western Siberia.

It is important to note that wheat lines that were first identified in Omsk under moderately dry conditions of the mid-Irtysh area and then subjected to screening in the southern Urals in more favorable conditions, had broader adaptability. When the initial and breeding materials began at CSRIA, this regularly led to the loss of drought tolerant genotypes. Every year 30-50 seed samples (50 g in each) are sent to CSRIA from OSAU and then sown in breeding nursery-2 (BN-2) and a control nursery by OSAU. After that they send them to us the same way. Leaf rust resistance is evaluated at CSRIA as they have good epidemic conditions practically every year and also for seed carbohydrate-protein impoverishment. Breeders screen for drought tolerance in Omsk. At present, 10-15% of breeding stocks, from BN-2 to preliminary cultivar testing, are produced in cooperation with CSRIA. Seventeen spring bread wheat cultivars (Erythrospermum 59, Niva 2, Zauralskaya 90, Tertsiya, Lutescens 78, Zlatozara, Geya, Cherniava 13, Sonata, Quinta, Tyumenskaya 99, Duet, Nadine, Golubkovskaya, Chebarkulskaya, Pamiati Riuba, and Cheliaba 2) were developed as a result of multi-year complex breeding. Fourteen of them were produced in cooperation with the scientific institutions of the western Siberian and Ural Regions. Currently, seven cultivars have been included in the State Registration List (SRL), (i.e. Erythrospermum 59, Tertsiya, Niva 2, Zlatozara, Cherniava 13, Sonata, and Duet).

Erythrospermum 59 was developed jointly with breeders from OSAU and CSRIA by individual selection of the hybrid population obtained by crossing winter wheat Chaika with spring wheat Irtyshanka 10. It is intermediate to late-maturing. Erythrospermum 59 was included in SRL for western Siberian and Ural Regions in 1994. Its maximum yield was 6.43 t/ha in the State Cultivar Test; it is drought tolerant and included in the list of varieties with high bread-making quality.

Tertsiya was developed in collaboration with breeders from OSAU, ICG SB RAS, and the Kurgan Scientific Research Institute of Agriculture (KSRIA) by numerous individual selections from the hybrid population obtained by crossing analogues of Novosibirskaya 67: ANK-1 (red grain; gene *R3* from Arin, FRG) x ANK-2 (leaf rust resistance gene *LrTr* from donor K54049) x ANK-3 (powdery mildew resistance gene *Pm4b* from Solo, FRG) x ANK-7A (hard pubescent leaf; donor: K-26011 from China). It is intermediate to late maturing. Its maximum yield of 5.2 t/ha was achieved at the Gorky State Cultivar Test Station (SCTS). It is included in the list of wheat economic traits for its grain quality, has complex leaf rust and powdery mildew resistance, and is not affected by leaf-eating pests (leech and others) due to its thick, hard, pubescent leaf. Tertsiya was included in SRL all over the Ural, western Siberian, and northern Caucausian regions.

Niva 2 was bred in cooperation with CSRIA by means of individual selection from a population produced through hybridization of winter wheat cultivar PS 360/76, Romania, x spring wheat Irtyshanka 10. Niva 2 is an intermediate maturing cultivar. Maximum yield, at the Gorky SCTS, was 5.6 t/ha in 1997; it is resistant to leaf rust and powdery mildew, not affected by loose smut; included in list of wheat cultivars with high bread-making quality and economic traits. Niva 2 was included in SRL all over the Ural, western Siberian, and middle Volga Regions.

Zlatozara was developed in cooperation with breeders of the Scientific Research Agricultural Institute of the South Trans-Urals through individual selection of hybrid population Krasnovodopadskaya 210 x Irtyshanka 10. It is a *Erythrospermum* variety, intermediate to early, has high yield potential, and was included in the list of valuable cultivars and SRL in 1999 for the western Siberian Region.

Cherniava 13, a spring bread wheat, was developed at OSAU in cooperation with SRIA in the northern Trans-Urals through individual selection of early maturing plants from hybrid population F_5 (ANK 17 x OmSHI 6) x OmSHI 6. It is a *Lutescens* variety, has high yield potential, and is intermediate to early in its vegetative period. Cherniava 13 has shown high technological indices in cultivation, tolerance to drought, waterlogging, grain-filling and pre-harvest sprouting, loose smut, and leaf rust. In 2000 it was included in SRL for the western Siberian Region.

Sonata was bred through double individual selection from hybrid population Tselinnaya x Tertsiya. It has high yield potential, drought tolerance, leaf rust resistance (gene *Lr-Tr*), good grain quality, and technological indices in cultivation; and was included in SRL for the western Siberian Region in 2002.

Duet was developed through individual selection from hybrid population Erythrospermum 59 x (Tselinnaya 20 x ANK 102). It has high yield potential, drought tolerance, and leaf rust resistance, was developed in cooperation with CSRIA and included in SRL for the Ural and western Siberian Regions in 2003.

High yielding and disease resistant Quinta, Chebarkulskaya, Cheliaba 2, and Pamiati Riuba were developed in cooperation with CSRIA. Cultivars Tyumenskaya 99 and Nadine, developed in cooperation with SRAI of the northern Trans-Urals, are currently undergoing SCT. Cultivar Golubovskaya, outstanding for its high tolerance to alkalinity, has been undergoing SCT since 2002.

The methodology used in breeding spring bread wheat for adaptability was theoretically and experimentally based on:

1. Crossing wheat varieties tolerant/resistant to different types of drought and diseases;
2. Screening for genotypic variability for traits important to breeding under different moisture levels;
3. Selecting under stress conditions (drying, early sowing date, disease epidemics, ecological locations, alkaline soils) and in environments of genetically conditioned half-lethality;
4. Searching for and incorporating genes for improved plant adaptability to environmental stresses;
5. Conducting a wide range of ecological tests on initial materials in different locations of western Siberia and the Urals.

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Doubled Haploid and Somatic Embryo Plant Biotechnologies in Kazakhstan

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Enhanced progress in plant breeding and selection may be achieved through the use of biotechnological methods including experimental haploidy, embryoculture, and cell selection. Cellular development and selection can be observed *in vitro* involving recombination, mutation, hybridization, and selection, while organism selection is achieved through conventional breeding methods. Biotechnological methods will not replace conventional breeding, but may enhance its effectiveness by accelerating the breeding process. Theoretical and applied aspects of cultivated cell biology have been studied and used to develop wheat, barley, rice, and alfalfa.

Embryo culture methods were developed that allow hybrid embryo viability to increase, thereby facilitating plant regeneration in wide-cross wheat hybrids. Typically, germination is drastically reduced in hybrid embryos, which abort due to endosperm incompatibility. Therefore, it was necessary to cultivate immature early embryos and "drive" them to "autonomy" under *in vitro* conditions. This achieved embryo independence from surrounding tissue, allowing normal embryogenesis to be completed outside the parent organism. Isolated embryos are transferred to White medium supplemented with glutamine at the rate of 400 mg/l; alanin, 400 mg/l; tirozin, 10 mg/l; triptophan, 10 mg/l; phenylalanine, 10 mg/l; and cistein, 10 mg/l. Culture dishes with isolated embryos were transferred to the light room at 24 °C, with 16 hours of photoperiod, 3000 lk light intensity, and 80% relative humidity. After two weeks, embryos were transferred to a regeneration medium.

The most critical moment is when plant regeneration occurs from cultivated embryos. The regeneration process consists of two stages: induction of 1) tillering and 2) plant rooting. After two or three weeks, the plants are transferred to Murasige and Skoog medium (MS) with addition of 1.0 mg/l of IVA and 0.5 mg/l of kinetin. Intensive plant growth occurs on this medium after three or four weeks. Plants are then transferred to a hormone-free MS medium. Plants with a height of 8-10 cm and well-developed roots are selected, washed of agar, and transferred to pots containing a soil mixture and covered with plastic for moisture retention. After 7-10 days plants are removed from the plastic protection for 30 minutes, gradually increasing exposure time to the open air up to several hours each day. Complete adaptation of plant regenerants to natural conditions occurs within one week. Plants are then transferred to the greenhouse and grown to complete seed maturity.

Doubled haploid production in culture of isolated anthers and microspores is an effective method of accelerating the breeding process. The main advantage of doubled haploids is the possibility of quickly producing homozygous lines. Doubled haploids make it possible to select recombinant genotypes carrying favorable traits among relatively small populations early in the breeding process.

Haploid wheat plants can be developed *in vitro* using two routes of morphogenesis: 1) embryogenesis and 2) organogenesis. Embryoids (2-3 mm) are transferred to the media for regeneration and grown in light conditions with 16 hours photoperiod. Hormone-free Gamborg B5 medium is used with addition of mineral salt (50%), sucrose (20 g/l), and agar (8 g/l). Morphogenic calli are stored on Gamborg B5 medium with addition of iron chelate (50%), 20 g/l sucrose, and 0.2 mg/l IVA. MS medium with addition of 2 mg/l 2.4 – D and 30 g/l sucrose is used for callus development. Calli are cultured under dark conditions at 25 °C.

The chromosomal haploid set is doubled using vacuum infiltration of a colchicine solution (0.15% colchicine in a 4% dimetilsulfooxide solution) at the three-leaf stage of normal plant development. The colchicine solution is applied to the entire plant surface. The plant is placed in a vacuum chamber, and the air is evacuated to a pressure of 76 mm of mercury. After 20 minutes, air is slowly allowed into the chamber;

the procedure is repeated three times. Plants are rinsed with water, and a root sample is fixed for cytological analysis. The plants are sown in pots containing soil, grown in well lighted conditions, and treated daily with a mixture of gibberellic acid (2 mg/l), kinetin (0.5 mg/l), and nikotinamid (3 mg/l) during the first week.

Haploids were obtained from winter wheat genotypes through cross combinations: BC_1 Grecum-476 x Lyutescens-103M35) x (Lyutescens-103M35) and (F_1 Lyutescens –293H436 x Gostianum-88). The best result for spring wheat is obtained using the following genotypes: (F_2 (Mirinivskaya –808 x Skala)x Skala) and (F_2 (Spartanka x Eritrosperum –14) x Eritrosperum 14). Doubled haploid seeds are obtained from F_2 combinations (Spartanka x Eritrosperum-14) Eritrosperum-14 and F_2 Kazakhstanskaya-126 MK x Saratovskaya-29).

Artificial seed technology discloses possibilities for mass heterotic effect in hybrids, conservation of unique genotypes, and creation of plant germplasm bank. The first stage of artificial seed production is ensuring safe control of the outgrowth process and cell differentiation *in vitro*, somatic embryogenesis synchronization, and increase the number of somatic embryoids. As the result of research, conditions for mass production of somatic embryoids and conversion of embryoids into entire plants were optimized.

Experiments to optimize the somatic embryoid production of wild species of alfalfa were conducted involving *Medicago sativa, M. borealis, M. falcata, M. trautvetteri*, and *M. varia*. Explants were planted on media with the addition of 2.4-D, kinetin, and kazein hydrolizat. Mass production of calli was observed. It was noted that inclusion of kazein hydrolizat (1 g/l) in the medium increased embryogenesis. When differentiated tissue was transferred onto MS liquid medium, somatic embryogenesis was induced. To synchronize development of somatic embryos, suspensions were sieved to achieve groups of cells having different diameters. Bleidis medium with yeast extract, 10 mM abcisic acid, and 6% sucrose was the main medium used for maturing the embryoids.

Somatic embryos were dried using the following saturate salt solutions: NaCl (78%), NH_4NO_3 (63%), $Ca(NO_3)_2 \times 4H_2O$ (51%), $K_2CO_3 \times 2H_2O$ (43%). The drying procedure was carried out for one week until embryo moisture content reached 15%. Storage of somatic embryos was carried out under room conditions in closed Petri dishes. Dried somatic embryos can be planted on Shenk-Hildebrandt medium with addition of 25 mg/l gibberellic acid. Embryoids, after one week of storage, regenerate into complete plants with roots and leaves. Consequently, results of somatic embryogenesis induction can serve as the methodological basis for developing artificial seed production technology for alfalfa.

In general, biotechnological methods developed in Kazakhstan accelerate and facilitate the applied breeding process. Through embryo culturing methods, wide-cross wheat hybrids were produced with wild relatives of wheat. Homogeneous lines of wheat and barley have been included in the crossing programs, using haploid technology. Methodological bases of artificial alfalfa seed production were developed.

These biotechnological methods were developed for use in plant breeding in collaboration with the research centers of Kazakhstan's Ministry of Agriculture.

Development of Herbicide Resistant Bread Wheat through Biolistic Transformation

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The unique properties of wheat flour and the wide geographical distribution (FAO, 2001) of wheat make it one of the three most important crops in the world. Traditionally, genetic diversity has been the result of crossing followed by strict selection to identify new useful recombinants. Plant biotechnology offers many opportunities to solve these problems through the development of new cultivars at the molecular level. The creation of transgenic plants is a complex procedure that includes introducing DNA into cells, integrating vector nucleotide sequences into genomic DNA, and achieving the expression of new genes in a desired direction. Compared with conventional breeding methods, use of new plant biotechnology achievements can considerably reduce the time needed to produce cultivars with improved characteristics (Alpeter et al., 1996a,b). Moreover, biotechnological approaches allow plant breeders to use genes of practically any origin as a tool for plant improvement, thereby increasing the gene pool (Lazzeri et al., 1997).

Wheat plays an important role in Uzbekistan's economy. Local wheat varieties possess such specific characteristics as drought and salt tolerance and resistance to different pathogens. But it should be noted that sometimes the main disadvantage of potential local elite resistant wheat cultivars is the poor bread-making quality of wheat flour. Therefore, wheat varieties can be an attractive "target" for plant genetic engineering, especially taking into account that novel gene constructs have been created recently to improve the bread-making quality of wheat flour (Blechl and Anderson, 1996).

Development of plants resistant to biotic and abiotic stresses using genetic engineering methods is one of the most promising directions in wheat biotechnology in Uzbekistan. The work reported here was aimed at obtaining transgenic wheat plants resistant to Basta herbicide by biolistic transformation, as an alternative to Agrobacterium-mediated transformation.

Materials and Methods

Plant materials

In this work immature embryos of wheat (*Triticum aestivum* L.) cultivars Intensivnaya, Marjon, Gairat, lines 407, 408 from the Uzbek Plant Industry Research Institute (PIRI) collection, and high embryogenic CIMMYT variety Bobwhite were used. Plants were grown in field stations of the Institute of Genetics and Experimental Plant Biology (IGPEB) and Uzbek PIRI.

Culture media

Immature embryos were used for callus induction 12-14 days after pollination. Caryopses were sterilized in 70% ethanol and then rinsed three times in sterile water. Immature embryos were isolated under a Wild M8 microscope (Switzerland).

As a basic nutrient medium for cultivation of explants, induction of callusogenesis, and morphogenesis, we used media containing MS salts (Murashige and Skoog, 1962), B5 vitamins (Gamborg and Eveleigh, 1968), sucrose 3%, agar 0.8%, @ 5.8, supplemented with hormones such as 2,4-D, KIN, and IAA.

In biolistic transformation experiments for explant cultivation and transformant selection, eight media (all containing 0.8% agar and having 5.8 pH) were used:

1. MS salts; B5 vitamins; 3% sucrose; supplement: 2 mg/l 2,4-D;
2. MS salts; B5 vitamins; 3% sucrose; supplements: 2 mg/l 2,4-D, 3 mg/l Basta;
3. MS salts; B5 vitamins; 2% sucrose; supplements: 10 mg/l zeatin or 0.5 mg/l KIN, 3 mg/l Basta;
4. MS salts; B5 vitamins; 2% sucrose; supplement: 4 mg/l Basta;
5. 1/2 MS salts; 1/2 B5 vitamins; 1% sucrose; supplements: 0.2 mg/l IAA, 2 mg/l Basta;
6. medium 1 supplemented with 500 mg/l glutamine and 300 mg/l casein hydrolisate;
7. MS salts; B5 vitamins; 2% sucrose; supplements: 5.0 M $CuSO_4$, 1 mg/l KIN, 1 mg/l BAP, 3-4 mg/l Basta;
8. 1/2 MS salts; 1/2 B5 vitamins; 1% sucrose; supplements: 0.02 mg/l IAA, 2 mg/l Basta.

Plasmid

For biolistic transformation plasmid pAHC25 (Christensen and Quail, 1996) containing chimeric genes of ubiquitin-b-glucuronidase (Ubi-GUS) and ubiquitinphosphinothricine (Ubi-bar) (resistance to herbicide Basta) was used.

Transformation

During biolistic transformation 3 l of pAHC25 were precipitated and adsorbed on gold particles (10 l at the rate of three shots from a stock solution with 60 mg/ml concentration). The DNA-covered particles were introduced into callus tissue, using PDS-1000/He (Bio-Rad, Germany). 10 l of the prepared particle suspension were put onto a surface of a macro carrier.

Histochemical analysis

GUS activity in the transformed tissues was histochemically evaluated (Jefferson, 1987) in callus culture seven days after biolistic transformation.

PCR analysis

Genomic DNA was isolated from young leaves of control and transgenic wheat plants (Dellaporta et al., 1983). PCR analysis was carried out using primers that are a part of the *bar* gene coding region. About 50 ng of matrix DNA were subjected to 35 cycles of amplification in 25 l of the reactive solution. PCR products were analyzed by gel electrophoresis in 1% agarose gel.

Results and Discussion

In transformation experiments a method for rapidly obtaining wheat transgenic plants was applied (Alpeter et al., 1996a; b). After screening local wheat varieties (Muhkamedhkanova et al., 1999; 2001), we used the following cultivars: lines 407 and 408 from the Uzbek PIRI collection; high-embryogenic model cultivar Bobwhite from CIMMYT; Marjon, Gairat, and Intensivnaya, which have the most embryogenic and regeneration activity *in vitro*; and embriogenic callus cultures of Marjon immature embryos. Calluses were induced on medium 1, while callus proliferation and embryogenesis induction took place on medium 6. Immature embryos were bombarded 5 to 7 days after cultivation initiation on medium 1, and embryogenic callus cultures, 1 to 1.5 weeks after cultivation initiation on medium 6.

We used plasmid pAHC25 (Christensen and Quail, 1996), containing the selectable *bar* gene encoding the enzyme phosphinothricin acetyltransferase (PAT) and the GUS reporter gene (*uid*A) encoding -glucuronidase; both were driven by a maize ubiquitin promoter (Figure 1). Plasmid DNA was precipitated, adsorbed on gold particles, and delivered to target tissues using a PDS-1000/He device (BioRad, USA).

Immature embryos (0.7-1.5 mm in size) were isolated aseptically, placed on induction medium 1, and bombarded after 5-7 days of cultivation in the dark after occurrence of callus tissue. Before bombardment, explants were incubated for 4-6 hours in the dark on medium 1 without sucrose and the addition of equal amounts of mannitol and sorbitol (0.4 M osmotic). Many researchers (Alpeter et al., 1996a; b; Brettschneider et al., 1997; Sanford,

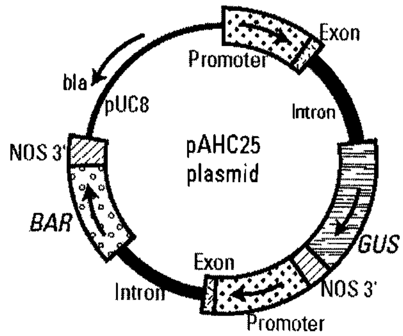

Figure 1. Plasmid pAHC25.

1991) have reported that osmotic treatment of explants before and after bombardment is necessary for successful regeneration and stable transformation. Between 12 and 16 hours after bombardment, cultures were transferred onto medium 1 or 2 (the beginning of selection) and cultivated for two weeks in the dark. Thus the selection process started either immediately after bombardment or two weeks after explant cultivation on medium 1.

For formation of shoots embryogenic calluses were transferred onto medium 3 with 10 mg/l zeatin and maintained under fluorescent light. Shoot elongation was carried out on medium 4, and their rooting on medium 5. During callusogenesis, treatments with osmotic and regeneration cultures were maintained at 24-27°C. Every embryogenic callus obtained from single immature embryos of Bobwhite formed shoots 12-15 days after being transferred onto medium 3. Morphogenesis and regeneration on medium 3 in lines 407 and 408 proceeded much more slowly, but they were comparable between themselves. Thus morphogenic calluses were obtained only 25-28 days after the beginning of cultivation. Shoots developed only 30-35 days after explants were transferred onto medium 3. Thus frequency of regeneration and transformation for these lines was much lower than in the Bobwhite variety. Regeneration frequency was also lower when cultures were transferred onto selective medium 2 immediately after bombardment.

A 3 mg/l concentration of herbicide Basta was lethal for control explants, while processes of morphogenesis and regeneration were observed in bombarded cultures (Figure 2). Shoot elongation in the presence of 4 mg/l Basta was one of several criteria for determination of transformed plants.

To reduce damage during bombardment, explants were maintained on medium 1 in which sucrose was replaced by equal concentrations of mannitol and sorbitol (0.4 M) 4-6 hours before and 16-20 hours after bombardment. After bombardment calluses were cultivated for two weeks on non-selective medium 6 and then transferred onto selective medium 7 (with 3 mg/l Basta), where shoot induction took place. Shoot elongation was carried out on medium 7 with addition of 4 mg/l Basta (Figure 3). Their rooting was conducted on medium 8, prior to their adaptation to soil in greenhouse conditions.

During these experiments the high embryogenic tissue obtained on medium with the addition of glutamine and casein hydrolisate (medium 6) was used as a target for biolistic transformation. The subsequent transfer of transformed embryogenic cultures onto a medium with increased content of ions Cu $^{2+}$ (medium 7) allowed to get high output regenerating callus tissues which survived after selection on medium with 4 mg/l of herbicide Basta. From 500 individual explants of Marjon variety we obtained four callus cultures regenerating on selective medium with increased herbicide content; transformation frequency was 0.8%. In opinion of many researchers the use of embryogenic callus cultures as targets for biolistic transformation can considerably facilitate the development of genetically modified monocotyledonous plants. Thus, cultivation of transformed calluses on medium containing kinetin and increased amount of ions Cu^{2+} promotes a high regeneration and transformation frequency even in genotypes characterized by low regeneration activity *in vitro* (Cho et al., 1999; Kim et al., 1999).

For proof of transformation we conducted histochemical staining of bombarded calluses of all varieties and leaf tissue of the plant regenerants of Bobwhite. GUS activity (dark blue color after staining) was revealed in callus cultures of all varieties and also in epidermal layer, mesophyll, and vascular tissue of Bobwhite plants (Figure 4). Activity of phosphinothricin acetyltransferase (PAT activity) was revealed by resistance of plantlets to herbicide treatment. The analysis of both GUS and PAT activity has shown that many of putative transformants were chimeric. Frequency of transformation on average was 0.05% for line 407, 0.03% for line 408, and 0.1% for Bobwhite.

The PCR analysis of F1 lines was carried out for molecular proof of *bar* gene presence in the plant genome of five putative transgenic Bobwhite lines. It confirmed the *bar* gene was integrated into the plant genome (Figure 5). Lines T10, T11, and T25 contain *bar* gene loci (465 kb) corresponding to plasmid pAHC25. Intensity of similar bands in lines T1 and T7 is insignificant, which confirms the presence of individual copies of the gene.

Figure 2. Selection of transformed calluses on a medium supplemented with 3 mg/l Basta.
A = control, non-transgenic calluses on non-selective medium; B = transformed calluses on selective medium; C = control calluses on selective medium.

Figure 3. Shoot elongation of wheat transformed regenerants on medium containing Basta (4 mg/l).

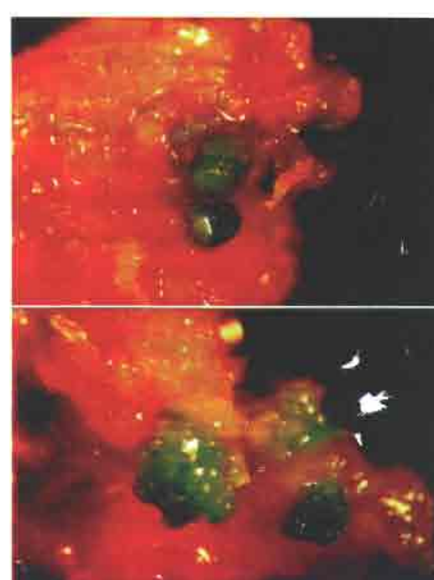

Figure 4. GUS activity of transformed callus cultures.

Conclusions

An effective system for obtaining transgenic wheat plants through biolistic transformation of immature embryos and embryogenic callus tissue obtained from them was developed. Transformed callus cultures and the plants growing with 4 mg/l of herbicide Basta were obtained. Observed GUS activity and PCR analysis confirm the presence of foreign genes in transformed wheat tissues.

Based on these results, it is possible to conclude that a reliable system of transformation has been developed that allows specific genetic manipulations with isolated wheat tissues and regeneration of genetically transformed plants. This provides new opportunities for studying the integration and inheritance of transgenes and their expression.

In recent years, there have been revolutionary changes due to the use of recombinant DNA technology in combination with plant transformation. This has made it possible to carry out specific gene changes and to study their subsequent influence on plant development, physiology, and biochemistry. Plant genetic engineering certainly cannot be considered as a panacea for all difficult problems in agriculture. But we are confident that this vigorously developing research direction will open new, significant prospects in agronomics.

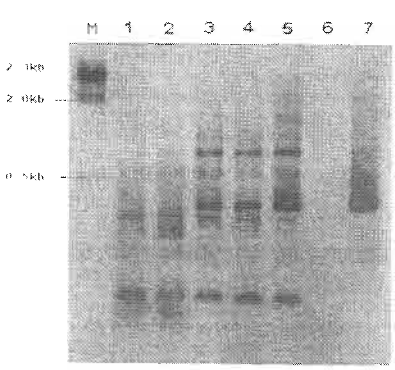

Figure 5. PCR analysis of F1 DNA.
M – marker; 1 – transgenic wheat T1; 2 – transgenic wheat T7; 3 – transgenic wheat T10; 4 – transgenic wheat T11; 5 – transgenic wheat T25; 6 – control non-transgenic wheat; 7 – plasmid pACH25.

The main grain crops are priority targets for genetic manipulation, despite the fact that monocotyledonous plants are more resistant to transformation than dicotyledonous ones. Although this seriously hinders the application of the latest technologies to grain crops, the situation is improving, and there is reasonable hope that transformation of grain crops in the future will be as simple as it is for some dicotyledonous crops at present.

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Biotechnology Applications for Wheat Improvement at CIMMYT

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Traditional plant breeding activities have resulted in tremendous yield gains in most cultivated crop species. Global wheat breeding efforts over the past 40 years have made significant contributions to enhancing yield potential and stability, as well as developing cultivars with more durable levels of resistance/tolerance to a diverse array of biotic and abiotic stresses. Average developing country yields for most crop species have more than doubled in this time span, avoiding major famines. However, efforts of wheat breeders are constantly challenged by various biotic and abiotic stress factors that threaten yield stability in many wheat growing regions. In biotic stresses, this is due to the ability of the pathogens to evolve and mutate into more virulent forms. Among biotic stress factors, diseases such as leaf (brown) rust, stripe (yellow) rust, and head scab are considered globally important diseases in wheat. The challenges due to abiotic stress factors such as limited water availability, and soil acidity and alkalinity continue to pose significant challenges for the wheat breeding community. It is estimated that by 2020, the global demand for wheat will be about 40% greater than its current level of 552 million tons (Rosegrant et al., 1997).

Plant breeders have made significant contributions, and the last few decades have seen major advances in science, specifically in the area of molecular biology. Recent advances in biotechnology have resulted in understanding the genetic basis of living organisms as well as products and processes useful for the well-being of humanity. These scientific advances have resulted in increased understanding and characterization of various genes at the molecular level that are associated with traits important to plant breeders. Tools based on DNA markers, made available by countless researchers around the world, have begun to significantly contribute to further increase the effectiveness of crop breeding.

This paper reports the activities underway at CIMMYT's Applied Biotechnology Center utilizing biotechnology applications to facilitate the efforts of wheat breeders to meet the challenges.

Biotechnology Applications

Biotechnology research efforts at CIMMYT are based on applied research that will benefit the Center's two mainstream crop improvement activities as well as providing training in biotechnology applications for staff of national agricultural research programs of the developing world. Current research efforts are focused on the development of molecular markers for traits of importance to the wheat program; adoption and application of markers that have resulted from other global research efforts; genetic diversity studies aimed at characterizing wheat germplasm collections to identify useful alleles for genes of interest; and genetic engineering activities aimed at developing genetically modified spring wheats with value added traits.

Durable Resistance to Leaf and Yellow Rusts

CIMMYT's strategy for helping to combat yellow (stripe) and leaf (brown) rusts, globally important wheat diseases, is to concentrate on developing cultivars with good levels of slow rusting response, which has proven to be durable in nature. Table 1 lists the populations and strategies currently being used to identify, characterize, and develop markers for genes that confer durable leaf and yellow rust resistance. Instead of developing full linkage maps to achieve the above objectives, which in wheat can be time-consuming and resource-intensive, we are combining bulked segregant analysis and partial linkage mapping to meet the goals. Bulked segregant analysis (BSA), which involves pooling entries at the two extremes for a segregating trait (Michelmore et al., 1991), has been effectively used for identifying molecular markers associated with disease resistance genes in a number of species (Eastwood et al., 1994; Williams et al., 2001).

In an Avocet x Pavon 76 population, we have been able to identify three loci that have significant effects on leaf rust resistance and five that have effects on yellow rust resistance. Bulked segregant analysis enabled identification of markers associated with *Lr46* (Singh et al., 1998) as well as to establish the association of *Lr46* with *Yr29* (William et al., 2003). Linkage mapping of the markers associated with *Lr46/Yr29* using the International Triticeae Mapping Initiative (ITMI) population established the precise genomic location of these genes on the long arm of chromosome 1B (William et al., 2003).

In Avocet x Pavon 76 and other populations listed in Table 1, some of the loci identified have common effects on both leaf and yellow rusts, whereas other loci have individual effects on only one of these diseases. In Avocet x Parula and Avocet x Tonichi populations also we have been able to characterize several loci associated with resistance to the two rust diseases (see Singh et al., 2003– this conference proceedings). Molecular markers have proven to be advantageous and quick for identifying these slow rusting loci and establishing their genomic locations. In wheat, where alien transfers in the form of chromosomal translocations are common, many race-specific resistance genes for a wide range of biotic stresses have been introgressed into wheat from wild relatives, and markers have been used for tagging such genes. A large number of publicly available microsatellites (Roder et al., 1999), as well as techniques such as amplified fragment length polymorphisms (AFLPs) (Vos et al., 1995), have also enabled identification of markers associated with genes that confer durable resistance to diseases such as leaf and yellow rusts (Messmer et al., 2000; Suenaga et al., 2003), powdery mildew (Liu et al., 2001), and fusarium head blight (Anderson et al., 2001).

Marker Implementation

When a molecular marker is considered for use in the breeding program, several criteria are taken into account: 1) linkage between the marker and the gene of interest, to avoid false positives; 2) repeatability and reliability of the marker(s); and 3) cost and reliability of field screening. If the marker is located within the gene of interest, it can be used as a diagnostic marker, since there is no recombination between the marker and the gene of interest. As for markers with some recombination with the genes of interest, they may be used to increase allele frequency for the gene of interest in breeding populations based on the recombination frequency.

Marker repeatability and reliability ensure the robustness of the assays and develop the confidence of plant breeders. Markers should ideally be used in scenarios where field screening is expensive and/or when such screening is laborious or unreliable due to environmental influences. A laboratory that is capable of providing these tools for the benefit of plant breeders should have the capacity to conduct high throughput, high quality DNA extractions and high throughput marker assays. At the Applied Biotechnology Center, we are using a set of PCR based markers for key traits that are difficult to screen reliably in the field.

The following markers are currently being used on a routine basis:

- Cereal cyst nematode resistance gene, designated as *Cre1*. Developed by CSIRO-Plant Industry group in Canberra, Australia. The gene was identified in an Australian cultivar and is located on chromosome 2BL. The marker is diagnostic for *Cre1*.
- Cereal cyst nematode resistance gene, designated as *Cre3*. Developed by CSIRO-Plant Industry group in Canberra, Australia. The gene was identified in *Triticum tauschii*, is located on chromosome 2DL, and a diagnostic marker is available (Lagudah et al., 1997).
- A marker for barley yellow dwarf virus (BYDV) resistance, derived from an introgressed chromosome segment from *Thinopyrum intermedium*, is located on chromosome 7DL. The marker was developed at CIMMYT (Ayala et al., 2001).

Table 1. Populations used for mapping adult plant resistance (APR) to leaf and yellow rust.

Population	Estimated APR genes for leaf rust in the R parent	No. RILs[a]	Strategy used for mapping
Frontana (R) x INIA66	*Lr34* + 2-3 genes	223	Full linkage map
Avocet x Pavón 76 (R)	*Lr46* + 2 genes	148	BSA[b] + partial mapping
Avocet x Parula (R)	*Lr34* + 2-3 genes	141	BSA[b] + partial mapping
Avocet x Tonichi (R)	*Lr34* + 2-3 genes	144	BSA[b] + partial mapping
Avocet x Pastor	*2/3*	40 F5 families	BSA[b] + partial mapping

[a] Recombinant inbred lines.
[b] Bulked segregant analysis.

- Marker for Chinese Spring *ph1b* mutant. Developed at John Innes Center and is diagnostic for the deletion that involves the *Ph1* gene on chromosome 5BL, a suppressor of homoeologous chromosome pairing (Qu et al., 1998).
- Marker for *Aegilops ventricosa* derived resistance to stripe rust (*Yr17*), leaf rust (*Lr37*), and stem rust (*Sr38*) (Oliver Robert, pers. comm.). The translocation from *Ae. ventricosa* is present on chromosome 2AS.

The sources containing *Cre1* and *Cre3* genes have been extensively used in crosses with improved CIMMYT wheats with the aim of introgressing these genes into wheats targeted mainly to marginal environments but also high rainfall and irrigated areas. Better root health is critical in marginal environments, where poor water uptake is often related to poor root health. In addition, these sources also have been used in durum x bread wheat crosses. We are routinely applying these markers to identify materials in segregating populations to enable the breeders to selectively advance lines containing genes of interest. Crosses have also been made with the aim of combining *Cre1* and *Cre3* genes utilizing markers in high yielding backgrounds.

The microsatellite marker derived from *Thinopyrum intermedium* (*gwm* 37) is being used effectively to transfer the alien chromosome segment from TC14 line carrying the introgression into different bread wheats with the ultimate aim of combining the alien derived resistance with tolerance available in wheat for BYDV. The STS marker derived from *Ae. ventricosa* is used in a limited capacity, mainly in bread wheat x durum wheat crosses, to identify the durum derivatives carrying the translocation.

Genetic Engineering

The Applied Biotechnology Center has been successful in developing techniques for the mass production of fertile transgenic wheat (*Triticum aestivum* L.) through biolistic methods using immature embryos (Pellegrineschi et al., 2002). CIMMYT's elite cultivars are co-bombarded with a marker gene and a gene of interest with co-transformation efficiencies of around 25-30%. The reliability of this method opens the possibility for the routine introduction of novel genes that may induce resistance/ tolerance to biotic and abiotic stresses. It may also have applications in various wheat quality and nutritional parameters. We are aware of the public perception of genetically modified organisms and are of the opinion that through education and communication, public opinion will eventually favor the deployment of transgenics on a broad scale. CIMMYT will continue to work on establishing stable transgenics with genes of economic importance in both wheat and maize. Its policy is to share those materials with national programs in countries whose policies allow the deployment of genetically modified organisms.

The first group of genes being evaluated are the pathogenesis related (PR) proteins, such as the thaumatin-like protein (TLP) from barley, chitinase, and 1-3 b-glucanase. Stable integration of the genes in the genome and inheritance in the progeny were determined by phenotypic analyses that challenged the plants against a wide range of pathogens. The anti-fungal activity of the endogenous thaumatin-like proteins were analyzed in T_1 and T_2 progeny plants. The transgenic wheats were challenged by a host of pathogens including *Alternaria, Fusarium, Helminthosporium, Pythium,* and *Rhizoctonia*. The preliminary results from the *in-vitro* and *in-vivo* assays have indicated that for *Alternaria*, the plants containing tahumatin-like constructs showed positive responses in the form of disease reactions including immunity in some cases. Current wheat transformation activities include use of constructs with receptor-like kinase protein isolated from rice, anti-secalins, low molecular weight glutenins, and certain constructs containing genes of interest in tolerance to drought and other abiotic stresses (DREB genes).

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Approaches for Breeding for Drought-Tolerant Winter Wheat in Romania

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Romania's very diverse climate is described as "moderate continental." Average annual rainfall decreases from west to east, from 630 mm in the Northwestern Plain, to 500 mm in the eastern Danubian Plain and less than 400 mm in Dobrogea, the southeastern part of Romania, near the Black Sea.

Very large year-to-year variation in annual rainfall and in rain distribution during the year is common, making drought a frequent phenomenon. Historical data show that, out of 100 years, 3 were very dry, 58 dry, 24 rainy, and 15 very rainy (Ionescu-Sisesti, 1946). In recent years, drought was even more frequent, and large water deficits, as compared with estimated average evapotranspiration, occurred in four years out of five (Figure 1). The largest deficit was recorded in 2002, when total rainfall during the wheat vegetative period was less than 250-300 mm in many regions. There was large variation among test locations in the intensity and evolution of water stress, with cumulative rainfall covering 34-64% of estimated potential evapotranspiration.

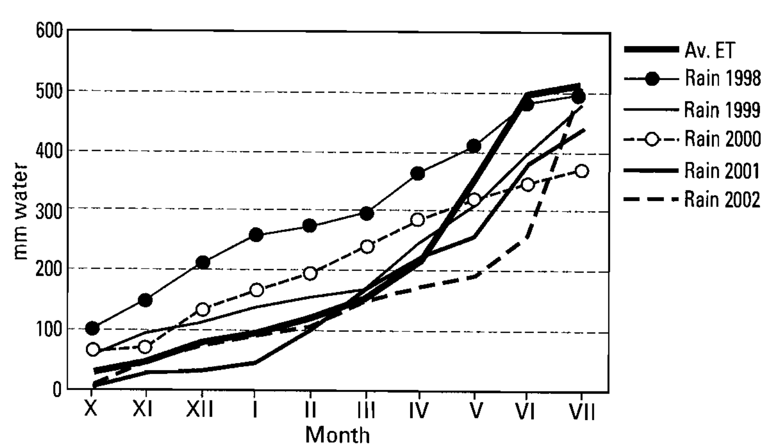

Figure 1. Cumulative average potential evapotranspiration and rainfall during the winter wheat vegetative period, 1998-2002, Fundulea, Romania.

Although winter wheat is considered a relatively drought tolerant crop, total rainfall during the wheat vegetative period explained more than 40% of yield variation in 50 yield trials (Saulescu et al., 1998).

Materials and Methods

Taking into consideration the large variation in rainfall from one year to another, wheat cultivars for Romania have to combine reasonable levels of lodging and disease resistance and yield potential in favorable environments, with good performance under drought. For this reason, our winter wheat breeding program in Fundulea includes:

- selection done alternatively in dryland conditions and under irrigation,
- parallel testing under irrigation and dryland conditions, beginning from the first unreplicated yield trials in the F5,
- multilocational yield trials, 2 under irrigation and 6 without irrigation, beginning in the F6, and
- multilocational yield trials of advanced lines in 6 locations with and without irrigation, plus another 6 environments without irrigation.

Data from locations where yield trials are conducted under different levels of water availability are used to compute drought susceptibility indices (DSI) (Fischer and Maurer, 1978). Genotypes that combine the smallest DSI with the highest yielding potential are selected.

We have also tried to use several physiological methods to characterize the genotypic differences in plant response to water stress. Some, such as cuticular transpiration (as measured by water loss from excised leaves of 5- to 8-leaf plants) and response to Paraquat-induced oxidative stress, have shown significant correlation with yield performance under drought (Balota and Saulescu, 2000). These physiological traits have been used for parent selection, but are not sufficiently adapted for large-scale testing of early generations. However, the information obtained by applying physiological tests was useful in defining our strategy to improve yield under water stress.

Results

The very dry year 2002 allowed a good characterization of the performance of many Romanian cultivars, along with some cultivars from other countries. On average drought reduced yield in six locations of southern Romania by 52%, but yield reduction in various locations ranged from 35 to 96% (Table 1). Yield under drought was correlated with yield under irrigation at lower stress levels (R≤= 0.36 to 0.63), but showed no correlation under severe stress.

Yield reduction was associated with height reduction (on average by 27%), number of spikes/m≤ (on average by 27%), number of kernels/spike (on average by 26%), and individual grain weight (on average by 22%). Large variation was found among locations in the level of reduction by water stress in various plant traits (Table 2). This variation can be explained by differences in the evolution of stress intensity and by compensation between traits. Plant number was only reduced in two locations where drought was present in the fall. Under moderate stress, greater reduction in plant and spike number was associated with a smaller reduction in the number of grains per spike and grain weight. It is interesting to note that test weight was very little affected, in all locations, probably because of smaller grains having a better packing efficiency.

Table 1. Average grain yield of winter wheat cultivar trials, with and without irrigation, southern Romania, 2002.

Location	Average yield with irrigation	Average yield without irrigation	Percent-age yield reduction
Caracal	8560	5601	34.6
Marculesti	4716	3075	34.8
Teleorman	5963	3594	39.8
V. Traian	6941	3794	45.3
Fundulea	4858	1918	60.5
Simnic	(8560)	380	95.6

Yield variation among cultivars, expressed as percentage from the average yield of the trial, was larger under stress than under irrigation (39% vs. 26%). Average yield reduction caused by water stress varied among cultivars from 49% to 63% of the yield under irrigation.

The response of the main winter wheat cultivars to water availability was estimated by computing the DSI (after Fischer and Maurer, 1978), based on data from irrigated and dryland yield trials in five locations of southern Romania. The DSI showed large variation among locations and years for each cultivar, suggesting that the response to drought is very much dependent on the intensity and timing of water stress. However, significant differences among the tested cultivars were found.

Average DSI varied from lower than 0.85, in Bezostaya 1 and F948, to almost 1.15 in Delia (Figure 2). The low DSI in Bezostaya 1 was associated with low yield under irrigation. Fischer and Maurer (1978) observed that DSI and potential yield tend to be positively associated and suggested that it may be due the fact that some traits advantageous for yield potential might be inherently disadvantageous for drought tolerance. Blum (1996) noted that "as stress intensifies, high yield potential and drought resistance become mutually exclusive." In a previous study with older Romanian cultivars, we found a significant correlation between yield under irrigation and DSI (Saulescu et al., 1998). However, the 2002 data showed no such correlation. The new line F948, which had the second lowest DSI, had higher than average yield under irrigation, and several other

Table 2. Average reduction (%) in different plant traits observed in yield trials under water stress, as compared with trials under irrigation.

Location	Number of plants	Height	Grain filling duration	Number of spikes	Grains/ spike	Grain weight	Test weight
Caracal	0	14.9	15.0	7.9	10.2	14.1	0.9
Teleorman	0	10.0	19.2	12.0	12.0	11.9	1.0
V. Traian	34.9	21.0	16.9	42.5	12.2	2.9	8.1
Fundulea	4.9	28.8	24.9	6.9	28.9	29.5	3.9
Simnic	27.6	61.7	30.0	65.0	64.5	53.1	10.7
Average	**13.5**	**27.3**	**21.2**	**26.9**	**25.6**	**22.3**	**4.9**

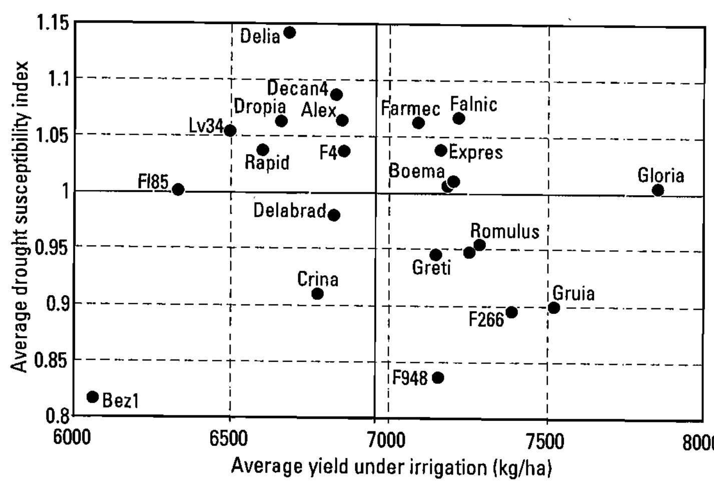

Figure 2. Average yield under irrigation and drought susceptibility index of Romanian winter wheat cultivars (average of five locations), 2002.

new cultivars combined good yield potential with relatively low response to drought. This suggests that, at the stress intensity experienced in 2002, an acceptable level of drought tolerance can be achieved in high yielding wheat through selection and testing under both irrigation and water stress.

At Fundulea in 2002, we had the opportunity of comparing the performance under severe drought of several cultivars bred in other countries with that of locally bred cultivars. A first trial included several cultivars from France and Hungary, along with Romanian checks. As seen in Figure 3, although many test cultivars were competitive under irrigation, most yielded less than the checks under water stress.

Cultivars bred under different conditions can be also be compared based on the results of the 4th WWEERYT grown under water stress at Fundulea in 2002 (Figure 4). Grain yield averaged over countries of origin, as well as minimum and maximum yield for the entries originated from various countries, show that Romanian winter wheat germplasm are competitive with cultivars from Ukraine and Russia, and superior to tested cultivars from other regions, in performance under drought.

Correlations between yield under stress and other traits can be useful in designing future breeding strategies. Our 2002 data show that yield without irrigation was correlated with yield under irrigation in only two locations out of five, which had the lowest stress intensity (Table 3). Even at the highest stress intensity, good performance was not associated with low yield potential.

Only under severe stress were yields correlated with plant height under stress (r= 0.41 to 0.46). However, when correlated with normal plant height (measured under irrigation), yield under stress showed no correlation in four

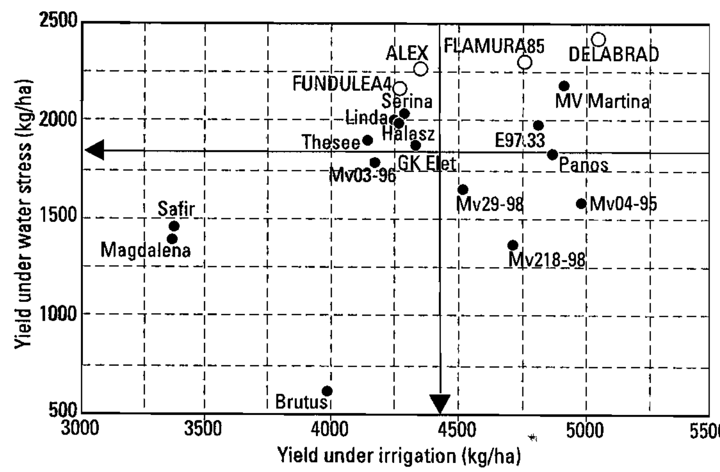

Figure 3. Grain yield of several winter wheat cultivars with and without irrigation, Fundulea, 2002.

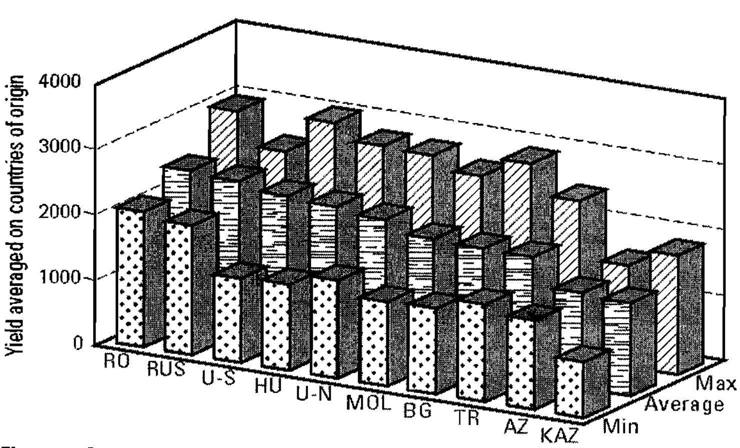

Figure 4. Grain yield (dryland) averaged over countries of origin in the 4th WWEERYT, Fundulea, 2002.

Table 3. Correlations between different traits and yield under water stress.

Location	Average yield reduction due to water stress (%)	Correlation coefficients between yield under water stress and: Yield under irrigation	Plant height under water stress	Plant height under irrigation	Heading date	Spikes per m²	Grains per spike	Grain weight
Caracal	34.6	**0.48**	0.29	-0.31	-0.12	0.20	0.11	-0.30
Teleorman	39.8	**0.80**	0.35	0.31	**-0.85**	**0.58**	n.a.	n.a.
V. Traian	45.3	0.04	0.33	0.20	**-0.40**	**0.42**	**0.40**	0.22
Fundulea	60.5	0.00	**0.46**	-0.31	**-0.46**	**0.52**	0.30	-0.17
Simnic	95.6	-0.01	**0.41**	**-0.62**	-0.04	**0.40**	**0.50**	0.15

Coefficients written in bold characters are significant at the 0.05 probability level.
n.a. = data not available.

locations and a negative correlation in the location with the highest stress. Height under irrigation was not correlated with height under severe water stress. For us this is an important observation, because it shows that it is not impossible to breed semidwarf wheat (with good lodging resistance and yield potential in favorable years) that would perform well in dry years. This conclusion is not contradicted by a comparison between tall and dwarf isolines of spring wheat, included in CIMMYT's 1st International Adaptation Trial, grown at Fundulea without irrigation in 2002 (Table 4). Although most tall isolines were superior at this level of water stress, in two genotypes dwarf isolines performed better, meaning that there is a strong interaction between height reducing genes and the genetic background.

Cultivar yields under stress were negatively correlated with date of heading (r varied from -0.40 to -0.85) in three locations where water stress intensified towards the end of the vegetative period, but showed no correlation where stress was more or less continuous (Table 3).

Among yield components, number of spikes was correlated with yield under stress in four out of five locations, and number of grains per spike in only two locations with higher stress level; differences in grain size were not associated with performance under drought (Table 3).

We defined our strategy for further improving yield under water stress based on previous experience and recent data and observations. This strategy is based on an adaptation of the framework proposed by Passioura (1977) and of the ideas developed by Richards at al. (2002), to the specificity of winter wheat in our environment. As shown by Passioura, in environments where water is limiting, yield is equal to the product of the amount of water used by the crop, the efficiency with which water is used to produce biomass, and the part of the biomass partitioned to the grains (harvest index). Every one of these components can be influenced by a variety of plant traits, some of which are relatively amenable to genetic progress (Figure 5).

In our approach, a special emphasis is put on improving early vigor, which can influence both root depth (and therefore the amount of water used) and stand establishment (and, therefore, water use efficiency, by reducing soil evaporation). Many traits, such as coleoptile length, embryo and grain size, larger seedling leaves (greater specific seedling leaf area), growth rate at low temperatures, and seed health, can influence early vigor and, therefore, are potential breeding objectives. All advantages conferred by improved early vigor can be lost during the winter if winterhardiness is not sufficient. Consequently, in winter wheat, breeding for winterhardiness can be considered as part of breeding for higher yield under water stress.

Earliness is highly desirable to ensure better transpiration efficiency (by having as much biomass accumulation as possible at lower temperatures), to conserve water before flowering (in order to have it available during grain filling) and to increase harvest index. This limits the potential use of longer vegetative period to help obtaining a deeper root system, and creates difficulties in combining earliness with a high enough level of winterhardiness.

Table 4. Yield of dwarf and tall spring wheat isolines in CIMMYT's International Adaptation Trial, Fundulea, 2002.

	Grain yield (kg/ha)	
Genotype	Tall isoline	Dwarf isoline
Nesser	510	850
Pavon	1150	830
Seri	1210	830
Kauz	1030	650
Galvez	790	780
Yavaros	480	480
Aconchi	430	370

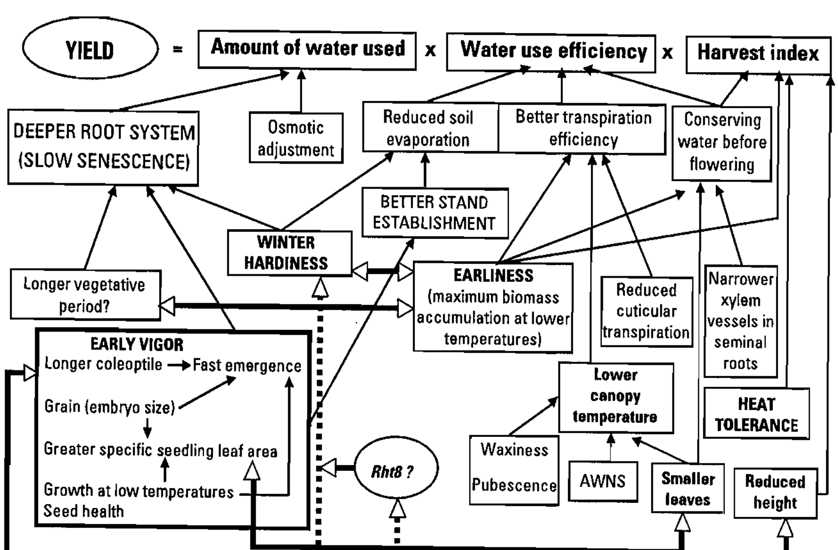

Figure 5. Strategy for improving yield under water stress in winter wheat.

Reduced height is desirable, even under drought, for a high harvest index, and is essential under favorable conditions for lodging resistance and yield potential. The association between reduced height controlled by the gene *RhtB1* (present in most Romanian semidwarf cultivars) and short coleoptile poses a difficult challenge in improving early vigor of semidwarf wheat. The use of *Rht8* gene, suggested by Richards et al. (2002), might prove to be more difficult in winter wheat, because of a possible association of this gene with lower winterhardiness.

Conclusions

- The very dry year 2002 allowed a good evaluation of drought tolerance and identification of potential parents for its improvement.
- Early heading proved to be useful for improving drought tolerance, but good tolerance was also found in some later-heading cultivars.
- Plant height under no or low water stress was not indicative of height under severe stress. Some semidwarf lines had the tallest plants and were the best performers under severe stress.

Recently released Fundulea cultivars, as well as some new lines, showed relatively good performance under water stress in 2002. Thus selection based on performance with and without irrigation seems to have been effective in improving both yielding potential and stress tolerance.

A complex breeding strategy for further improving winter wheat performance under drought has been defined; it involves increasing the amount of water used, improving water use efficiency, and optimizing harvest index under stress. Several simpler traits that are amenable to breeding, such as early vigor, slow drought induced senescence, winterhardiness, earliness, and higher canopy reflectance, are also included in this strategy.

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Selecting Drought- and Salt-Tolerant Wheat Genotypes

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The development of transgenic stress tolerant genotypes requires a more precise understanding of the morphological, physiological, biochemical, and genetic processes that mediate the adaptation of plants to single or multiple environmental stresses. Drought-tolerant plants can use several mechanisms to maintain productivity under stress conditions. Glutamate synthase (GS) accounts for most of the assimilation of NH_4+ (Miflin and Lea, 1980) under normal conditions. Glutamate dehydrogenase (GDH: EC 1.4.1.2) is present in abundance in plant tissues, but its function has not been well defined. GDH catalyzes the amination of oxoglutarate to glutamate (aminating NADH-GDH) and the deamination of glutamate to oxoglutarate (deaminating NAD-GDH). GDH could operate in either the assimilation or deassimilation of ammonium, complementing the enzymes of the glutamate synthase cycle in the synthesis of glutamate, especially under stress conditions (Yamaya et al., 1984; Srivastava and Singh, 1987). It could act in the deamination of glutamate, connecting the GDH with carbon metabolism rather than nitrogen metabolism (Robinson et al., 1991).

Aldehyde oxidase (AO) proteins in plants are a group of isozymes with different substrate specificity and tissue distribution that presumably fulfill different metabolic roles in each plant organ. Four AO proteins were observed in barley plants, of which at least three were detected in plant roots. Only one major band was observed in leaves and seeds, capable of oxidizing a number of aliphatic and aromatic aldehydes. Western blots revealed three of the AO proteins in roots (Omarov et al., 1999). The influence of salinity and nitrogen source on xanthine dehydrogenase (XDH) and aldehyde oxidase was studied in annual ryegrass. The increased need to assimilate ammonium in roots of plants under saline conditions is evident also by the enhanced GS activity and the resulting increase in organic N in annual ryegrass (Sagi et al., 1998).

In the present study, considerable changes in activity of key enzymes of the nitrogen pathway (GS, GDH, AO) induced by drought and salinity have been detected.

Materials and Methods

"Rolling leaf" (RL) wheat genotypes, which are remarkably drought-tolerant, have been developed by traditional breeding programs by crossing a range of wheat genotypes carrying the *RL1* and *RL2* genes. *RL1* and *RL2* genes were genetically identified and have been located on chromosomes 6A and 4D (Bogdanova et al., 1988). These genes contribute to the expression of adaptational traits of plants with rolling leaves that improve water balance and contribute to water conservation at high temperatures (above 36 °C) and/or drought-affected soils.

Doubled haploid RL-lines (DHL) of wheat (*Triticum aestivum* L.) were obtained by modern haploid biotechnology for culture of isolated anthers and microspores *in vitro* (Anapiyaev et al., 1999). Haploid technology allows the rapid production of homozygous constant lines from hybrid populations; if applied in breeding programs, this technology can considerably reduce the time it takes to develop new high yielding cultivars and lines (De Buyser et al., 1987).

Seeds of wheat (Grecum 476, donor of genes *RL1* and *RL2*), Kazakstanskaya 4 (check), seven DHL, and barley (cv. Steptoe) were germinated, then transferred to hydroponics in a greenhouse for further growth in 1/10 strength modified Hoagland's nutrient solution (Hoagland and Arnon, 1938). Inorganic nitrogen was provided by adding NaNO3 to the nutrient solution at a concentration of 4 mM. Osmotic shock was simulated by adding osmolyte–mannitol (0.3 M) to the nutrient solution. The pH of nutrient solution was adjusted to 6.2–6.8. Salinity was modulated by 50 mM NaCl added to the nutrient solution after seedlings transfer to hydroponics. Root and leaf samples were extracted immediately after harvesting.

Enzyme assays

Optimum conditions of buffer, pH, substrate concentrations, etc., resulting in maximum enzyme activity were determined for each enzyme to be measured and were subsequently used for assays.

Enzyme activities were directly proportional to volume of extract added in the ranges used for assays.

Crude extracts for GS assays were obtained following the method described by Rhodes (1975) as modified by Lea (1985). GDH activity in the extracts was measured in both the aminating and deaminating directions spectrophotometrically (Milton-Roy Spectronic Genesis 2), monitoring absorbance for 3 min due to NADH at 340 nm (Pahlich and Joy, 1971). Native gel electrophoresis for GDH was carried out as described by Pahlich and Joy (1971).

Results

Changes in the activity of the nitrogen assimilation enzymes GS, GDH and AO in response to salinity and osmotic shock were established. Seedlings were subjected to 50 mM NaCl and 0.3 mM mannitol as osmolyte during 2, 3, 4 weeks. Increased GS activity (200-300%) was detected for Grecum476 and DHL RL genotypes in comparison with check Kazakstanskaya 4 (data not shown). GS activity was five times higher in the leaves than in the roots. Opposite effects of salinity and drought on GS activity were observed in leaves (Figure 1). GDH may participate in ammonia assimilation under salinity and drought. GDH-aminating activity was enhanced/or induced by osmotic shock and salinity by 5-7-fold for roots (Figure 2). Decrease of activity of this enzyme was observed in leaves (Figure 3). The enhanced contribution of the root, relative to the shoot, to the provision of organic nitrogen compounds to sustain plant growth under stress is an important characteristic of stress-tolerant plants. Salinity and drought enhanced activities of AO were more pronounced in the roots than in the shoots for stress tolerant RL wheat genotypes. For stress sensitive genotypes enhanced AO activity was detected in the leaves rather than in roots (Figure 4).

Discussion

The major pathway for the assimilation of ammonium by higher plants (Lea et al., 1990; Oaks, 1994) involves the glutamate synthase cycle, including the combined actions of glutamine synthetase (GS: EC 6.3.1.2) and glutamate synthase (GOGAT: EC 1.4.1.13). The products of this cycle are usually glutamate (GLU) and

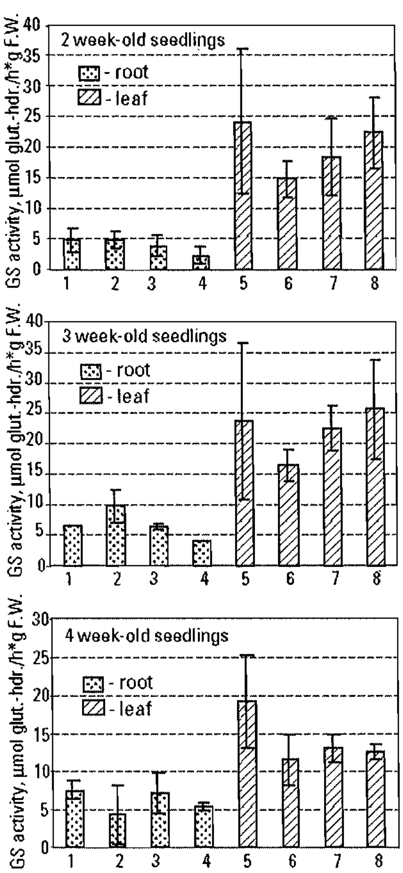

Figure 1. GS activity (µmol glutamyl-hydroxamate /h*g F.W.). 1.,3.,5,7 - control: 2,6 - salinity (50 mMNaCl):4,8 - drought (0.3 mM mannitol).

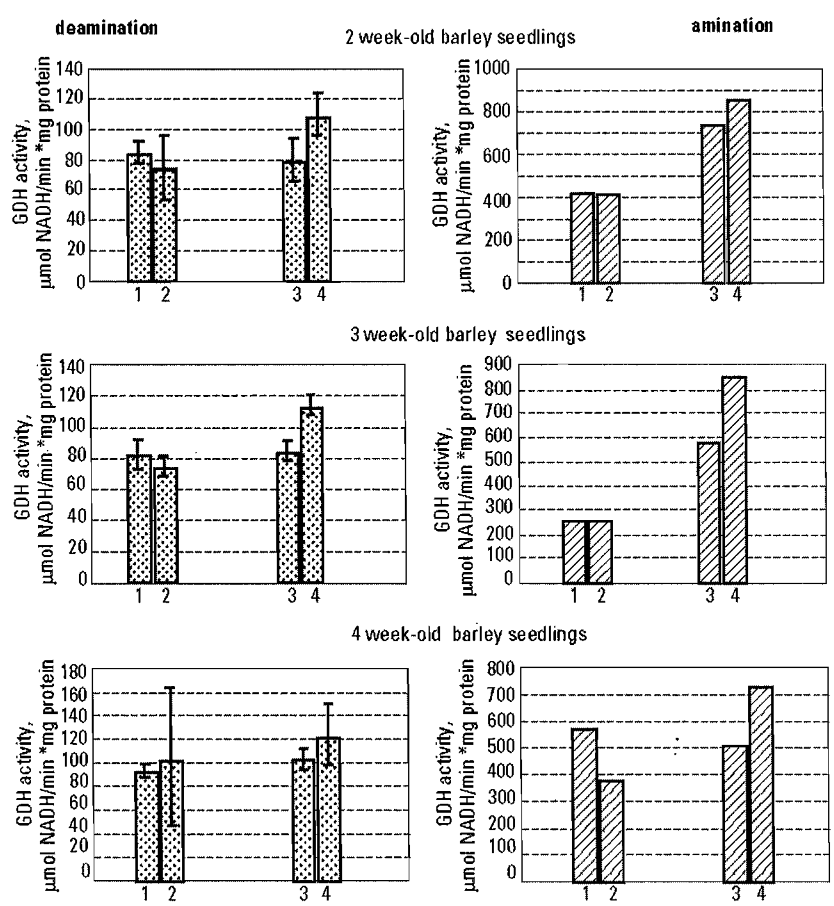

Figure 2. GDH activity (deamination, amination) in root of barley seedlings (cv. steptoe) under salinity (50 mM NaCl) and drought (0.3 mM mannitol): 1,3 -control; 2 - salinity, 4 - drought.

glutamine (GLN) which are loaded onto the xylem sap by xylem parenchyma cells and transported to the shoot of the plant (Figure 5). MDH-GOT catalyses the deamination of glutamate without ammonium accumulation. The activity of this enzyme complex in cereals was 100-fold higher than the activity of the GDH deamination reaction (Koldasova et al., 1977). The level of activity of GS, GDH, and MDH-GOT complex (malate dehydrogenase-glutamate-oxaloacetate aminotransferase) may play an important role in the detoxification of products of protein degradation resulting from stresses: salinity, drought, infection. Plants with high activities of GDH and MDH-GOT survive better and maintain high productivity (Tsvetkova, Gilmanov, 1995; Koldasova et al., 1977).

AO proteins in plants are a group of isozymes with different substrate specificity, tissue distribution and presumably fulfilling different metabolic roles in each plant organ. Four AO proteins were observed in barley plants, of which at least three were detected in plant roots while only one major band was observed in leaves and seeds, capable of oxidizing a number of aliphatic and aromatic aldehydes. Western blots revealed three of the AO proteins in roots (Omarov et al., 1999).

It is expected that the plant tissues should share some common mechanism to tolerate salinity and drought, because in nature, too, increased drought tolerance of plants is often associated with increased salt tolerance (cross tolerance). Therefore, the tissue tolerant to NaCl might also be a prospective material to screen for drought tolerance (Nabors, 1990). Experiments with different plant genotypes have already indicated that tissues can cross tolerate diverse type of stresses if previously adapted to certain other stress (SabbahandTal, 1990; Sumaryati et al., 1992).

Conclusions

The early recognition of stress enhanced enzymes of nitrogen assimilation could be used to select stress tolerant plants at early stages of plant development. The levels of active GS, GDH, and MDH-GOT may play an important role in the detoxification of products of protein degradation taking place during abiotic and biotic stress conditions such as salinity, drought, insect, and fungi attacks. Plants with high activities of GS, GDH, AO survive better and maintain high productivity. Rapid and simple determination of these adaptational changes in the activity of key enzymes of nitrogen metabolism can be used as biochemical markers for screening of cereal drought- and salt-tolerant genotypes.

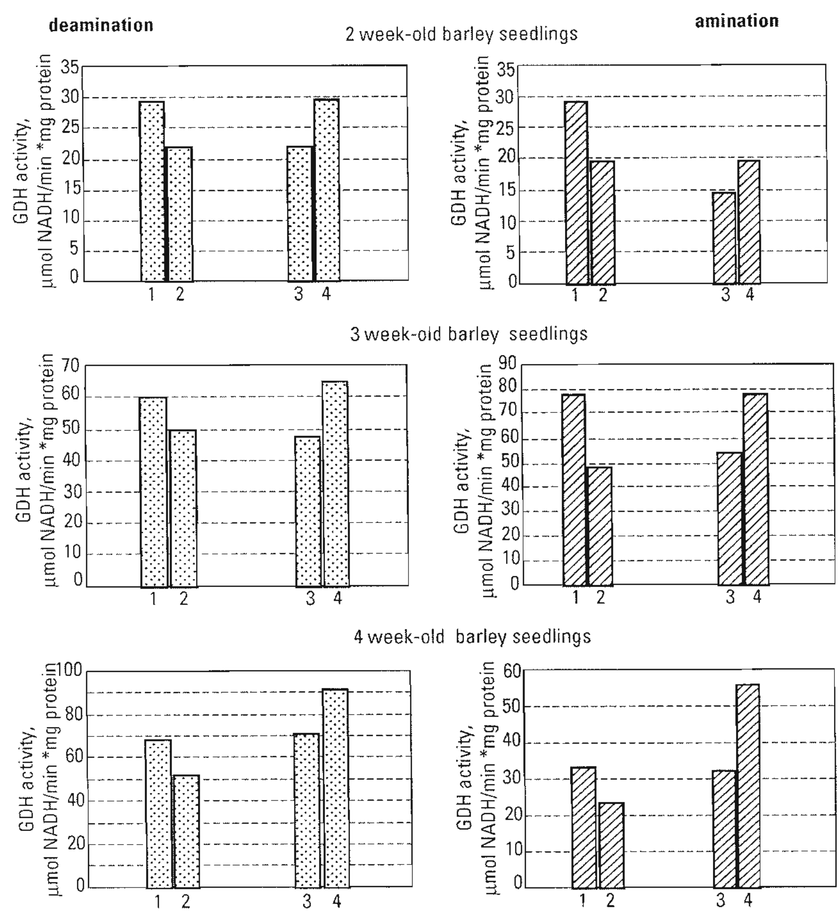

Figure 3. GDH activity (deamination, amination) in leaf barley seedlings (cv. steptoe) under salinity and drought :1,3 - control: 2 - salinity (50 mM NaCl): 4 - drought (0.3 mM mannitol).

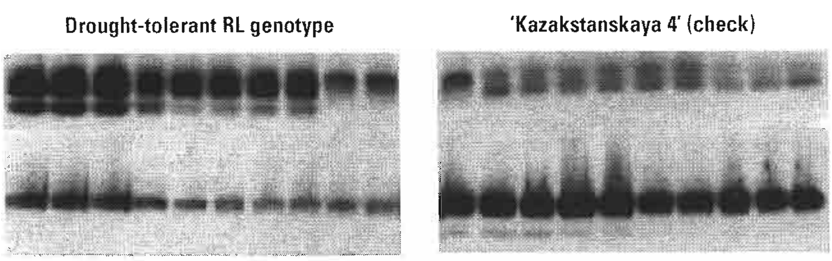

Figure 4. Native PAGE of aldehyde oxidase (AO) proteins of wheat roots and leaves. Aldehyde oxidase activity was determined using indole-3-aldehyde as a substrate.

Drought- and salt-tolerant crops can and do use alternative mechanisms of nitrogen assimilation in roots to maintain pro
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Acknowledgments

We are grateful to E.D. Bogdanova and B.B. Anapiyaev for providing the wheat cultivars and DHL.

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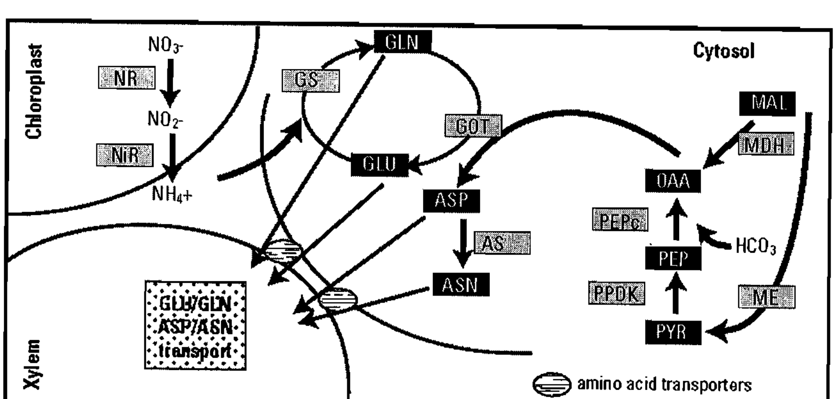

NR - nitratye reductase; NiR - nitrite reductase; GS - glutamine synthetase; As - aspartate synthetase; GOT - glutamine-oxaloacetate transaminase; PEPc - phosphoenolpyruvate carboxylase; PPDX - Pyruvate, phosphate dikinase; MDH - malate dehydrogenase; ME - malic enzyme; GLN - glutamine; GLU - glutamic acid; ASP - aspartic acid; ASn - asparagine; MAL - malate; OAA - oxaloacetate; PEP - phosphoenolpyruvate; PYR - pyruvate.

Figure 5. Pathway for nitrogen assimilation in plants. An important element that increases performance under stress conditions is the continued activity of these enzymes.
The major pathway for ammonium assimilation by plants (Lea and Miflin, 1974; Stewart et al.,1980; Lea et al.,1990; Oaks, 1994) involves the glutamate synthase cycle including the combined actions of glutamine synthetase (GS: EC 6.3.1.2) and glutamate synthase (GOGAT: EC 1.4.1.13). The products of this cycle are usually glutamate (GLU) and glutamine (GLN), which are loaded onto the xylem sap by xylem parenchyma cells and transported to the shoot of the plant. This pathway, however, is considerably altered under stress conditions (Cramer and Lips, 1995).

Control of Cold Hardiness in Spring and Winter Cereals Vernalized and Acclimated under Field Conditions

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Abstract

Low-temperature (LT) stress is a major limiting factor of plant survival in cold regions of Iran. To cope with freezing stress, winter cereals regulate their development through adaptive mechanisms that are responsive to temperature and photoperiod. The objective of this study was to clarify the relationship between vegetative/reproductive transition and control of freezing tolerance in spring- and winter-habit wheat (*Triticum aestivum* L. em. Thell), barley (*Hordeum vulgare* L.), and rye (*Secale cereale*) cultivars in plants vernalized and acclimated under field and controlled conditions. Five wheat, three barley, and one rye cultivars with different vernalization response and photoperiod sensitivity were planted in the field at the Maragheh Dryland Agricultural Research Institute (DARI) (37°15′N, 46°15′E; 1720 m) in Iran and vernalized and acclimated during growing season in 2002-2003. One spring barley cultivar was grown at 4ʃC under 8 h short day (SD) and 20 h long day (LD) photoperiods for various acclimation periods up to 98 d under controlled conditions.

Final leaf number (FLN) and growth of shoot apex were determined at intervals throughout the vernalization and acclimation periods to measure vernalization saturation and phenological development, respectively. The FLN of spring-habit cultivars did not change when they were grown at temperatures in the vernalization range, indicating that these cultivars do not have a vernalization requirement. In contrast, a significant decrease in FLN and delayed double ridge (DR) formation indicated that vernalization response delayed phenological development in the winter-habit cultivars.

Low temperature tolerance, as measured by LT_{50}, was determined during plant acclimation in the fall and winter seasons of 2002-2003. The plants began to acclimate at a rapid rate, producing a curvilinear relationship between freezing tolerance and days of acclimation. The winter-habit cultivars reached their maximum freezing tolerance as vernalization saturation occurred. The maximum range in cultivar LT_{50} was observed at vernalization saturation point. The spring-habit cultivars with no vernalization requirement, which had already entered the reproductive phase (double ridge formation), had only a limited ability to acclimate; they reached their maximum level of cold tolerance very quickly, once they were exposed to acclimation temperature. However, the very SD sensitive barley delayed DR formation by 4 of December compared to the less SD sensitive barley cultivar, which formed DR very soon after planting on 27 of October. This delay in phenological development of SD sensitive barley plants grown under field or controlled conditions was reflected in increased expression of LT tolerance. From these results it is concluded that vegetative/reproductive transition corresponds to the loss of freezing tolerance.

Low-temperature (LT) stress is a major factor limiting plant survival. To properly time flowering and cope with LT stress, winter cereals regulate their development through adaptive mechanisms that are responsive to day length and temperature. Photoperiod and vernalization requirements are the two major mechanisms that control the transition from the vegetative to the reproductive phase.

Vernalization is defined as the acceleration of the ability to flower by a chilling treatment (Chouard, 1960). On LT exposure, vernalization-requiring plants continue to reduce their final leaf number (FLN) up to the point of vernalization saturation (Wang et al., 1995). Vernalization requirement is critical to winter plants as it prevents transition to the reproductive phase in regions with cold winters. Fulfillment of vernalization requirement has been suggested for loss of LT tolerance of over-wintering cereals (Roberts, 1990).

Day length is one of the most important environmental variables that influence the flowering of plants. Length of day affects apical morphogenesis, leaf production, tillering, and other developmental processes in cereals (Kirby and Appleyard, 1980). Long day (LD) accelerates floral initiation and heading by reducing the number of leaves in vernalized or spring plants (Pinthus and Nerson, 1984). Under short day (SD) regimes, double ridge (DR) formation is delayed (Lucas, 1972) in sensitive genotypes, and the plants produce more leaves rather than a reproductive inflorescence (Holmes, 1973) until a genetically determined maximum leaf number is attained (Pinthus, 1985).

Initiation of floral primordia, which is determined by the interplay of the response of the genotype to daylength and temperature, determines the final number of leaves produced by the main shoot (Hay and Kirby, 1991). Transition from the vegetative to the reproductive phase can be determined by recording FLN or by dissection of the plant crown to expose the shoot apex.

Low temperature acclimation in cereals is a cumulative process characterized by a rapid initial LT response followed by a gradual reduction in rate of change to the point of vernalization saturation (Fowler et al., 1996). If transition from the vegetative to the reproductive phase is the critical developmental switch that initiates the down-regulation of LT-induced genes, photoperiod and vernalization responses should interact to determine the level of LT tolerance gene expression (Mahfoozi et al., 2001a). Consequently, the objective of the present study was to clarify the relationship between vegetative/reproductive transition, which is regulated by photoperiod and vernalization responses in winter and spring cereals vernalized and acclimated under field or controlled conditions.

Materials and Methods

Phenological development and LT tolerance were determined for Norstar Azar2, Sardari winter wheat, Kohdasht and Zagroos spring wheat, Puma rye, Dobrinya and Kold winter barley, and Dicktoo and Rihane-03 spring barley cultivars vernalized and acclimated under field conditions at the Maragheh Dryland Agricultural Research Institute (DARI) (37°15′N, 46°15′E; 1720 m) in Iran. These cultivars were planted on 7 October in 2002. All cultivars were subjected to LT acclimation from 27 of October to 12 of February and sampled at 14 weekly intervals. Soil temperature at 5 cm depth and minimum air temperature at shelter height was recorded at the Maragheh station from September 2002 to end of March 2003. Under controlled conditions, the very SD sensitive Dicktoo barley was subjected to two photoperiod (8 h and 20 h day length) treatments and twelve 4° C acclimation periods (0, 7, 14, 21, 28, 35, 42, 49, 56, 70, 84, and 98 d). FLN and LT_{50} were determined for each treatment.

Phenological development

Two methods were used to determine the stage of phenological development: (1) dissection of the plant crown to reveal shoot apex development, and (2) the FLN procedure described by Mahfoozi et al. (2001). Therefore, shoot apices of the plants grown both in the field and hydroponic tanks were dissected and photographed for the establishment period and each acclimation period to determine when the DR stage occurred. Growth conditions and acclimation times for the FLN study were the same as those described for LT acclimation.

To determine FLN number on the main shoot, at 0 d treatment (without exposing to low temperature) and at the end of each vernalization period, pots containing two plants grown in the field or under controlled conditions were moved to 20°C until flag leaf emergence and leaves numbered on the main stem. Transition from the vegetative to the reproductive phase was considered complete when the FLN became constant (Delecolle et al., 1989).

Low-temperature tolerance

LT_{50} (temperature at which 50% of the plants are killed by LT stress) of each genotype was determined for each treatment. The experimental design for LT tolerance (LT_{50}) was a 10 (genotype) x 14 (acclimation period) factorial in a two-replicate randomized complete block design (RCBD) under field conditions at the Maragheh station during the growing season of 2002-2003. Under controlled conditions, Dicktoo SD sensitive barley cultivar with 12 acclimation periods and two photoperiod regimes (8 h and 20 h) was tested using a randomized block design with three replications.

For LT_{50} determination under field conditions, plants were collected from the field at the end of each acclimation and vernalization periods started from 27 of October in 2002. The procedure outlined by Limin and Fowler (1988) was used to determine the LT_{50} of each genotype at the end of each LT acclimation period for plants collected either from field or controlled conditions.

Germinated seeds were then grown at 20ʃC under 8 h (SD) or 20 h (LD) day lengths at a light intensity of 320 µmol m^{-2} s^{-1} for 14 d before being exposed to corresponding LD or SD conditions at 4ʃC for LT acclimation.

Results and Discussion

Soil temperature at 5 cm depth and minimum air temperature (at shelter height) recorded at the Maragheh station show that there were favorable weather conditions for plants to acclimate and vernalize in the field during the 2002-2003 growing season (Figure 1).

When exposed to LT acclimating temperatures, Norstar, Azar2, and Sardari winter wheat, and Dobrinya winter barley reduced their leaf number from 26 to 12.0, 21 to 10, 16 to 9, and 19 to 11, respectively (Figures 2 and 5), indicating that these cultivars are winter-habit genotypes with a vernalization requirement (Wang et al., 1995; Mahfoozi et al., 2001a). Spring-habit cereals, such as Rihane-03 barley and Zagroos and Kohdasht spring wheat cultivars, did not reduce their FLN when grown at acclimation temperatures under field conditions. Spring-habit plants reached their minimum leaf number very shortly after planting, indicating that these cultivars do not have a vernalization requirement (Figures 2 and 5).

Dicktoo produced 26 leaves when grown in a controlled environment under continuous SD and 8.0 leaves under continuous LD conditions at constant 20°C (never exposed to 4°C); this indicates that it is also a very SD responsive spring-habit cultivar (Figure 8). At 4°C for 98 d, Dicktoo produced 6.5 more leaves under SD than LD conditions indicating that, although there were differences in magnitude as measured by FLN, sensitivity to SD was also expressed under both warm and cold temperatures (Figure 8). Further evidence that Dicktoo barley does not have a vernalization requirement can also be drawn from the fact that it did not decrease its FLN when exposed to low temperature. It appeared that Dicktoo increased its FLN during acclimation rather than decreasing it (Figure 5); however, more replicates for FLN are required to determine the exact pattern of FLN production under field conditions.

Initiation of floral primordia is determined by genotype and environment interactions, which in turn determine the FLN produced by the main stem (Hay and Ellis, 1998; McMaster 1997). Fulfilment of the LT requirement (vernalization saturation), which is also an indication of the point of transition from the vegetative to the reproductive phase (Robertson et al., 1996; Mahfoozi et al., 2001a and 2001b), is considered complete once the cold treatment no longer reduces FLN (Wang et al., 1995; Mahfoozi et al., 2001a). FLN measurements indicated that vernalization saturation was achieved between 18 to 25 of December for Norstar winter wheat, 18 of December for Puma winter rye, 4 to 11 of December for Sardari and Azar2 Iranian winter wheat cultivars (Figure 2), and between 4 to 11 of December for Dobrinya winter barley (Figure 5).

Double ridge formation is another clear indication that transition to the reproductive phase has begun (McMaster, 1997). Double ridge formation was apparent within a short time after planting (about 3 November) in Kohdasht and Zagroos spring wheat cultivars

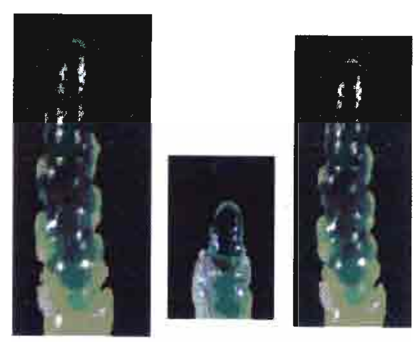

Figure 3. Phenological development (apical development) of Norstar, Sardari, and Azar2 winter wheat and Kohdasht and Zagroos spring wheat cultivars grown from 9 of Oct to end of March at the Maragheh agricultural research station, Iran. Comparative phenological advancement to double ridge formation is illustrated.

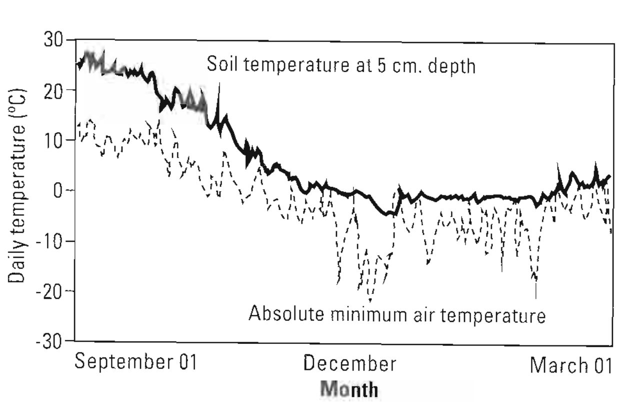

Figure 1. Soil temperature at 5 cm depth and minimum air temperature as recorded at the Maragheh agricultural research station, Iran, 2002-2003.

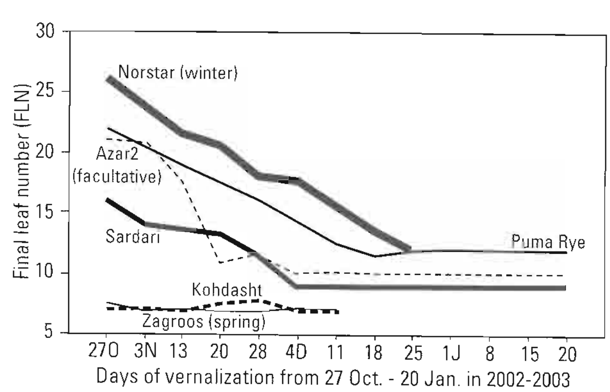

Figure 2. Final leaf number of Norstar, Sardari, and Azar2 winter wheat, Kohdasht and Zagroos spring wheat, and Puma winter rye vernalized under field conditions at the Maragheh agricultural research station, Iran, from Oct 27 to Jan 20, 2002-2003.

(Figure 3). In contrast, it was not observed until around 6 of March in rye and 4 of April in the winter wheat cultivars (Figure 3). Although minimum leaf number was reached about 18-25 December in winter wheat and rye cultivars, DR was not visible, indicating that the signal for reproductive transition occurred long before the physical manifestation of DR formation under the LT growth conditions of this experiment. These observations show conclusively that floral initiation occurs before DR formation, as suggested by Delecolle et al. (1989). Similarly, in Rihane-03 spring barley, DR was reached very soon after planting (about 27 October), while in Dobrinya winter barley DR was visible about 5 December (Figure 6). Also, in SD sensitive Dicktoo spring barley DR was visible very late (about 4 December), indicating that short day sensitivity delayed the vegetative / reproductive transition under field conditions (Figure 6). Similarly, under controlled conditions, Dicktoo plants grown under LD and SD formed DR within10 d after planting and after 70 days of acclimation, respectively (data not shown).

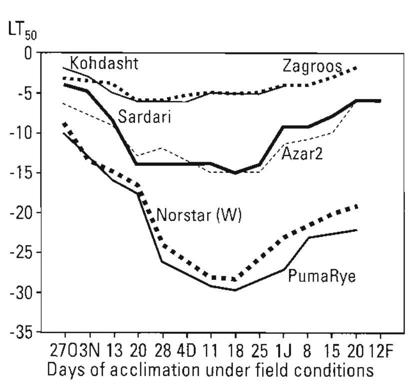

Figure 4. Low-temperature tolerance of Norstar, Sardari, and Azar2 winter wheat, Kohdasht and Zagroos spring wheat, and winter Puma rye acclimated under field conditions at the Maragheh agriculture research station, Iran, from Oct 27 to Feb 12, 2002-2003.

Low-temperature tolerance

Winter wheat, barley, and rye cultivars grown under field conditions started to acclimate at a rapid rate. The rate of change in LT tolerance then gradually slowed until LT tolerance began to be lost. Norstar wheat and Puma rye reached their maximum LT tolerance between 18 to 25 December, which is about the same time as vernalization saturation occurred (Figures 2 and 4). Azar2 and Sardari obtained maximum LT tolerance about 4 December, which is also about the same time as vernalization saturation occurred (Figures 2 and 4). This indicates that the signal of the end of the vegetative phase, as indicated by FLN measurements (Figures 2 and 4), corresponds to the start of LT tolerance loss.

Kohdasht and Zagroo spring wheat cultivars formed DRs by 13 November (Figure 3), and thus had a limited ability to acclimate to low temperature. Their maximum LT tolerance was achieved soon after planting, and they quickly lost most of their LT tolerance (Figure 4).

Rihane-03 spring barley also had limited ability to cold-acclimate

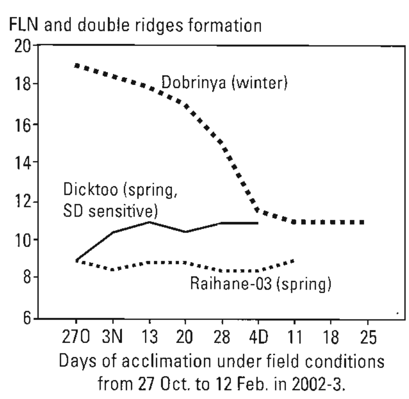

Figure 5. Final leaf number (FLN) of Dobrinya winter barley, Rihane-03 spring barley with no vernalization requirement, and Dicktoo very short day sensitive spring barley vernalized under field conditions at the Maragheh agricultural research station, Iran, from Oct 27 to Dec 25, 2002-2003.

(Figure 7), as it had already reached its reproductive phase and formed DRs around 26 October 2002 (Figure 6). However, the SD sensitive spring Dicktoo acclimated to a colder temperature, and its LT_{50} was similar to Dobrinya and Kold winter barley cultivars (Figure 7). Higher level and longer duration of the expression of LT tolerance in Dicktoo under field conditions appears to be the result of an extended vegetative period that delayed the transition to the reproductive phase as illustrated in Figures 5 and 6.

The results from field conditions were similar to those found under controlled conditions for Dicktoo (Figures 8 and 9). Under controlled conditions, Dicktoo acclimated to a lower temperature and retained its LT tolerance for a longer period of time under SD compared to LD (Figure 9). The increased expression of LT tolerance in Dicktoo under SD (Figure 9) was associated with the delayed transition from the vegetative to the reproductive phase (Figure 8).

The results of this study show that photoperiod response and vernalization requirements interact with temperature to influence the rate of phenological development and the expression of LT tolerance genes. They also verify that vernalization requirement (Fowler et al., 1996; Mahfoozi et al., 2001a)

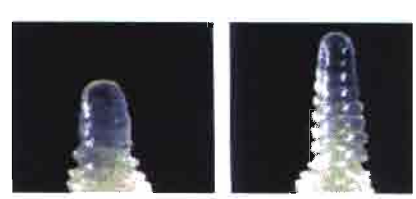

Figure 6. Phenological development (apical development) of Dobrinya winter barley and Rihane-03 spring and Dicktoo a very short day sensitive spring barley cultivars grown from 9 of Oct to end of March at the Maragheh agricultural research station, Iran, 2002-2003. Comparative phenological advancement to double ridge formation is illustrated.

and SD photoperiod sensitivity (Mahfoozi et al., 2000 and 2001b) allow LT tolerance genes to be expressed for a longer period of time at temperatures in the LT acclimation range. These results demonstrate that any factor that delays the transition from the vegetative to the reproductive phase can increase the duration of expression of LT tolerance genes. It is concluded that the transition from the vegetative to the reproductive phase corresponds to the loss of LT tolerance in cereals under field and controlled conditions.

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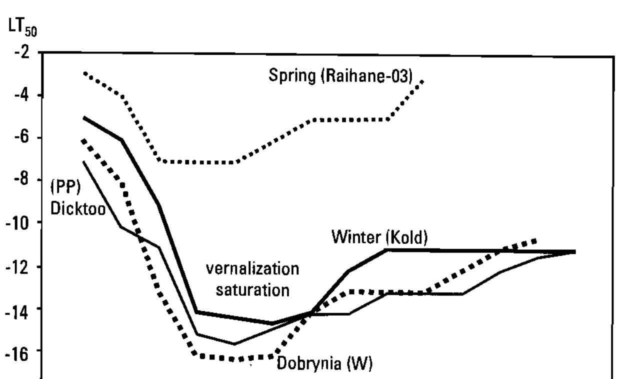

Figure 7. Low-temperature tolerance of Dobrinya and Kold winter barley, Rihane-03 spring barley and Dicktoo very short day sensitive spring barley acclimated under field conditions at the Maragheh agricultural research station, Iran, from Oct 27 to Feb 12, 2002-2003.

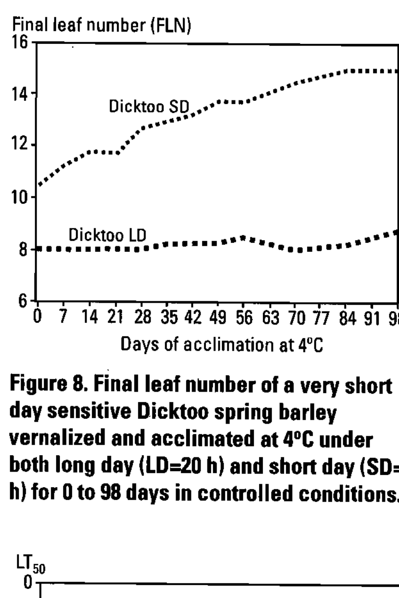

Figure 8. Final leaf number of a very short day sensitive Dicktoo spring barley vernalized and acclimated at 4°C under both long day (LD=20 h) and short day (SD=8 h) for 0 to 98 days in controlled conditions.

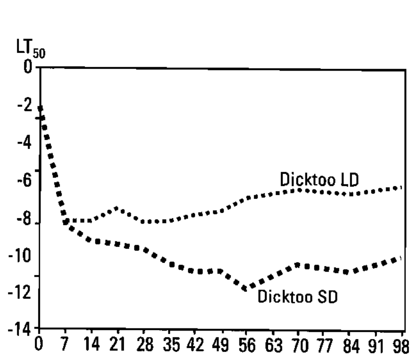

Figure 9. Low-temperature tolerance of Dicktoo SD sensitive spring barley acclimated at 4°C for 0 to 98 days under both long day (LD=20 h) and short day (SD=8 h) in controlled conditions.

Winter Wheat's Main Survival Mechanisms in Siberia: Low Metabolic Rate and High Frost Tolerance

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The need to develop winter wheat in areas such as Siberia is obvious for three reasons. First, winter wheat yield is double that of spring wheat in Russia. Second, winter wheat is, as a rule, harvested in dry weather at the end of summer, which makes it possible to produce high quality food grain at a low cost. In contrast, spring wheat matures later and is often harvested in rainy weather. Third, cultivation of winter wheat makes labor in fields more uniform.

Sources of genetic diversity and breeding methods were required to develop winter wheat in Siberia. These were based on analysis of the data in the literature and ours. Data on the physiology, biochemistry, and genetics of the winter hardiness trait were analyzed to support our studies on winter hardiness. Based on data on plant metabolism in autumn, winter, and spring, it was concluded that the lower the wheat plants' metabolic rate, the higher their frost tolerance (Tumanov, 1979) and their resistance to other damaging effects of winter (Barashkova and Vinogradova, 1988).

This conclusion enabled us to develop a method of breeding for high winter hardiness. First, plants were selected for their ability to maintain a low metabolic rate during winter. Second, they were selected for high frost tolerance. Grassy plants can barely survive during winter because they are unable to maintain a low metabolic rate under thick snow cover on thawed soil. They suffer from the absence of soil temperatures moderately below zero. Another unfavorable area is the steppes, which are covered by a very thin layer of snow because of strong winds. As a result, soil temperature is reduced in winter.

Material and Methods

In our studies on winter wheat, we found that the activities of endogenous growth regulators, plant morphology before winter, winter hardiness, and autumn weather were closely related. It is known that sunny autumn weather with wide daily fluctuations in air temperature promotes the formation of small cells and causes a reduction in the size of above-ground plant parts. Plants thus acquire high winter hardiness. Cloudy, warm autumn weather has the opposite effect (Tumanov, 1979). Using biotests, we observed a relative dominance of the activities of endogenous growth inhibitors in favorable sunny autumn weather and relative high activity of growth stimulators in cloudy autumn weather.

Exogenous treatment of seedlings with growth inhibitors (e.g., abscisic acid) led to the formation of plants showing the morphology and winter hardiness of those grown in sunny autumn. In contrast, application of gibberellic acid allowed us to model autumn conditions unfavorable for winter wheat. This allowed us (1) to develop the first step of a new breeding method, namely, to reproduce autumn conditions extremely unfavorable for the development of plants before they overwinter under thick snow cover (this breeding was conducted for two consecutive generations); and (2) to involve as parents a great number of winter wheat cultivars that were, at least to some extent, able to overwinter in the forest-steppe area of Siberia. These were primarily cultivars developed in sites of Krasnodar and Mironovka.

Hybridization was the second source of parental material. One group of hybrids was obtained by crossing wheat lines derived from the cultivar Ulianovka with lines selected using gibberellic acid. Ulianovka survived two winters in sowing boxes kept in an unheated greenhouse without snow. During winter, these plants experienced very sharp (from -10 to -37°C) day-night fluctuations in temperature due to the daytime greenhouse effect.

The other group of genotypes was produced by crossing cultivars developed in Krasnodar and Mironovka with inbred clones of *Agropyron glaucum*. The clones were obtained after five generations of inbreeding, which considerably reduced the heterozygosity of *A. glaucum*. As a result, F_{6-7} hybrids were phenotypically stable, had the appearance of true wheat, and were highly winter hardy under thick snow cover (Chekurov et al., 1992).

The two groups of hybrids were not exposed to gibberellic acid during the first step of breeding. Another source of parental material was the winter wheat collection at the All-Union Institute of Plant Breeding, St. Petersburg. These were the most tolerant genotypes, chosen from about 15,000 entries that had been tested in winter in the forest-steppe of Siberia for 3-5 years. Their sowings were not exposed to gibberellic acid.

Selection for frost hardiness was carried out in two climatic areas, the steppe and forest-steppe. Autumn weather in the steppe favors the development of high frost hardiness. Sunny weather and wide daily fluctuations in air temperature prevail. The offspring that survived in the steppe were subjected to more intense selection. They developed under cloudy autumn weather in the forest-steppe and under additional shading, which strongly suppressed frost hardiness. Then the boxes were transferred from outdoors to refrigerators, where temperature was decreased by 3°C every 2 days till it reached -24°C. Temperature was maintained at -24°C for 3 days. Thereafter, it was increased stepwise 3°C every 2 days (Chekurov et al., 1998).

Results

Before discussing the results, observations demonstrating the co-relation between growth regulator activity in plants during autumn and their winter hardiness will be considered.

Three cultivars of contrasting winter hardiness under conditions of Siberia are given as examples: Ulianovka, with high winter hardiness; Mironovskaya Yubileinaya, moderate winter hardiness; Kavkaz, low winter hardiness. Treatment of plants in plots altered the relative proportion of endogenous plant regulators (Table 1). It is clear that the earlier it became biased in favor of growth inhibitors (treatment with abscisic acid and the retardant chlorcholinchloride), the greater the increase in winter hardiness. The first treatment time was at the beginning of plant development, in autumn (at the one-leaf stage). The treatment affected the morphology of the forming plant (data not shown) and its winter hardiness. A certain morphology and relative proportion of growth regulators were observed in plants grown in plots untreated at time 1. Treatment of these plants allowed us to demonstrate the co-relation between plant winter hardiness and the relative proportion of growth regulators, irrespective of morphology. When treatment was biased in favor of inhibitors, winter hardiness increased in all plants. The bias in the relative proportion caused by gibberellin significantly reduced winter hardiness.

The experiments showed that autumn weather had a similar effect on morphology and winter hardiness in different years and with different relative proportions of growth regulators. Thus, treatment of seedlings with gibberellic acid simulated unfavorable conditions for plants in autumn. We decided to use gibberellic acid as a strategy for intense selection of plants in autumn from one year to another. We found that applying this treatment for two consecutive generations increased winter hardiness in the survivors. Table 2 shows some of the experimental results obtained on plants selected from cultivars Krasnodar and Mironovka (Chekurov et al., 1992).

In this way, we identified lines in which 85-100% of plants vernalized in the forest-steppe. However, not more than 40% of these cultivars were able to vernalize. This increase in tolerance during vernalization may protect plants under thick snow cover. It should be noted that snow thickness varied sharply from one part of the field to another and over the years. Consequently, additional selection was required for high frost hardiness. This was achieved by subjecting genotypes that had been selected in the forest-steppe to selection for survival (Table 3) (Chekurov and Kozlov, 1992, 1998).

Table 1. Vernalization under forest-steppe field conditions of winter wheat plants related to the time of their treatment with growth regulators.

Cultivar	Treatment time*	Vernalized plants** (%)			
		Control	ABA	CCC	GA_3
Mironovskaya	1	59.9	92.0$^{x, xx}$	78.5^{xx}	45.1$^{x, xx}$
Yubileynaya	2	58.0	87.4^{xxx}	77.8^{xxx}	36.4^{xxx}
Ulianovka	1	75.9	94.0^{x,xx}	84.1^{xx}	43.5^{xx}
	2	76.5	88.7^{xxx}	81.3^{xxx}	39.6^{xxx}
Kavkaz	1	42.8	86.8^{x,xx}	74.7^{x,xx}	32.3^{x,xx}
	2	42.3	68.8^{xxx}	61.7^{xxx}	25.3^{xxx}

* Treatment time 1, at the first leaf stage; treatment time 2, before the first autumn frosts begin and snow covers the new plots.

** ABA: 50 mg/l (abscisic acid); CCC: 2 mg/l (chlorcholinchloride); GA_3: 100 mg/l (gibberellic acid). The significance of the differences as the percentage of plot vernalization: x: between treatment time 1 and 2; xx: between treatment time 1 and the control; xxx: between treatment time 2 and the control (P= 0.95).

The size of all the genotype groups decreased mostly in the first two generations. A comparison of groups I and II emphasizes the importance of continued low metabolic rate during vernalization for plant survival. The pattern of decrease in the size of group III underlines the importance of selecting both parents for high winter hardiness in developing highly winter hardy lines among their offspring. Although the parents of the WWH hybrids were not subjected to such preliminary selection, we obtained virtually the same results. This convincingly demonstrates the value of *A. glaucum* as a donor of winter hardiness in wheat.

Only 12 genotypes from the world winter wheat collection in the 1980s survived after three generations in the steppe. This indicates that the sources of parental diversity we used for the winter hardiness character are valuable.

The cultivar Bagrationovskaya was derived from Mironovskaya Yubileinaya by way of experiments using gibberellin and selection in the steppe. Bagrationovskaya is the accepted standard of frost hardiness in winter wheat in Russia. One of the WWH hybrids has been designated cultivar Kulundinka. It is recommended for cultivation in South Yakutia, in the Buriat Republic.

Table 2. Comparison of winter hardiness of parent cultivars and lines selected using GA_3, forest-steppe field conditions, winter of 1984-85.

Parent cultivars*	Vernalized cultivars (%)	Number of identified lines	Number of lines and vernalization percentage** 1-64	65-74	75-84	85-100
Bezostaya 1	10.0	27	2	6	11	8
Avrora	10.0	42	2	8	20	12
Kavkaz	12.5	57	4	7	22	24
Krasnodarskaya 46	15.0	61	2	16	21	22
Krasnodarskaya 39	25.0	47	0	11	12	24
Bezostaya 2	5.0	21	9	11	1	0
Rannia 12	7.5	16	7	7	2	0
Rannia 47	30.0	40	1	19	14	6
Mironovskaya Yubileynaya	25.0	59	1	23	20	15
Ilyichevka	40.0	51	0	6	30	15
Stelutsa	35.0	16	4	12	0	0

* After 6-7 generations of re-seeding in the forest-steppe.
** F_9 generation after treating two consecutive generations with gibberrellin.

Table 3. Time course of the survival of winter wheat representing groups of three generations grown in the steppe.*

Genotype group/ Sowing year	I	II	III	*WWH*	K	Min. temp. (°C)**
	Group size, number (%)					
1985	225 (100%)	72 (100%)	622 (100%)	433 (100%)	152 (100%)	-16
1986	25 (18%)	53 (73%)	619 (95%)	294 (18%)	27 (18%)	-19
1987	18 (8%)	47 (65%)	466 (75%)	252 (58%)	12 (8%)	-34
Lines harvested in 1988	17 (7.5%)	40 (55%)	448 (72%)	247 (57%)	12 (8%)	

* Genotypes with 1-100% of plants vernalized per plot were considered survivors and planted in the next generation.
** Minimum soil temperature at a depth of 3 cm.
Note: Group I: Genotypes selected from the Russian collection, using gibberellin. Group II: Offspring of a single best spike from a group 1 plot after vernalization on thawed soil during a long winter/cold spring. This served as additional selection for duration of low metabolic rate. Group III: F_5 hybrids (from group 1 genotypes x Ulianovka-derived genotypes with increased frost hardiness). WWH: Wheat x wheat-grass F_{6-7} hybrids (*Agropyron glaucum* x cultivars selected in Russia). Parents not preselected for degree of winter hardiness. K: Genotypes (from the collection of the All-Union Institute of Plant Breeding) most resistant to forest-steppe conditions.

Thus, we demonstrated that it is feasible to produce winter wheat genotypes capable of overwintering well under thick snow cover and to develop the frost hardiness needed for overwintering in the steppe under thin snow cover. For this purpose, we found efficient sources of parental material. We developed a selection method based on the role of the relative proportion of growth regulators in plant survival, which is to maintain the minimum metabolic rate in winter wheat during overwintering.

As noted above, the fields of the forest-steppe are covered by an uneven snow layer. Accordingly, winter wheat has to develop a level of frost hardiness that meets survival requirements in the steppe. For this reason, the offspring of genotypes that survived 2-3 generations in the steppe were grown in sowing boxes under forest-steppe conditions in autumn. Subsequently, the offspring were placed in chambers where they were frozen. Soil temperature was reduced to -24°C and remained unchanged for 3 days. A summary of the results of our experiments follows (Chekurov et al., 1998).

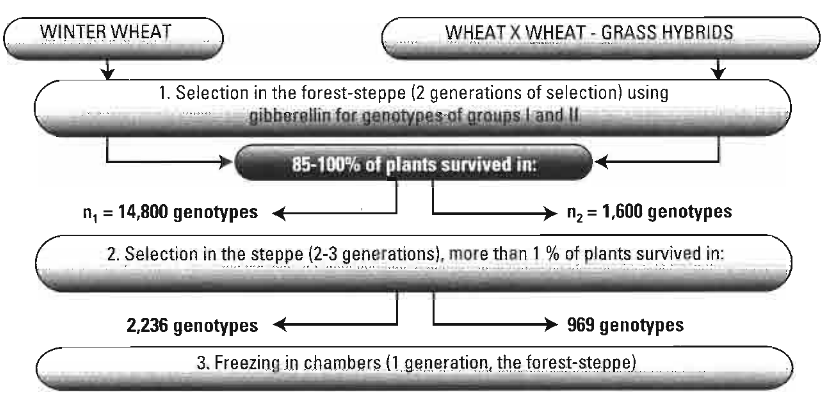
Results of selection are given in Figure 1. Results for genotypes of wheat origin are on the left, and those for wheat x wheat-grass hybrids are on the right. It was found that 85-100% of plants of genotypes of true wheat origin sown in the forest-steppe vernalized. Only 1.5% were able to develop frost resistance to the weather in this area, at a soil temperature not lower than -24°C, and tolerated this temperature continuously for 3 days.

However, of the winter wheat x inbred *A. glaucum* clone hybrids, 1,600 survived well under thick snow in the forest-steppe. Of these, 10.9% developed frost hardiness at a temperature of -24°C.

Conclusions

Taken together, the preceding results justify the following conclusions.

- The relative proportion of growth regulators is important for overwintering of winter wheat, and is influenced mostly by weather conditions during plant development in autumn.
- The morphology and capacity of plants to maintain a low metabolic rate in winter are formed under the influence of this relative proportion.
- It is feasible to considerably increase winter hardiness under thick snow using gibberellic acid.
- Intense selection for winter hardiness under thick snow cover substantially increases the proportion of genotypes able to survive in the steppe under thin snow cover and very low soil temperatures.
- It is feasible to produce genotypes able to overwinter under thick snow and develop winter hardiness in unfavorable autumn weather at -24°C and to tolerate this temperature for 3 days. The proportion of such genotypes is significantly higher among wheat x wheat-grass hybrids.
- The world winter wheat collection of the 1980s contains virtually no genotypes able to overwinter well under thin snow cover in the Siberian steppe and forest-steppe.



Number of genotypes frozen	Number of survived genotypes, %		
	0	1-79	80-100
2,236	1,348	621	227
% of n_1 = 14,800			
15.1	9.0	4.6	1.5

Number of genotypes frozen	Number of survived genotypes, %		
	0	1-79	80-100
969	165	689	175
% of n_2 = 1,600			
63.9	10.0	43.0	10.9

Figure 1. A schematic representation of the results of selection for frost hardiness among true wheat hybrids and wheat x wheat grass hybrids in the forest-steppe and chambers.

Acknowledgment

Genotypes from the collection of the All-Union Institute of Plant Breeding were kindly provided by the Wheat Testing Station in Omsk and by the Siberian Plant Breeding Institute (Novosibirsk).

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Developing Salt Tolerant Winter Wheat Varieties in Mirzachul

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Soil salinity creates unfavorable conditions for plant growth. Under the influence of salt plants accumulate intermediate metabolism products (ammonia, some amino acids, diamids, etc.) that have toxic effects (Stroganov, 1973). Due to these effects, the quality and quantity of production are diminished. Increasing yields under these conditions is of great interest. Crop improvement methods and selective ones can be applied to increase plants' salt tolerance.

Research on this problem has been done and is still being done in many states (Korenkov, Smirnov) and under the conditions of Mirzachul since 1990 (Holikov, Kushiev). Winter wheat yield potential under the conditions of Mirzachul is rather low due to different salinity levels in 90% of the soil. Climatic conditions in this region are sharply continental, with low temperatures in winter and high temperatures in summer.

The change in temperature is especially noticeable during flowering and grainset, when it reduces the quality and quantity of wheat production. For this reason, it is urgent to determine whether winter wheat production is feasible in this region. The problem needs to be solved on a scientific basis, using parental sources with the appropriate genetic traits to develop high yielding wheat varieties that can grow well under saline conditions.

To develop winter wheat varieties tolerant of salinity, we examined materials from genebank collections at IP, CIMMYT, and ICARDA, which contain the best global and local varieties. These materials were assessed based on different parameters: earliness, cold tolerance, heat tolerance, drought tolerance, and the degree of exposure to wheat diseases. Varieties that ranked high were subjected to ecological trials together with local cultivars divided into district varieties. We paid special attention to varieties that survived under extreme conditions and produced a good harvest.

In the course of our work, we selected and developed local varieties that can tolerate heat and salinity under Mirzachul conditions. Some materials selected from collections in Syria, Morocco, and Jordan were used. The close resemblance of soil and natural conditions between these countries and Mirzachul is the ground for investigation.

Materials and Methods

The experiments were conducted on soils of low and intermediate salinity in Mirzachul, which match conditions in the Syrdaria region of Uzbekistan. Field plots were provided for these experiments, and microplots in areas requiring irrigation were prepared. Two hundred wheat lines from the collection of the Scientific Research Institute of Uzbekistan were included this experiment, as well as 500 soft wheat lines from CIMMYT and ICARDA, and local varieties.

Winter wheat varieties and lines were sown in plots 2 x 25 m in size with 4 replications. Sowing density was 400 seeds per m^2, and the area where data were recorded in each plot was 1 m x 1 m.

Soils in the test plots differed according to meteorological conditions, the amount of precipitation, and the temperature regime. Test materials were agrobiologically evaluated and based on all these factors. Sowing was done manually with the help of a fixed seeding machine. Soil preparation, fertilizer application, irrigation, and crop management were conducted according to methods recommended for the given area by the wheat branch of the Scientific Research Institute of Uzbekistan. Cotton was the preceding crop. All observations were made according to the methods of UPI (Union Plant Institute) and other recommendations on growing winter wheat.

We investigated the vegetative period, disease and pest resistance, productive tillering, plant height, spike length, number of grains per spike, distance between 1-2 nodes, 1000-kernel weight, and yield potential of test varieties. Biochemical analyses were done in lab conditions according to practical chemistry methods, and coefficients of correlation were calculated.

Results

The decisive factor for raising yield potential and achieving high production is the use of new, more productive varieties, especially varieties responsive to fertilizers and irrigation, tolerant of heat and salinity. These varieties should also have high grain quality. Development of good quality, high yielding varieties requires using parental materials having the desired traits, e.g., special attention should be paid to varieties that survive extreme conditions and produce a good harvest.

Length of vegetative period is an important parameter under the conditions of Central Asia, where the temperature rises sharply when wheat grains ripen. This causes the grains to become undersized, which reduces grain quality and yield. Thus it is important to develop early-maturing varieties.

Varieties such as K-9802 from Syria combine high yield potential and earliness. Yield is a complex trait consisting of many elements. That is why we are in the process of selecting K-9802, 9821, 9851, 9924 from CIMMYT, and K-92-599 from Syria for high yield, based on the number of grains per spike (no less than 1000) and productive tillering. The soft winter wheat lines are being evaluated based on these traits. The highest level of tillering was shown by K-9813, K-9924 (CIMMYT), K-001586, and K-001606 (Turkey). Varieties from Romania and Turkey produce 1000 grains per spike. High yield potential is typical of K-9828, K-9855, K-9869 (CIMMYT), K-001283 (Romania), and K-001586 (Turkey). The following varieties are resistant to diseases and pests: K-9802, 9813, 9851, 9855, 9869 (CIMMYT), K-001586 (Turkey), K-551768, and K-92-583 (Syria) (Table 1).

High yielding, salt tolerant, and disease resistant varieties (local cultivars such as Yonbosh, Marjon, and Gairat and international materials such as K-9813, K-9924 [CIMMYT] K-92-598 [Syria], K-001586, and K-001606 [Turkey]) were selected based on their positive values and the number of traits. They were crossed and selected by individual selection, and such salt tolerant varieties as Hasan-Orif, Bayaut-1, and GulDU were developed. These varieties showed good salt and heat tolerance, and resistance to some diseases. Other heat and salt tolerant varieties such as Dustlik, H-104, Sanzar-8, and Sanzar-4 were also identified.

Based on a number of valuable economic and biological traits, special attention should be paid to the selection of soft wheat varieties of the intensive type. According to the literature, yield is one of the most complex and variable traits. Yield variability depends on climatic conditions.

Despite this, yield is the main selection criterion for developing salt tolerant wheat. In other words, varieties are selected for salt tolerance after undergoing selection for yield components. Spike length and number of grains per spike are the main traits of salt tolerant wheat and barley (Ivanov, 1973). Thus the selection criteria are components that are needed under stress conditions.

Table 1. The best winter wheat entries evaluated for economically valuable traits under conditions of Mirzachul.

Catalogue No.	Origin	Country	Vegetative period (days)	Plant height (cm)	Productive tillering	1000-kernel weight (g)	Grain weight per plot (g)	Drought-tolerance (%)	Disease in points	
									Yellow rust	Brown rust
St	Sanzar-8	Uzbekistan	204	116	3.9	3.8	531	78.4	0/70	0/30
St	Polovchanka	Russia	210	220	3.8	40.8	600	71.6	0/20	0/40
9802		CIMMYT	191	123	4.3	42.0	691	78.1	0/0	0/0
9813		CIMMYT	205	125	4.8	48.2	776	89.5	0/0	0/0
9820		CIMMYT	207	120	4.0	41.0	621	80.7	0/10	0/5
9821		CIMMYT	200	115	4.0	40.2	603	82.7	0/10	0/10
9828		CIMMYT	212	118	3.8	44.1	582	72.4	0/0	0/0
9851		CIMMYT	201	110	4.2	41.8	62.5	88.4	0/0	0/0
9855		CIMMYT	206	122	4.2	47.8	763	90.1	0/0	0/0
9869		CIMMYT	207	120	4.0	48.8	794	98.2	0/0	0/0
9924		CIMMYT	201	110	4.4	43.0	648	100.0	0/0	0/0
001606		Turkey	207	105	4.5	44.0	732	96.2	0/5	0/10
001283		Romania	209	109	4.2	46.6	723	84.1	0/5	0/5
001634		Turkey	210	110	4.8	41.0	776	98.0	0/0	0/0
001586		Turkey	206	112	4.6	46.0	776	87.2	0/0	0/0
001078		Bulgaria	206	110	3.0	43.0	660	73.4	0/10	0/0
551768		Syria	209	100	3.8	43.0	623	98.0	0/0	0/0
556818		Tunisia	207	102	3.9	42.1	645	988.0	0/10	0/0
92-583		Syria	197	115	4.2	42.8	744	95.2	0/10	0/0

Today different methods of quantitative genetics are used for trait characterization (Dragavtsev and Averyanova, 1983; Anashchenko and Rostova, 1986). With the help of these methods variability and determination of traits of various agricultural crops, including wheat, have been studied.

It should be noted that in the selection process we pay most attention to traits that are influenced from without, e.g., the degree of soil salinity. As previously mentioned, 90% of irrigated lands in Mirzachul are saline. It is the main difficulty of the selection process. Proceeding from this we have studied the mutual dependence between salinity level and variable and specific winter wheat traits.

Average values for the studied traits are given in Tables 2 and 3. From these we can see that the values of traits differ greatly among varieties.

Analyses of results between the traits of plants in soils with low salinity levels identified the following correlative links: spike length is positively associated with such traits as number of grains in the main spike, and number of grains per spike is negatively linked to grain weight per spike, spike density, 1000-kernel weight, and yield.

Based on results of previous studies, we know that spikes of late wheat varieties are long. Grainset of these varieties coincides with the hot season. In connection with it we can say that negative links exist between spike length, 1000-kernel weight, and yield.

We found positive links among traits of plants grown in soils with intermediate salinity levels, and negative links between spike length and spike density.

Analyses of variance and determination of traits showed that under conditions of low salinity the greatest relative variability having weak dependence on other traits is typical for yield. Spike length and number of grains in the main spike are the most stable traits.

Table 2. Average values for selected traits of winter wheat varieties on soils with low and intermediate salinity levels.

Traits	Low salinity level			Intermediate salinity level		
	X± m	Max.	Min.	X± m	Max.	Min.
Spike length (cm)	10±0.37	12.5	7.6	9.2±0.67	12.0	6.5
Number of grains in main spike	18.1±0.58	22.2	15.0	17.6±1.09	21.4	14.7
Average number of grains per spike	43.7±2.73	55.6	30.7	40.2±3.32	51.8	28.5
Grain weight per spike (g)	2.1±0.15	2.5	1.7	0.95±0.15	1.4	0.3
Spike density	18.9±0.41	22.5	15.1	17.62±1.52	22.5	14.6
1000-kernel weight (g)	46.7±2.71	33.2	57.3	31.3±2.58	40.1	21.0
Yield (g/m^2)	605.4±67.8	370.0	870.0	325.9±41.3	490.0	153.0

Table 3. Average indicators for selected sorts of winter wheat varieties on soils with low* and intermediate salinity levels.**

Varieties	Spike length (cm)	Number of grains in main spike	Average number of grains per spike	Grain mass per spike (g)	Spike density	1000-kernel weight (g)	Yield (g/m^2)
Knyajna	8.50*	19.1	45.4	2.2	22.2	48.9	620
	7.9**	19.5	44.6	0.9	21.2	29.1	327
Sanzar-8	10.0	19.0	55.6	2.5	18.3	44.8	650
	9.3	14.6	35.9	0.7	14.6	35.4	471
Polovchanka	10.8	20.9	44.2	2.2	18.4	45.7	608
	10.0	18.7	40.7	1.0	16.6	25.1	252
K-9904	9.6	16.7	37.2	1.8	19.5	44.8	490
	9.5	14.7	34.2	0.7	21.0	40.1	322
K-9802	9.6	15.0	37.9	1.7	15.0	54.9	560
	9.4	15.1	33.7	0.8	15.0	38.9	439
K-9924	10.0	18.7	30.7	1.7	17.7	44.9	490
	9.2	18.1	30.8	1.3	18.2	27.2	321
Andijon-2	9.5	17.0	43.5	1.8	17.9	40.9	503
	9.0	16.0	42.1	1.0	16.6	28.0	490
K-92-599	12.5	19.2	53.0	1.9	15.0	38.8	450
	12.0	18.9	47.7	1.3	16.6	21.0	403
K-001606	8.5	17.7	44.7	1.8	19.6	38.7	403
	8.2	17.0	40.0	1.4	20.7	28.0	391
Dustlik	9.2	18.5	42.7	2.3	19.0	45.8	642
	8.8	16.3	28.5	0.7	15.1	31.0	408
Marjon	9.6	19.0	45.0	2.2	18.7	57.3	660
	9.3	18.1	45.1	1.0	19.8	35.8	519
Yonbosh	8.8	17.6	48.0	2.5	19.0	48.7	810
	8.4	16.7	41.4	1.2	19.8	34.2	426
Hasan-Orif	11.5	22.2	42.6	2.2	18.4	50.4	730
	11.2	19.6	42.1	0.7	17.7	31.0	570
Gayrat	11.5	20.5	55.0	2.5	17.0	52.8	820
	11.2	21.4	41.0	0.8	18.2	27.2	290
K-001586	10.0	16.2	41.0	2.2	15.2	51.8	620
	9.3	15.4	38.1	0.9	15.5	32.4	401
N-104	10.3	18.2	43.2	1.8	17.0	33.2	476
	9.9	16.5	41.8	1.1	15.8	31.9	317
Boyovut-1	9.6	20.5	51.2	2.4	22.5	51.9	870
	9.5	20.0	51.8	1.7	22.5	36.1	633
X±m*	9.79± 0.64	18.58± 0.94	44.9± 3.37	2.1± 0.15	18.25± 1.09	46.7± 3.28	606± 74.73
X±m**	9.2± 0.67	17.6± 1.09	40.2± 3. 32	0. 95± 0. 15	17.62± 1. 52	31.3± 1.52	325.9± 41.3

Under intermediate salt conditions yield was highly variable in comparison with yield under low salinity conditions. This means that on salty soils there were sharp differences among varieties with respect to yield. Salt tolerant varieties gave rather a good harvest. Here spike length was a comparatively weakly variable trait. On soils with low and intermediate salinity the coefficient of determination of spike length was comparatively high and stable.

As stated above, under stress conditions conjugation of traits increases, as is apparent from the data in Figures 3 and 4. The coefficient of productive determination in soils with low salinity is equal to 0.11 and in soils with intermediate salinity level, 0.15. It means that under salt conditions coordination of the conjugation trait increase.

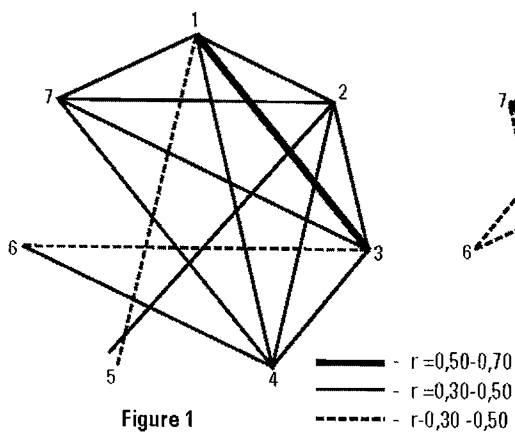

Figure 1

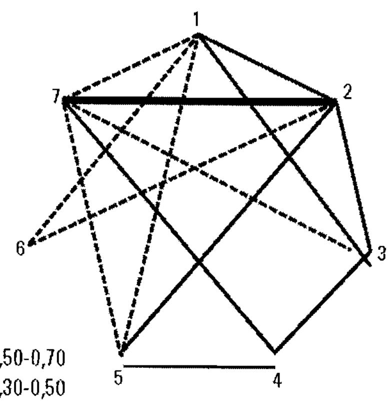

Figure 2

Correlation of selected winter wheat traits on soils with low salinity (Figure 1) and intermediate salinity levels (Figure 2). Note: 1,2,3 traits in Table 1, correlation between the studied traits:

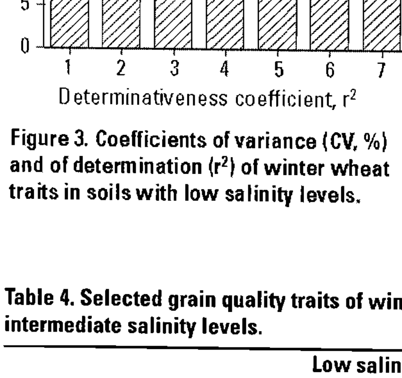

Figure 3. Coefficients of variance (CV, %) and of determination (r^2) of winter wheat traits in soils with low salinity levels.

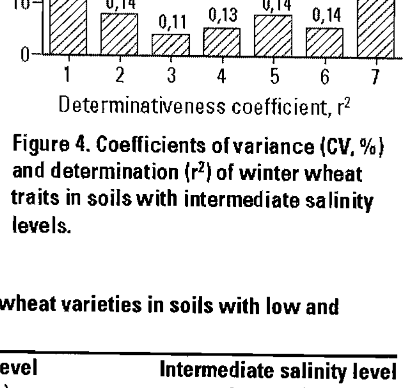

Figure 4. Coefficients of variance (CV, %) and determination (r^2) of winter wheat traits in soils with intermediate salinity levels.

Table 4. Selected grain quality traits of winter wheat varieties in soils with low and intermediate salinity levels.

Variety	Nature gr/L	Low salinity level Content (%) Protein	Gluten	Lysine	Nature gr/L	Intermediate salinity level Content (%) Protein	Gluten	Lysine
Polavchanka	780	14.0	27.7	2.7	735	13.1	26.3	2.1
Lutestsens 2448	790	13.7	31	2.1	710	10.8	27.2	2.2
Eritrospermum 2978	795	13.8	30.1	2.1	715	13.2	27.0	1.6
GulDU	781	16.8	29.3	2.8	720	14.8	27.8	2.5
Hasan-Orif	820	18.1	32.3	2.85	740	16.1	28.0	2.3
Boyovut-1	815	17.1	31.7	2.9	760	15.8	29.3	2.5
L-17	785	13.8	30.3	2.7	746	12.9	27.3	1.8
Sanzar-8	800	15.7	31.2	2.7	730	14.6	28.7	2.2
Robin	780	16.0	30.6	3.1	735	15.0	28.1	2.4

On the basis of statistic processing of data under different degrees of soil salinity we observe conjugations of various degrees among traits. And spike length turns out to be comparatively less variable with a high coefficient of determination. This trait can be the criterion of plants' soil-resistance selection as this trait's variability occurs in association with changes in other traits. Based on these criteria we selected new winter wheat varieties under saline soil conditions. Such varieties as Dustlik, Yonbosh, Boyovut-1, Hasan-Orif, and Andijon 2 can be considered relatively salt tolerant since they produced stable and comparatively rich harvest on soils with low and intermediate salinity. It should be noted that late-maturing varieties produce a poor harvest in saline soils.

Data on the food and fodder quality of wheat grain can be obtained after determining its protein and gluten content. According to biochemical analyses over four years, the average percentages of protein, gluten, and lysine content in the grain of test varieties are given in Table 4. Protein, gluten, and lysine contents differ little on soils with low and intermediate salinity levels.

Invariability of the quantity of protein and gluten on saline soils for several years can be considered a remarkable trait of salt tolerant winter wheat.

Conclusions

Local varieties (such as Yonbosh, Marzhan, Gairat, and Makuz-3) and international materials (Turkey) that were selected based on the most economically valuable traits could be used in future as sources of parental materials for selecting soft wheat adequate for intensive agriculture under saline and irrigated conditions in Mirzachul.

Under saline soil conditions the traits of salt tolerant winter wheat varieties conjugate. Spike length, a less variable trait, can be used as a criterion in selecting for salt tolerance.

Correlation between traits increase under stress conditions. For this reason, it is necessary to take into consideration the structure of correlation links among traits, when selecting for salt tolerance.

Protein and gluten content is a criterion for selecting winter wheat for good end-use quality in saline soils.

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Genetics and Breeding for Durable Resistance to Leaf and Stripe Rusts of Wheat

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Yellow (or stripe) and leaf (or brown) rusts, caused by *Puccinia striiformis* and *P. triticina*, respectively, are important diseases of wheat worldwide. This is mainly due to the pathogens' ability to mutate and multiply rapidly, and to use their air-borne dispersal mechanism from one field to another and even over long distances. With the discovery of the genetic resistance by Biffen (1905), physiological specialization in rusts by Stakman and Levine (1922), and gene-for-gene interaction by Flor (1956), the utilization of the hypersensitive (race-specific) type of resistance has predominated in wheat improvement. The phenomenon of the loss of effectiveness of such genes, or their combinations, led scientists to look for alternative approaches to resistance management. The concept of horizontal, or race-nonspecific, resistance was widely used in breeding stem rust resistance in wheat by Borlaug (1972) and leaf rust resistance by Caldwell (1968).

Application of such a concept in breeding for leaf rust resistance, commonly known as slow rusting (Caldwell 1968), or partial resistance (Parlevliet 1975), has dominated in CIMMYT's bread wheat (*Triticum aestivum* L.) improvement for more than 25 years. Our results indicate that durable resistance (Johnson 1988) to leaf and stripe rusts of several cultivars is based on the slow rusting genes having additive effects. In this paper we briefly explain how slow rusting resistance can be used in wheat improvement and our thoughts on what needs be done in the Central Asian region to achieve a long-term control of yellow and leaf rusts.

Identification and Characterization of Slow Rusting Resistance

Slow rusting to leaf rust is characterized by slow disease progress in the field despite a compatible, or high or susceptible, infection type. Cultivars carrying slow rusting resistance show high infection type in the seedling growth stage. For stripe rust, which progresses in plants also in a systemic manner, it is often not possible to identify fully compatible stripes in adult growth stages. Johnson (1988) presented examples of adult resistance genes that are race-specific in nature. It is difficult to distinguish such resistance from the resistance conferred by genes of race-nonspecific nature based on the adult plant infection type. At least some reduction in infection type is most often associated with low disease severity to stripe rust. However, we have observed that in the case of potentially durable slow rusting resistance, the first uredinia to appear are moderately susceptible to susceptible. Subsequent growth of the fungal mycelium causes some chlorosis or necrosis; therefore, the final infection type of the stripe, not uredinia, is usually rated as moderately resistant to moderately susceptible (MR-MS).

Slow rusting can be readily identified within the improved germplasm (Singh and Rajaram 1991). The existence of slow rusting resistance in most cultivars is often a chance inheritance from their ancestors. This was clearly demonstrated in Australia where stripe rust did not exist before 1979 but where several cultivars developed before 1979 carry moderate, and a few high, levels of adult plant resistance. Searching for slow rusting resistance in land races and alien sources should be considered only if it is not available in improved germplasm.

Slow rusting can be characterized in greenhouse experiments by evaluating latent period, infection frequency (number of uredinia per unit area or receptivity), size of uredinia or infection, inoculum production, etc. under quantitative inoculation. Characterization of 27 bread wheats of CIMMYT origin by Singh et al. (1991) indicated that this was phenotypically diverse for all components measured (Table 1). The area under disease progress curve of these wheat lines in field ranged from 1 to 50% of the very susceptible check cultivar Morocco (Table 1). Singh et al. (1991) also reported the likelihood of pleiotropic genetic control of the components of slow rusting because of highly significant positive or negative phenotypic correlation among latent period, number of uredinia and size of uredinia. If it is assumed that same gene controls various components of slow rusting, then it can be hypothesized that perhaps only a few genes with additive effects could retard disease progress to a rate that final disease level remains to an acceptable low level.

Linked Genes *Lr34*/*Yr18* and *Lr46*/*Yr29* for Slow Rusting to Leaf and Stripe Rusts

Dyck (1987) designated gene *Lr34* located in chromosome 7DS, which is now known to be present in several cultivars with durable resistance to leaf rust. Singh (1993) identified its presence in several CIMMYT-derived Mexican wheat cultivars. The heterogeneous Mexican wheat cultivar Jupateco 73 was reselected for the presence and absence of *Lr34* by Singh (1992a). These isogenic Jupateco 73R (*Lr34* present) and Jupateco 73S (*Lr34* absent) genotypes and those of Thatcher developed by Dyck (1987) have yielded useful information on the nature of slow rusting resistance. Our studies, using the Jupateco pair have shown that *Lr34* affects all three components of slow rusting, i.e. it increases latent period and decreases number and size of uredinia (Table 2). The effect was more pronounced in post seedling growth stages, although measurable differences also occurred in the seedling stage. Temperature can influence the expression of resistance conferred by the gene *Lr34* (Singh and Gupta 1992). Comparison of grain yields of Jupateco isolines in leaf rust protected (by fungicide) and non-protected plots indicated that though leaf rust could significantly reduce grain yield by approximately 15% in the presence of *Lr34*, the reductions in the absence of *Lr34* were substantially higher and ranged between 42.5 to 84% depending on planting date and year (Singh and Huerta-Espino 1997).

Studies of Singh (1992b) and McIntosh (1992) have shown that gene *Lr34* is closely linked with gene *Yr18*, which confers slow rusting to stripe rust. Using the Jupateco 73 near-isogenic reselections, studies at CIMMYT have shown that the gene *Yr18* also increases latent period, and decreases infection frequency and length of infection lesions (stripes) to stripe rust in greenhouse experiments (Table 3). The conclusion again was that these components were under pleiotropic genetic control. Comparison between stripe rust protected and non-protected treatments showed that stripe rust infection caused grain yield losses of 31 to 52% in *Yr18* carrying Jupateco 73R and 74 to 94% *Yr18* lacking Jupateco 73S (Ma and Singh 1996). This shows that slow rusting resistance based on *Yr18* protected grain yield in the range of 36 to 58% depending on the year and sowing date. This level of protection was not considered sufficient in the environment of Toluca, Mexico where the experiments were conducted.

Rubiales and Niks (1995) studied the infection process and indicated that partial resistance due to *Lr34* was based on reduced rate of haustorium formation in the early stages of infection, in association with no or relatively little plant cell necrosis. Electron microscopic studies of Alvarez-Zamorano (1995) on Jupateco 73 isolines have shown an accumulation of unknown electro-dense substances in the cells of *Lr34* line near the site where haustorial mother cells try to dissolve the cell wall of mesophyll cells for the formation of haustoria. It would appear that the accumulation (cell wall apposition) causes a thickening of cell wall, which reduces the establishment of haustorial tube. If haustoria are formed, the slow mycelial growth

Table 1. Range of variability for components of slow rusting (partial) resistance to leaf rust observed in 28 bread wheats (given as % of susceptible check variety Morocco).

Component	Variability range
Latent period	+14 to +49
Uredinium number	-42 to -98
Uredinium size	-34 to -78
Area under the disease progress curve	-50 to -99

Table 2. Comparison of the three components of slow rusting resistance to leaf rust in seedling and flag leaves of the near-isogenic *Lr34* Jupateco 73 reselections tested at 15°C.

	Latent period (days)		Uredinia/cm²		Size of uredinia (mm²)	
Genotype	Seedling	Flag	Seedling	Flag	Seedling	Flag
Jupateco +*Lr34*	13.8b[A]	18.0b	21a	6a	0.21a	0.07a
Jupateco -*Lr34*	12.8a	12.7a	47b	30b	0.38b	0.27b

[A] Different letters following the values indicate significant difference between the means at P=0.05.

Table 3. Comparison of the three components of slow rusting resistance to stripe rust in flag leaves of the near-isogenic *Yr18* Jupateco 73 reselections tested at 15°C.

Genotype	Latent period (days)	Infection frequency (stripes/cm²)	Length of stripes (mm)
Jupateco +*Yr18*	20.1b[A]	0.7a	12.5a
Jupateco −*Yr18*	15.9a	7.1b	47.7b

[A] Different letters following the values indicate significant difference between the means at P = 0.05.

may be due to a restricted movement of fungus from one cell to other by a similar phenomenon. Alvarez-Zamorano (1995) also observed structural change in the *Lr34* line leading to invagination, or contraction of cell wall, which may delay the completion of infection process. These observations indicate a different mechanism for *Lr34* based slow rusting than hypersensitivity, which is associated with race-specific genes. Because pathogen isolates can vary for aggressiveness (Lehman and Shaner 1996), it may be difficult to differentiate pathogenic variation for increased capability to overcome slow rusting resistance of this type from aggressiveness.

One of the slow rusting genes present in Mexican wheat cultivar Pavon 76, which has moderate levels of durable adult-plant resistance to leaf and yellow rusts, was recently designated as *Lr46* (Singh et al. 1998). Gene *Lr46* is located in chromosome 1BL and is linked (or pleiotropic) to gene *Yr29* that confers moderate levels of adult-plant resistance to stripe rust (William et al. 2003). Gene *Lr46* also affects all components of slow rusting resistance to leaf rust (Martinez et al. 2001).

Combination of *Lr34*, *Lr46*, and Other Genes for Durable Leaf Rust Resistance

The South American cultivar 'Frontana' is considered to be one of the best sources of durable resistance to leaf rust (Roelfs 1988). Genetic analysis of Frontana and various CIMMYT wheats possessing excellent partial resistance to leaf rust worldwide has indicated that adult plant resistance is based on the additive effects of *Lr34* and two or three additional slow rusting genes, commonly known as the *Lr34* complex (Singh and Rajaram 1992). In Mexico, leaf rust severity on most cultivars can be related to the number of slow rusting genes they carry (Table 4). Cultivars with *Lr34* and three or four additional genes show a stable response in environments tested so far, with final leaf rust ratings lower than 5% even under heavy rust pressure. The presence of *Lr34* can be indicated by the presence of leaf tip necrosis in adult plants, which is closely linked with it (Singh 1992a). Results of Sayre et al. (1998) show that 7.7 to 10.4% losses in grain yield of cultivars that carry such combinations of 2 or 3 genes with *Lr34* were similar to 6.6 to 10.2% losses in cultivars that carry hypersensitive types of resistance under high leaf rust pressure.

Our genetic studies have shown that at least 10-12 different slow rusting genes are involved in the adult plant resistance of a group of CIMMYT wheats. We have also identified lines where *Lr34* is absent, but whose level of resistance is high. We therefore believe that durable resistance is feasible even in the absence of *Lr34*, as in the case of Pavon 76 (Table 4).

Combinations of *Yr18*, *Yr29*, Yr30, and Other Genes for Durable Stripe Rust Resistance

Singh (1992b) and McIntosh (1992) have indicated that the moderate level of durable adult plant resistance of the CIMMYT-derived US wheat cultivar Anza is controlled by gene *Yr18*, which is also present in winter wheats such as Bezostaja. As mentioned earlier, this gene is completely linked with the *Lr34* gene. The level of resistance it confers is usually not adequate when present alone. However, combinations of *Yr18* and 3-4 additional slow rusting genes (the *Yr18* complex) result in adequate resistance levels in most environments (Singh and Rajaram 1994). Cultivars carrying such *Yr18* complexes are listed in Table 5. Our genetic study on a few selected cultivars indicated the presence of genes different from *Yr18*. We believe that these slow rusting genes can be pyramided to achieve adequate resistance levels. The durability of such slow rusting genes is not known; however, when combinations are deployed, the longevity of the resistance can expected to be high, as evident in Australia for wheat cultivars Cook and Hartog (=Pavon).

Table 4. Seedling susceptible bread wheats that carry good adult plant resistance to leaf rust in Mexico and other countries.

Genotype(s)	Usual leaf rust response[a]	Additive genes[b] for resistance
Jupateco 73S	100S(N)	Highly susceptible
Jupateco 73R	50MSS	*Lr34*
Nacozari 76	30MSS	*Lr34* + 1 gene
Sonoita 81, Bacanora 88, Rayon 89	20MSS	*Lr34* + 1 or 2 genes
Frontana, Parula, Trap, Tonichi 81	10MSS	*Lr34* + 2 or 3 genes
Chapio, Tukuru, Kukuna, Vivitsi	1MSS	*Lr34* + 3 or 4 genes
Pavon 76	40MSS	*Lr46* + 1 gene
Genaro 81, Attila	40MSS	2 genes
Amadina	5MSS	4 genes

[a] Leaf rust response evaluated in Mexico has two components: % severity based on the modified Cobb scale (Peterson et al. 1948) and reaction based on Roelfs et al. (1992). The reactions are: MSS = moderately susceptible to susceptible, i.e., medium to large sized uredinia without chlorosis or necrosis; S = susceptible, i.e. large uredinia without chlorosis or necrosis; N = necrotic leaves following high leaf rust severity.

[b] Minimum number estimated from genetic analysis.

Recent studies at CIMMYT (William et al., 2003) have shown that gene *Lr46* is either closely linked (or pleiotropic) to gene *Yr29*, which confers slow rusting to yellow rust. Another minor gene, *Yr30*, involved in the adult plant resistance of several CIMMYT wheats was found to be in the chromosomal region carrying durable stem rust resistance gene *Sr2* (Singh et al. 2000). Genes *Yr29* and *Yr30* are widely distributed in CIMMYT wheat germplasm.

Molecular Markers for Genes Conferring Slow Rusting Resistance

Although advances in finding closely linked markers are notable with race-specific genes, especially those transferred into wheat from alien sources, progress with slow rusting genes has been slow and limited. QTL analyses have shown several chromosomal regions that enhance resistance to leaf or yellow rust (William et al. 1997, Nelson et al. 1997, Messmer et al. 2000, Singh et al. 2000, William et al. 2003, Suenaga et al. 2003). Chromosomal regions involved in slow rusting resistance to leaf and yellow rusts in Pavon 76 and Parula were identified at CIMMYT by testing RILs (recombinant inbred lines) from the crosses of these wheats with susceptible cultivar Avocet S (Table 6). The linkage between *Lr46* and *Yr29* was in fact first identified in the Avoct S/Pavon 76 cross. Other interesting features included the presence of additional QTLs that conferred resistance to both leaf and yellow rusts, and QTLs which were disease specific (Table 6).

It is also worth mentioning that presence of *Agropyron elongatum* segment carrying stem rust resistance gene *Sr26* had minor but significant effects in reducing leaf and yellow rust severities in at least Pavon population. This relationship was also found in the Avocet/Tonichi 81 cross (data not presented). A total of at least 6 distinct additive genes for leaf and yellow rusts were identified between Pavon 76, Parula and Tonichi 81. Such mapping efforts have been useful to understand the genetic basis of interactions among genes and their mapping. All attempts to find a diagnostic marker for slow rusting genes *Lr34* and *Yr18* have failed so far. The closest markers for *Lr34/Yr18* and *Lr46/Yr29* genes are about 10 cM away. We recommend that more efforts should be made in the future to find markers for slow rusting resistance genes rather than investing in race-specific resistance genes.

Incorporation of Resistance Based on Additive Slow Rusting Genes: The Single Backcross Approach

It is often believed that selecting for resistance based on additive minor genes is difficult. However, at CIMMYT we have launched a program to incorporate additive genes based durable resistance into important wheat cultivars/genotypes that have unacceptable levels of resistance to Mexican leaf and/or yellow rust races. We use one backcross approach where such cultivar/genotype is crossed with a

Table 5. Some seedling susceptible bread wheats that carry good adult plant resistance to stripe rust in field trials in Mexico and other countries.

Genotype(s)	Usual yellow rust response[a]	Additive genes[b] for resistance
Jupateco 73S	100MS	Moderately susceptible
Jupatco 73R	50M	*Yr18*
Parula, Cook, Trap	15M	*Yr18* + 2 genes
Tonichi 81, Sonoita 81, Yaco	10M	*Yr18* + 2 or 3 genes
Chapio, Tukuru, Kukuna, Vivitsi	1M	*Yr18* + 3 or 4 genes
Pavon 76	20M	*Yr29*, *Yr30* + 1 gene
Attila, Amadina	30M	3 genes

[a] Yellow rust response data from Mexico has two components, % severity based on modified Cobb scale (Peterson et al. 1948) and reaction based on Roelfs et al. (1992). The reactions are M = moderately resistant to moderately susceptible, sporulating stripes with necrosis and chlorosis; and S = sporulating stripes without chlorosis or necrosis.

[b] Minimum number estimated from genetic analysis.

Table 6. QTLs for slow rusting, additive genes involved in resistance to leaf and yellow rust diseases of wheat mapped by evaluating RILs from crosses of susceptible wheat 'Avocet S' and resistant 'Pavon 76' and 'Parula' for three years at field sites in Mexico.

Cultivar	Location	Marker	Disease severity reduction (%)[c] Leaf rust	Yellow rust	Named genes
Pavon 76	1BL	Wms259	35	27	*Lr46, Yr29*
	4B	Wms495	18	15	
	6A[a]	Wms356	14	18	
	6B	PaggMcaa	-	18	
	3BS	PacgMcgt	-	11	*Yr30, Sr2*
Parula	7DS	Wms295, *Ltn*[b]	56	46	*Lr34, Yr18*
	7B or 7D	Pcr156	29	-	
	1BL	Wms259	15	16	*Lr46, Yr29*
	Unknown	PaagMcta	22	14	
	3BS	Glk2	-	12	*Yr30, Sr2*

[a] Source of resistance is Avocet S.

[b] Leaf tip necrosis, a morphological marker linked to gene *Lr34*.

[c] Reduction is the mean difference in severity of lines with and lines without the marker allele.

group of about ten resistance donors (some listed in Tables 4 and 5) and then 20 spikes of the F_1 plants from each cross are backcrossed to obtain 400-500 BC_1 seeds. Selection is practiced from BC_1 generation onwards for resistance and other agronomic features under high rust pressure. Because the additive genes are partially dominant – partially recessive, BC_1 plants carrying most of the genes show intermediate resistance and can be selected.

About 1600 plants per cross are space grown in the F_2 whereas population sizes of about 1000 plants are maintained in the F_3-F_5 populations. Plants with low to moderate terminal disease severity in early generations (BC_1, F_2 and F_3), and plants with low terminal severity in later generations (F_4 and F_5) are retained. We use a selected-bulk scheme where one spike from each selected plant is harvested as bulk until the F_4 generation and plants are harvested individually in the F_5. Because high resistance levels require the presence of 4 to 5 additive genes, the level of homozygosity from the F_4 generation onwards is usually sufficient to identify plants that combine adequate resistance with good agronomic features. Moreover, selecting plants with low terminal disease severity under high disease pressure means that more additive genes may be present in those plants. Selection for seed characteristics is carried out on seeds obtained from individually harvested F_5 plants. Small plots of the F_6 lines are then evaluated for agronomic features, homozygosity of resistance, etc. before conducting yield trials.

By using the above methodology resistant derivatives of Baviacora 92, Seri 82, Attila, PBW343, Inqualab, and Pastor were developed recently. Some of the derived lines not only carry high levels of resistance to leaf rust or yellow rust or both diseases, but also carry about 5-15% higher yield potential than the original cultivar. We believe that this approach of wheat improvement allows us to maintain the characteristics of the original cultivar while improving its yield potential and rust resistance.

What Should Be Done in Central Asia to Achieve a Long-Term Solution to Rust Diseases?

We recommend that wheat breeders, rust geneticists and pathologists working in Central Asia assemble a group of winter and spring wheat cultivars known to carry adequate levels of durable resistance to yellow and/or leaf rusts and evaluate them in the seedling stage in the greenhouse with relevant rust races and in field trials at hot-spot locations to identify those cultivars that show resistance stability in the Central Asian environment. Resistance from these cultivars could then be transferred in a planned manner to the susceptible but locally adapted cultivars through a 'Single Backcross Breeding Approach', described above. In our view, any breeding program in the region can adopt this simple breeding methodology to achieve a long-term rust control.

Conclusions

Yellow (or stripe) and leaf (or brown) rusts, caused by *Puccinia striiformis* and *P. triticina*, respectively, are important diseases of wheat worldwide. Growing resistant cultivars is the most economical and environmentally safe control measure and has no cost to growers. Wheat (*Triticum aestivum*) cultivars that have remained resistant for a long time, or in other words carry durable or race-nonspecific resistance, are known to occur. Inheritance of resistance in these cultivars, conducted in different countries, indicate that they often carry a few slow rusting genes that have small-to-intermediate, but additive, effects. Our genetic and selection studies have shown that a high level of resistance (approaching immunity) to both rusts could be achieved by accumulating from 4 to 5 such genes.

We recommend that wheat breeders, rust geneticists and pathologists working in Central Asia assemble a group of winter and spring wheat cultivars known to carry adequate levels of durable resistance to yellow and/or leaf rusts and identify those cultivars that show resistance stability in the Central Asian environments. Resistance from these cultivars should then be transferred in a planned manner to the susceptible but locally adapted cultivars through a 'Single Backcross Breeding Approach', an efficient selection methodology currently used by us, that allows the simultaneous accumulation of desired number of slow rusting genes with increased grain yield potential and other traits.

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Inheritance of Yellow Rust Resistance in Winter Wheat

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Central Asia is one of the most important wheat producing regions in the world. In Kazakhstan wheat is grown on 12 million hectares (mln ha). In recent years yellow, or stripe, rust (caused by *Puccinia striiformis* f. sp. *tritici*) is a major factor that adversely affects wheat yields and quality, causing considerable economic damage. Yellow rust is principally a disease of wheat in areas with cool, wet climatic conditions (2-15 °C), associated mainly with northern latitudes or cooler years (Roelfs et al., 1992). Although the weather in spring and summer is usually unfavorable, yellow rust survived and spread in southern Kazakhstan, Uzbekistan, and Kyrgyzstan in 2000. During the 2001-2002 epidemic, the most widely grown high yielding local varieties were severely affected by yellow rust, which caused grain losses of 20-60%. Just in Kazakhstan and Uzbekistan, the area affected by yellow rust was estimated to be as high as 1.5 mln ha.

The cause of this yellow rust epidemic was the expansion of the area sown to wheat in Uzbekistan and Tajikistan, where mild conditions favor the development of yellow rust (Koishibayev, 2001). The wet, cool spring season promotes the spread of this pathogen in southern Kazakhstan.

Genetic host plant resistance is an effective, economical, and environmentally safe method of controlling yellow rust (Bimb and Johnson, 1997; Kumar et al., 1999). Two types of resistance are widely used: race-specific seedling resistance and durable, high-temperature, adult plant (HTAP) resistance, which is race-nonspecific (Chen et al., 1998). Adult plant resistance (APR) involves the slow rusting mechanism (Allan et al., 1966; Parlevliet, 1988; Singh and Rajaram 1994). Slow rusting is a type of resistance resulting in intermediate to low disease levels in response to all pathotypes of the pathogen (Caldwell, 1968). The most effective is durable resistance based on the additive interaction of slow rusting genes (Singh et al., 2001).

Most important for a rust resistance breeding program is to study the inheritance of resistance to understand the underlying mechanisms and genetic control of yellow rust resistance in local resistant cultivars. The identification of resistance genes and the study of their effects would be helpful in finding new resistance sources.

The overall aim of our work is to study the genetics of yellow rust resistance in a set of wheat cultivars with the following objectives:

- to identify winter wheat germplasm resistant to yellow rust;
- to determine the inheritance of resistance in segregating populations;
- to select valuable genotypes for breeding.

Materials and Methods

A total of 350 samples of wheat were included in field tests, including 155 from the Central and West Asian Yellow Rust Trap Nursery (CWARTN), 84 from the CAC – Regional Winter Wheat Exchange Nursery, 111 from nurseries of local breeding programs.

Disease severity and reaction types were recorded following McIntosh et al. (1995). Five infection types are described as follows:

0 = immune (no uredia or other symptoms of disease infection);
R = resistant (minute uredia, supported by distinct necrotic areas);
MR = moderately resistant (uredia small to medium, in green islands surrounded by chlorotic or necrotic tissue);
MS = moderately susceptible (uredia medium in size, no necrotic but chlorotic areas may be present);
S = susceptible (large uredia, no necrosis but chlorosis may be evident).

Cultivar Morocco and local cultivar Steklovidnaya 24 were used as susceptible checks during pathogen multiplication in the greenhouse and as spreaders in field tests. The inoculum used in field tests was a mixture of identified isolates maintained on susceptible varieties. This material was screened for yellow rust races that predominate in the region.

Genetic analysis based on the reaction data of F1 and F2 plants to infection was used for identifying resistance genes. The ratio of resistant versus susceptible plants in segregating populations was used to determine the mode of inheritance and the number of resistant genes.

Results and Discussion

Results of annual surveys indicated that the severe yellow rust epidemic in the western part of the Almaty region decreased in intensity from west to east, indicating the probable spread of airborne inoculum from the west, including the Shu Valley, Uzbekistan, and Tajikistan. The mountain ranges of Zailyisky, Kyrgyzsky, and Zhungarsky Alatau 50-100 km wide prevented further spread (Koishibayev, 2001).

Based on field tests. experimental lines were screened for *Puccinia striiformis* f. sp. *tritici* (Table1). Cultivars Almaly, Arap, Sultan, Taza (Kazakhstan), Kupava, Knyazhna, Umanka (Russia), Tilek, Adir (Kyrgyzstan), Ulugbek 600 (Uzbekistan), BWKLDN95, BWKLDN9, BWKLDN33 (ICARDA), MK-3744, MK-3745, MK-3750, MK-3796, and MK-3797 (CIMMYT) were resistant.

At present there are 30 known resistance genes for yellow rust. They are characterized by different genomic locations and promote different levels of resistance. The effectiveness of the same genes in different regions of the world may vary depending on frequency of corresponding virulent genes in local pathogen populations. Analysis of CWARTN (including yellow rust 8 "world differentials", 8 "European differentials", 30 "Cobbity differentials", 6 "supplemental" and resistant commercial varieties and advanced lines) was done to identify prevalent races of yellow rust pathogen and to assess the effectiveness of known resistance genes. Field responses to the disease are shown in Table 2.

A set of isogenic lines developed from cultivars Aroona and Avocet was used to differentiate the pathogen population. Monitoring sources with known resistance genes allowed us to rank experimental materials according to their effectiveness. Based on this data we were able to do a preliminary prognosis of pathotype virulence. Virulence for *Yr1*, *Yr6*, *Yr7*, *Yr9*, *Yr11*, and *Yr12* occurred in south and southeastern Kazakhstan. These genes and their sources are ineffective in the region.

Information on resistance genes in our commercial varieties is limited. Genotypic responses to *P. striiformis* isolates allowed us to postulate the presence of specific genes in several cultivars: *Yr1* in Krasnovodopadskaya 25, Yuzhnaya 12, Pamyat 47 (Kazakhstan), Adyr (Kyrgyzstan), and Ozoda (Tajikistan); *Yr9* in Skiphyanka, Kavkaz, and Ulugbek 600 (Uzbekistan); *Yr6*, *Yr7*, or combinations of these in Taragi

Table 1. Field responses to *Puccinia striiformis* f. sp. *tritici* among wheat entries, including to crosses (KazNIIZ, 2002).

Entries	Field response	Entries	Field response	Entries	Field response
Krasnovod.25	40S	Taza	10R	Yr15/6*AvocetS	5MR
Skifyanka	50S	Kupava	5R	Yr18/3*AvocetS	30S
Zhetisu	15S	Knyazhna	15R	Aroona S	40S
Stekljvidnaya 24	50S	Umanka	5R	Avocet S	50S
Morocco	100S	BDME9	50MS	Anza	30MR
Karlygash	60S	5th Faw#35	15R	Bezostaya1	30MS
Bermet	10S	Sultan	5R	BWKLDN95	R
Sanzar8	60S	Ani 591	20MS	BWKLDN9	R
Sharora	40S	Nairi 149	20MS	BWKLDN33	R
Yuzhnaya 12	40MS	Tilek	15R	MK-3732 Faw.	15S
Sapaly	50MS	Ulugbek	15R	MK-3744 Faw.	R
Naz	30MS	Adir	10R	MK-3745 Faw.	R
Oktyabrina	30S	Yr2	10R	MK-3750 Faw.	R
Almaly	5R	Yr4	5R	MK-3796 Faw.	R
Arap	10R	Yr10	5R	MK-3797 Faw.	R

R = resistant; MS = moderately resistant; MS = moderately susceptible; S = susceptible.

Table 2. Field responses to *Puccinia striiformis* f. sp. *tritici* among differentials in CWARTN (KazNIIZ, 2002).

Differentials, isogenic lines	Severity and field response	*Yr* gene	Genomic location
Chinese 166 (W)	80S	Yr1	2A
Lee (S)	85S	Yr7	2B
Heines Kolben (S)	30MR	Yr6	7B
Vilmorin 23 (W)	R	Yr3v	-
Moro (W)	R	Yr10	1B
Clement (W)	R	Yr9+	1B
Hybrid 46 (W)	R	Yr4+	2B
Heines Peko (S)	R	Yr6+	7B
Nord Desperz (W)	R	3N	-
Compair (S)	20S	Yr8	2D
Heines VII (W)	R	Yr2+, 11, 25	7B
Aroona (S)	50S	-	-
Aroona*5/Yr1 (S)	70S	Yr1	2A
Aroona*5/Yr5 (S)	15MS	Yr5	2B
Aroona*5/Yr8(S)	10MR	Yr8	2D
Aroona*5/Yr15 (S)	15MR	Yr15	1B
Aroona*5/Yr17 (S)	R	Yr17	2A
Yr1/6* Avocet S	60S	Yr1	2A
Yr5/6* Avocet S	R	Yr5	2B
Yr6/6* Avocet S	40S	Yr6	7B
Yr7/6* Avocet S	80S	Yr7	2B
Yr8/6* Avocet S	30S	Yr8	2D
Yr9/6* Avocet S	20S	Yr9	1B
Yr10/6* Avocet S	R	Yr10	1B
Yr11/6* Avocet S	25S	Yr11	-
Yr12/6* Avocet S	90S	Yr12	-
Yr15/6* Avocet S	R	Yr15	1B
Yr17/6* Avocet S	R	Yr17	2A
Yr18/6* Avocet S	20S	Yr18	7D
YrSp/6* Avocet S	5MR	YrSp	-
YrSk/6* Avocet S	20MR	YrSk	-
Jupateco R (Yr18)S	40MS	Yr18	7D
Avocet R (YrA)	5MS	YrA	-
Avocet S	80S	-	-
Oxley (Yr6+APR)S	R	Yr6+APR	7B
Cook (S)	R	APR	-
Anza (A+) S	30MR	Yr18+A	7D
Morocco (check)	80S	-	-

R = resistant; MS = moderately resistant; MS = moderately susceptible; S = susceptible.

(Azerbaijan), SN64//SKE/2*ANE//3/SX/4/BEZ/5/SERI (7H) (Bitarap) (Turkmenistan), Norman (5th FAWWON-37, ORE F1.158/FDL//BLO/3/SHI4414/CROW) and Tacika (5th FAWWON-35, TAS/SPRW//ZAR (Tajikistan) (Absattarova et al., 2001). The sources of *Yr1*, *Yr6*, *Yr7*, and *Yr9* cannot be used in breeding programs. Genes *Yr2+*, *Yr4+*, *Yr5*, *Yr10*, *Yr15*, and *Yr17*, which showed R-MR reactions, were effective against most yellow rust races in the region.

Entries in CWARTN with R, MR, MS, and S infection types are shown in Figure 1. About a third of the entries (28%) demonstrated a highly resistant infection type in the region. The group with resistant infection type (R) includes Vilmorin 23, Moro, Strubes Dickkopf, Suwon 92 x Omar, Clement, *T. spelta album*, Hybrid 46, Reichersberg 42, Heines Peko, Nord Desprez, Carstens V, Heines VII, Avocet R, Cham 1, Cook, Corella, Oxley, Ani 326, Karakylchyk 2, Azametli 95, Memof22, Seri 82, Alamout, Darab-2, Sabalan, Cham 4, Cham 6, Dustlik, Polovchanka, Ulugbek 600, ANAHUAC 75, Super Kauz, Tonichil81, Buck, and Car 422, plus isogenic lines of cultivar Avocet (Yr5/6*, Yr10/6*, Yr15/6*, Yr17/6*).

Not all resistant genotypes can be used as sources of resistance. For example, isogenic lines developed from susceptible cultivar Avocet cannot be used in breeding for resistance, since Avocet's negative traits would be transferred to the new genotypic background. As seen in the figure, 7% of genotypes had moderately resistant infection type (MR): Yr Sp/6*, CATCHER (W3201), Federation 4/Kavkaz, Bohouth 6, Kinaci 97, Turkmenbashi, Yuna, Ocal Red (durum), Pastor, and SNI/PBW65. A moderately susceptible reaction was shown by 6% of differentials. Most genotypes were susceptible to yellow rust (52%).

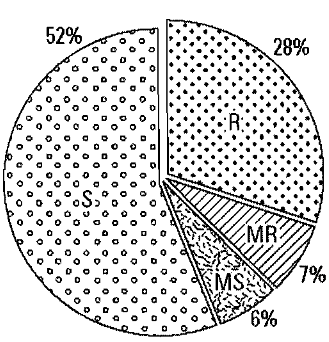

Figure 1. Set of wheat differentials grouped by the level of yellow rust resistance.

Breeding for disease resistance is complicated by the fact that the most effective *Yr* genes negatively influence productivity traits. Sources of resistance to yellow rust must have a longer vegetative period and be late maturing, which leads to absence of coincidence of development phase in partners of hybridization. For instance, highly resistant cultivars Ulugbek 600, Moro (*Yr10*), Heines VII (*Yr2+*), Hybrid 46 (*Yr4+*), and Lori 292 are late maturing (head 10-12 days later than St).

A study of the association between productivity and resistance in cultivars Ulugbek 600, Moro (*Yr10*), Heines VII (*Yr2+*), Hybrid 46 (*Yr4+*), Lori 292, and the isogenic lines (*Yr10*, *Yr15*, *Yr24*) has shown that number of grains per spike, grain weight per spike, and grain weight per plant are negatively correlated with resistance level (R^2 = -0.69, -0.71, and -0.82, respectively). To break the linkage and select transgressive forms with a desirable combination of disease resistance and high productivity, it is necessary to apply backcrossing in hybridization programs. Although Heines VII is highly resistant in the region, it possesses at least three genes, all of which are known to be race-specific. We will use strong resistance sources (Heines VII [*Yr2+*] and Hybrid 46 [*Yr4+*]) in pyramiding genes to achieve more durable yellow rust resistance in our breeding program.

The study of the inheritance of resistance is very important for improving yellow rust resistance. The recipient's positive agronomic traits (high yield potential and ecological plasticity) can be lost in the crossing and selection process. Therefore it is necessary to combine in one genotype resistance to diseases and high productivity. The identification of resistance genes and study of gene interaction will help to use sources of resistance effectively in breeding programs.

The first observation recorded is the response of F1 hybrids. A resistance response similar to that of the resistant parent was observed in crosses Adir x Steklovidnaya 24, Lori 292 x Steklovidnaya 24, Ulugbek 600 E Yuzhnaya 12, and Ulugbek 600 E KSI-13, indicating dominance of resistance. In other crosses we observed an intermediate response to disease.

The ratio of resistant:susceptible F2 plants indicates the number of resistance genes segregating in the cross (Table 3). In hybrids F2 Adir x Steklovidnaya 24 and Lori 292 x Steklovidnaya 24 segregation ratios were 3 resistant : 1 susceptible, which suggests genetic control of yellow rust resistance in absence of linkage by 1 dominant gene. It is known that Adir carries race-specific gene *Yr1* (Absattarova et al., 2001). The data of genetic analysis indicated presence of another dominant gene.

In cross Kyal x Steklovidnaya 24, the segregation ratio corresponded to expected three-way hybrid 27:37. In Kyal resistance is controlled by three complementary recessive genes. Non-allele gene interaction led to ratio of resistance and susceptible classes:

27ABC: 9ABc: 9AbC: 9aBC: 3Abc: 3abC: 3aBc: 1abc,

where in bold showed resistant classes.

In the F2 (Progress x Steklovidnaya 24) we observed dihybrid segregation with a phenotypic ratio of 1:15. Genotypic segregation is:

9A-B: 3A-bb: 3aaB-:**1aabb**

Genes "a" and "b" in this cross are interacting complementary. The resistance in cultivar Progress is controlled by two recessive duplicate genes. The segregation ratio in cross Sapaly x Steklovidnaya 24 is 1:3. Therefore resistance to yellow rust in Sapaly may be controlled by one recessive gene. The ratio in F2 Sansar 8 x Steklovidnaya 24 and Yanbash x Steklovidnaya 24 corresponds to three-way hybrid type 1:63 and indicates genetic control by three recessive duplicate genes. Non-allele gene interaction in three-way hybrid segregation leads to the following resistance:susceptible ratios:

27ABC: 9ABc: 9AbC: 9aBC: 3Abc: 3abC: **3aBc: 1abc,**

Segregation in F_2 Ulugbek 600 x Yuzhnaya 12 shows a phenotype ratio of 61:3 and indicates genetic control by two dominant and one recessive genes that interact duplicate.

In F_2 Ulugbek 600 x KSI-13, 61:3 segregation was also observed. It confirmed the data obtained in the last cross, i.e. Ulugbek's resistance is controlled by two dominant and one recessive genes. This showed the presence in this cultivar of rye translocation 1BL/1RS, tightly linked to *Yr9* (Absattarova et al., 2001). Genetic analyses indicate that in addition to *Yr9* another three genes confer protection from *Puccinia striiformis.*

The genetic factors conferring yellow rust resistance in commercial cultivars can be determined by studying disease genetics in local varieties. Based on the genetics of resistance sources, we will be able to develop cultivars possessing effective genes (or combination of genes) against known virulent races of the pathogen. We evaluated a number of advanced lines and cultivars to find rust resistant wheat germplasm.

We selected cultivars that lack effective major genes and have moderate-to-good levels of resistance to local rust pathotypes (Table 4). Almaly, Arap, and Sultan showed susceptibility at the seedling stage, and were resistant and moderately resistant in the field. These germplasms were crossed with the aim of achieving slow rusting resistance in wheat cultivars. Allelism tests involve crosses between resistant parents and isogenic lines with effective resistance genes.

The working collection and breeding materials in local breeding nurseries were studied (Tables 1 and 5). Our results indicated that 48 entries, including cultivars Almaly, Arap, Taza, Sultan, Ulugbek, as well as entries from CIMMYT and ICARDA, were stable in their resistance and could be used as sources of yellow rust resistance.

Conclusions

- Data on test differentials and resistant commercial varieties indicate that in the southern and southeastern parts of Kazakhstan, Ulugbek 600, Lori 292, Almaly, Arap, Moro (*Yr10*), Heines VII (*Yr2+*), Hybrid 46 (*Yr4+*), and near-isogenic lines *Yr10*, *Yr15*, and *Yr17* are effective and should be incorporated into wheat cultivars;
- Virulence for genes *Yr1*, *Yr6*, *Yr7*, *Yr9*, *Yr11*, and *Yr12* occurred in Kazakhstan. The loss of resistance in commercial varieties Krasnovodopadskaya 25, Yuzhnaya 12, Pamyat 47, Adir, Ozoda (*Yr1*), Skiphyanka,

Table 3. Inheritance of yellow rust resistance in F2 crosses between resistant and susceptible wheat cultivars.

Entry no.	Crosses	R:S ratio Observed	Expected	$x2$	P	Number of resistance genes
11-20	Adir x Steklovid. 24	76:31	3:1	0.89	0.20-0.50	1 dominant gene
91-100	Kyal x Steklovid. 24	54:65	27:37	0.50	0.20-0.50	3 recessive complementary genes
171-180	Lori292 x Steklovid. 24	77:36	3:1	2.84	0.05-0.10	1 dominant gene
211-220	Progress x Steklovid. 24	7:127	1:15	0.24	0.50-0.95	2 recessive complementary genes
312-320	Sansar 8 x Steklovid. 24	2:122	1:63	0.003	0.90-0.95	3 recessive genes
351-360	Sapaly x Steklovid. 24	28:95	1:3	0.32	0.50-0.95	1 recessive gene
434-440	Yanbash x Steklovid. 24	2:128	1:63	0	>0.99	3 recessive genes
1232-1241	Ulugbek 600 x Yuzhnaya 12	128:6	61:3	0.01	0.80-0.90	2 dominant, 1 recessive gene
1252-1261	Ulugbek 600 x KSI-13	134:10	61:3	1.01	0.25-0.50	2 dominant, 1 recessive gene

Table 4. Seedling and adult plant disease responses in resistant wheat germplasm.

Cultivar	Severity and infection type Seedling stage	Adult plant	Gene
Almaly	40MS-S	0	?
Arap	20MS	5MR	?
Sultan	40S	R	?
Adir	0	30MR	*Yr1* + 1 dominant gene (?)
Ulugbek	0	R	*Yr9*+ 2 dominant, 1 recessive gene (?)

? = Unknown; probably new resistance genes.

Kavkaz (*Yr9*), Taragi, SN64//SKE/2*ANE//3/SX/4Bez/5/Seri, Bittarap, Norman 3, and Tacika (*Yr6, Yr7*) could be due to the appearance of virulence to the resistance genes that protected these cultivars;
- Genetic control of resistance by dominant genes in Adir, Lori 292, and Ulugbek 600 indicates expediency of selecting in late generations (F_4-F_6); resistance based on recessive genes in Sanzar 8, Sapaly, and Yanbash allowed us to start selecting resistant lines from the F_3;
- Cultivars Almaly, Arap, and Sultan lack effective major genes and have moderate-to-good levels of resistance to local rust pathotypes. They may be useful in achieving slow rusting resistance in wheat cultivars.
- 48 entries including lines from local breeding programs, CIMMYT, and ICARDA were stable in their resistance and could be used as sources of resistance to yellow rust.

Table 5. Advanced wheat lines and entries of collections resistant to *Puccinia striiformis* f.sp. *tritici*.

Entry no.	Pedigree	Severity and field response
20/11-15-02	BC9 B-56/Spartanka	R
136/478-1-02	F_4 Zhetisu/Progress	20MR
143/480-1-02	F_4 Cornell/ Progress	10MR
165/486-1-02	F_4 25KK/Bezostaya 1	5MR
209/495-1-02	F_4 Agatha Lr19Sr25/ Komsom.1	10MR
358/528-1-02	F_4 Agatha Lr19Sr25/ Komsom.1	5MR
240/501-1-02	F_4 Zhetisu /*Timopheevii* Sr36	5MR
303/515-1-02	F_4 86AI/ Bezostaya 1	20MR
403/541-5-02	F_4 Progress/*Ae. tauschii*	10MR
498/569-1-02	F_4 Progress/*T. monococcum*	20MR
570/584-1-02	F_4 KSI-21/159Artur	20MR
576/585-1-02	F_4 KSI-21/159Artur	20MR
596/590-1-02	F_4 KSI-21/*T. monoc.* Sr35	20MR
679/607-1-02	F_4 KSI-13/94Sr36 *T. timoph.*	10MR
738/622-1-02	F_4 KSI-21/94Sr36 *T. timoph.*	20MR
770/338-1-02	F_4 KSI-3/96Lr19Sr25	10MR
819/352-3-02	F_4 KSI-21/*T. monococcum*	5MR
904/385-1-02	F_4 Zhetisu /Olesen dwarf	20MR
953395-2-02	F_4 Zhetisu /Argus	20MR
1018/409-2-02	F_4 25KK/ Progress	20MR
1072/420-2-02	F_4 Komsom.1/Argus	20MR
1088/424-2-02	F_4 25KK/97Lr19Sr25	10MR
1118/430-1-02	F_4 118SI/ Progress	10MR
1170/441-1-02	F_4 25KK/Olesen dwarf	5MR
1200/449-1-02	F_4 Progress /Mariam	10MR
1281/466-1-01	F_4 86AI/Steklovidnaya24	10MR
1302/470-1-02	F_4 Progress/*Ae. tauschii*	10MR
1347/83-02	BC9Albidum114/Krasn.210	5MR
1405/818-02	*T. ispanicum*	20MR
1418/824-02	*T. monococcum*	R
1424/827-02	*T. timopheevii*	R
1430-Zh-02	Grecum 476	20MR
1434-Zh-02	Mariam	R
1436-02	Obrii	5MR
1-A-02	Besostaya 1	20MR
10-A-02	Sapaly	10MR
13-A-02	Almaly	R
25-A-02	Naz	R
130-40A-020P	F5	20MR
135-408--020P	-"-	10MR
139-434A-020P	-"-	R
141-437A-020P	-"-	20MR
143-446A-020P	-"-	20MR
147-499A-020P	-"-	20MR
419-500-02-GF	-"-	20MR
454-576-02-GF	-"-	20MR
294-698-02-GF	-"-	R
5-72-III-02-GF	-"-	10MR

R = resistant; MS = moderately resistant; MS = moderately susceptible; S = susceptible.

Thus, the study of genetics of disease in local varieties allow to know the genetic factors conferring yellow rust resistance in commercial cultivars. Based on the genetics of donors we will be able to develop the cultivars possessing effective gene or combination of genes regarding to known virulent race of pathogen.

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Use of Haploids in Selecting Wheat for Rust Resistance

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The rust fungi, specialized parasites of wheat, are widespread in all wheat-producing regions of the world. The term "rust" includes symptomatically close diseases caused by different fungi of the genus *Puccinia*, class Basidiomycetes (Turapin and Mostovoi, 1995; Kohmetova, 1998). Significant wheat damage by stripe rust (caused by *Puccinia striiformis* West) is observed in years with fresh temperatures in the first half of summer. Stem rust (caused by *Puccinia graminis* f.sp. *tritici*) is one of the most destructive diseases of wheat. Leaf rust (caused by *Puccinia recondita* Rob. et. Desm. f. sp. *tritici* Eriks) causes frequent epidemics in almost all regions of wheat cultivation (Papilova and Loseva, 1991). The rust diseases of cereals are the main cause of yield losses in many important grain crops. Their harmful effects include decreased assimilation activity in crop plants, disturbance of physiological processes (Zhigalkina, 1986), reduced winterhardiness of winter crops, reduced glutenin formation in grain with low molecular weight, suppression of synthesis and storage of starch and proteins in the endosperm.

The rusts can reduce wheat yields by over 30% in epidemic years. A most reliable method of protecting wheat against the rusts is the introduction of new wheat cultivars resistant to these pathogens. In a process of co-evolution, many cereals have developed different mechanisms of resistance to pathogens. Wide hybridization of improved wheat and wild relatives is an effective method for improving tolerance/resistance to abiotic and biotic factors, and bettering end-use quality in wheat (Vavilov, 1987). One of the problems in breeding is how long it takes to develop new stable lines from segregant hybrid populations of wheat. One of the most effective methods for stabilizing hybrid populations is to culture isolated anthers and microspores *in vitro* (Anapiyayev, 2001a). Spontaneous or inducible doubling of chromosomes converts the haploid into a fertile homozygous plant. Haploid technology considerably reduces the time needed for producing fixed homozygous lines of wheat. In this sense, doubled haploids have great potential for use in plant breeding.

The objective of this research was to develop interspecific and wide-cross hybrids of soft wheat. Donor plants were grown under field conditions in the experimental plots of the V.R. Viliams Kazak Research Institute of Farming. *In vitro* culture of isolated anthers and microspores was conducted according to protocol (Anapiyayev, 2001b), using N6 and Blaydes nutrient media, with our modifications:

- N6 plus 1 g/l activated coil (N6+AC);
- N6 plus 80 g/l amylodextrin (N6+A).

For plant regeneration, the calli and embryos are transferred to MS media containing 20 g/l sucrose, 0.5 mg/l IAA. The calli and embryos were cultivated at 16 h photoperiod (1500 lux). Yields of the embryos and calli varied considerably. The maximum frequency of embryogenesis was observed in hybrid BC3 *Albidum 114* x *Triticum maha* (53) (15.6%). Genotype 53 on media N6+A produced 11 embryos from 20 cultivated anthers.

The high percentage of embryo induction on media containing amylodextrin is due to the fact that amylodextrin is less toxic than agar and an additional source of sugars for the developing microspores.

Green plant-regenerants, the basis for creating new doubled haploid lines, were produced during experiments with microspore culture of wide-cross hybrids.

More than 50 *Lr* genes have been described that confer rust resistance in grain crops. One of the most effective in our region is *Lr24*. A second series of experiments was conducted for developing laboratory techniques for the production of stable doubled haploid lines carrying marker gene *Lr24*. In these experiments, hybrids produced from an *Lr24* gene donor parent (isogenic line Thatcher) were used for culturing isolated microspores. Hybrids Kazakhstanskaya-17 x *Lr24*, F1 and Lutescens-70 x *Lr24*, F1 showed the highest capacity for embryogenesis *in vitro*, with embryo yields of 1.78% and 1.63%, respectively. Embryo yields of the parents were considerably lower: 0.76% for Kazakhstanskaya-17, 0.87% for Lutescens-70, and 0.45% for isogenic line *Lr24* (Table 1).

Green plant-regenerants from embryos were produced, and a laboratory technique for obtaining stable doubled haploid lines carrying marker *Lr24* gene conferring resistance to leaf rust was developed. This technique consists of several stages (Figure 1):

1) Cultivation of donor plants (intervarietal, wide intergeneric, interspecific hybrids, etc.). Hybrid materials should be sown on several dates. Under agroclimatic conditions of southern Kazakhstan, it is possible to plant 3 to 6 times if conditions are favorable, but the interval between sowing should be no *shorter* than 15 days. With this approach, embryos, morphogenic calli, and plant-regenerants can be produced from practically any genotype using *in vitro* microspore culture. Among other advantages, this method also allows researchers to determine the optimum cold pretreatment and composition of nutrient media.

2) Selection of donor plants. This is done at booting, when the base of the second leaf is located midway up the spike. However, in some dwarf wheats, this morphologic location of leaf does not always correspond to the vacuolated microspore stage. A more precise method is to use pressed preparations. The terms of donor plant cultivation can be an additional marker trait to ensure that microspores are at an optimal stage of development. The period from sowing to booting in donor plants spans 50 days on average.

3) Cold pretreatment of donor plants. This is done at 4-7°C in the dark, for a maximum of 30-40 days. If continued for a longer period, the cold pretreatment will damage the physiological condition of donor plants and have negative consequences for microspore culture. Based on our data, the optimum duration of cold pretreatment is from 3 to 20 days, depending on genotypic differences.

4) Inoculation of anthers and isolated microspores on nutrient media. The anthers of donor plants of first term are inoculated on different types nutrient media (N6, Blaydes, Murashige and Skoog, Gamborg B5, N6M, or N6P) and cultivated at 27°C in the dark. After 20-25 days it is possible to select glass tubes with

Table 1. Isolated microspore culture of soft spring wheat cultivars and hybrids carrying the *Lr24* gene.

Genotype	Number of cultivated anthers	Number of embryos obtained	(%)
Kazakhstanskaya-17	910	7	0.76
Lutescens-70	574	5	0.87
Isogenic line *Lr24*	659	3	0.45
Lutescens-70 x *Lr24*,F1	736	12	1.63
Kazakhstanskaya-17 x *Lr24*,F1	955	17	1.78

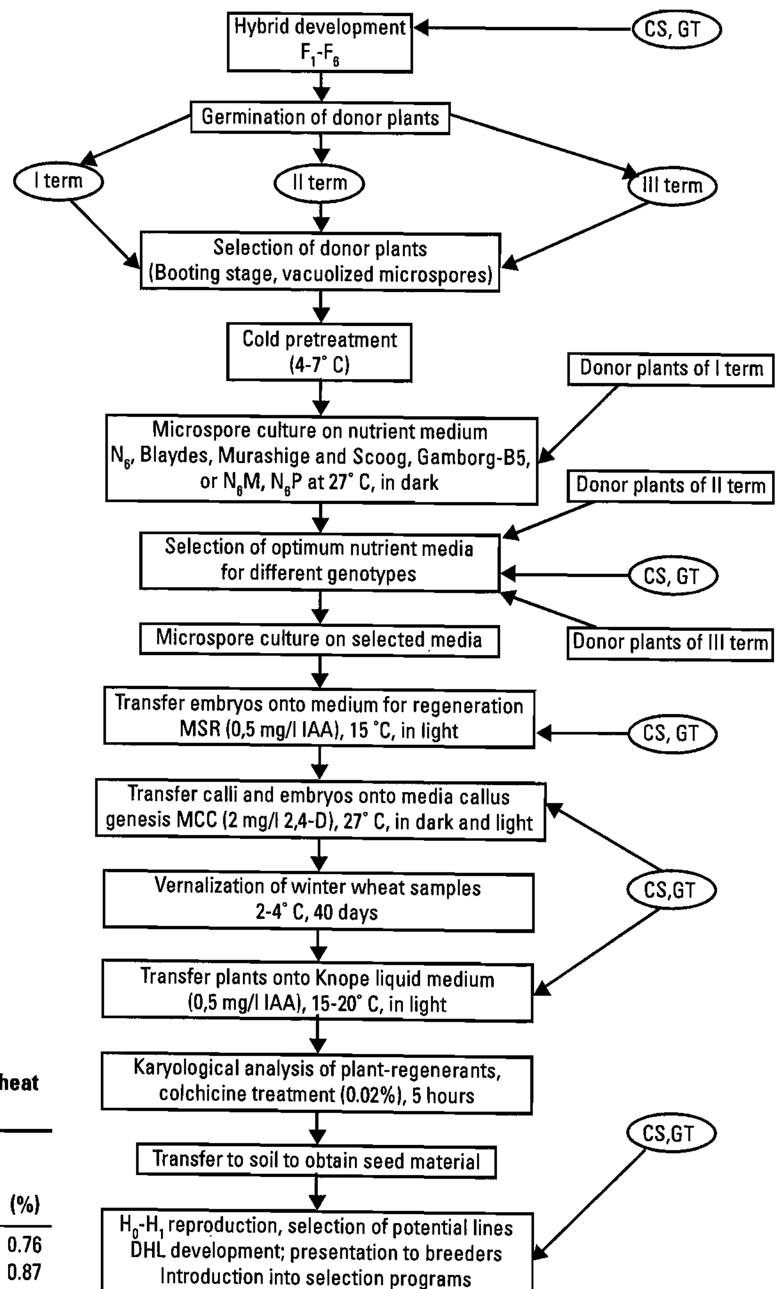

Figure 1. Doubled haploid development using *in vitro* wheat microspore culture.

embryos and morphogenic calli. Anthers and isolated microspores obtained from donor plants of second and third terms are inoculated on selected nutrient media with optimum cold pretreatment. This results in a high percentage of embryos, morphogenic calli, and plant-regenerants.

5) Embryo formation 20-25 days after beginning of cultivation. Embryos are transferred onto regeneration MCR (0.5 mg/l IAA) medium and cultivated at 15°C in light. Calli are formed 10-15 days later and then transferred onto MCC (2 mg/l 2,4-D) medium at 27°C. Depending on the objective of the experiments, the embryos can also be transferred onto media for calli genesis. In this case, embryo differentiation and morphogenic calli formation take place that can regenerate plants.
6) If plant-regenerants are obtained from winter wheat donors, it is necessary to do vernalization at 2-4°C for 40-50 days for seed production.
7) Transfer plants to Knope liquid medium containing 0.5 mg/l IAA; cultivate regenerants at 15-20°C in light to promote better root formation and facilitate karyological analysis of root tips. Haploid plants are treated with colchicine at 0.02% concentration for five hours for chromosome doubling. Colchicine treatment is a strong stress factor for plant-regenerants and frequently reduces their viability. Therefore, after colchicine treatment, the plant-regenerants are again transferred onto Knope liquid medium for recovery and improvement of physiological conditions.
8) When plant-regenerants reach tillering, they can be transferred to soil and cultivated at 27°C with photoperiod 16/8 hours for obtaining seed material.
9) Reproduction of H0-H1, selection of potential DHLs under field conditions in experimental plots. Selected potential DHLs are presented to breeders for introduction into the selection program.

This procedure—from sowing of donor plants to obtaining seed material—takes 10-12 months. It has been used successfully to develop DHLs carrying the *Lr24* gene that is responsible for resistance to leaf rust.

This technology can be used in cell selection and genetic engineering of plants. It should be noted that somatic cells (2n) are most frequently used when applying cell and genetic engineering as an aid in resistance selection. However, resistant cell lines obtained in such a way may lose their traits after a few reproductions, or segregate according to Mendel's laws. Thus it seems more reasonable from both the theoretical and practical aspects to use haploid cells (n) where genetic modification after cell selection and genetic transformation (n*) can be fixed in both loci of chromosomes after doubling (nn**, 2n*) (Anapiyayev, 2001b).

Haploid cells are frequently used for genetic transformation because they can provide stable expression of transformed genes after chromosome doubling in haploids and creation of homozygous samples. There are five different ways that haploids can be used in genetic transformation:

- Haploid (n) microspores with foreign DNA used to pollinate ovaries (*in vivo* and *in vitro*);
- Direct genetic transformation of haploid (n) cells of microspores *in vitro*;
- Genetic transformation of haploids (n) in suspension culture;
- Genetic transformation of haploid (n) calli cells, embryos and plant-regenerants;
- Culture of haploid (n) microspores of transformants obtained by use of somatic (2n) cells.

This series of experiments demonstrated the potential of haploid technology (cultivation of isolated microspores) in selecting for resistance to biotic stresses. The theoretical approach and methodology developed can be adapted for obtaining haploids of other agricultural crops and plant species, and used successfully in practical selection and cell and genetic engineering of plants.

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Controlling Foliar Blight of Wheat in South Asia: A Holistic Approach

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Abstract

Foliar blight is a major biotic constraint to wheat in the Gangetic Plains of South Asia, particularly in the rice-wheat system. The disease occurs as a complex of spot blotch and tan spot caused by Cochliobolus sativus and Pyrenophora tritici-repentis, respectively. Yield losses reach on average 15% but are variable depending on sowing time, years, locations and stress conditions. Resistance breeding has been the cornerstone of the control strategy. Through international agricultural research efforts in collaboration with national agricultural research systems (NARS), resistance sources from China, Zambia, and Brazil were identified and novel germplasm such as synthetic hexaploid wheats derived from crosses with Aegilops tauschii and tetraploid wheat were generated. Materials resulting from these pre-breeding activities are now combined to adapted spring wheat to produce new high yielding genotypes showing slower disease progress. Ongoing regional efforts include several wheat nurseries jointly organized by CIMMYT and NARS and specially targeted for warmer wheat growing areas. The stability of resistant genetic stocks remains essential considering that C. sativus is non-specific and forms a continuum of strains that may change rapidly. Although high moisture and temperature are known to favor the disease, little information is available on the exact role of climatic factors on symptom development. Stress factors appear to influence to a great extent disease progress and epidemics, suggesting that crop management practices are a critical component of integrated disease control. Understanding their role in foliar blight thus seems imperative when the increasing adoption of zero tillage in rice-wheat may affect inoculum survival and when genotypes more adapted to new tillage practices will be required. The role of alternate hosts and the source of primary inoculum in rice-wheat systems are still not well documented, but indications suggest that seed may play an important role in disease transmission. Seed treatment may prove useful as a part of an integrated disease management approach based on improved resistance and good agronomy.

In South Asia, spring wheat (*Triticum aestivum* L.) is grown during winter, from November-December to March-April. After the impressive progress in controlling leaf and stem rusts in modern varieties during and after the green revolution, foliar blight has recently emerged as the most important biotic constraint of second-generation wheat genotypes in warmer areas, in particular in the intensive rice-wheat system covering 13 million hectares in the Indian Subcontinent. The disease often occurs as a complex of spot blotch and tan spot caused by *Cochliobolus sativus* (Ito & Kurib.) Drechsler ex Dastur (anamorph *Bipolaris sorokiniana*) and *Pyrenophora tritici-repentis* (Died.) Drechsler (anamorph *Drechslera tritici-repentis*), respectively. In breeding programs where the fungi's old names are still widely used (Maraite, 1998), this disease complex is commonly referred to as helminthosporium leaf blight (HLB). In field conditions of South Asia, the anamorph stage of both pathogens is found. In the case of spot blotch, the teleomorph stage has been reported to occur only in Zambia. The tan spot pathogen's teleomorph stage is found in cropping systems where the stubble decomposes slowly and remains on the soil during the next crop cycle; this does not occur in the rice-wheat system, where paddy fields are flooded. In South Asia, foliar blight becomes more evident in mid-February as a result of rising temperatures and heavy dew that may remain in the crop canopy for several hours on foggy winter days.

Yield losses average up to 15%, depending on sowing time, year, location, and stress conditions

(Duveiller and Dubin, 2002). Late wheat sowing reduces yield because flowering coincides with hot winds or high temperatures that occur at the end of the following rabi (winter) season. When the crop is sown after optimum planting time (end of November-early December) or if the soil fertility is low, the effect of the disease on grain yield increases dramatically and may cause losses of up to 34% (Sharma and Duveiller, 2002).

Management of HLB has received more attention in recent years because of the urgent need to increase crop productivity and ensure food security in the warmer wheat growing areas of the Indian Subcontinent (Duveiller et al., 1998; Duveiller, 2002). Moreover, concerns have emerged regarding the sustainability of the rice-wheat system in South Asia, its decreasing total factor productivity (Hobbs and Morris, 1996), the role of foliar blight, and the need to adopt new tillage technologies to produce rice and wheat at a lower cost. This paper summarizes the strategy being used in South Asia to better control foliar blight.

Materials and Methods

Field surveys are conducted on regular basis in Bangladesh, India, and Nepal to assess the incidence of both foliar blight pathogens. In Nepal, detailed epidemiological studies were conducted for two years (2001-2002 and 2002-2003) at IAAS, Rampur (228-masl, 27° 40' longitude and 84° 19' latitude) to evaluate possible inoculum sources for both pathogens, and to observe symptom initiation and production of *B. sorokiniana* and *D. tritici-repentis* spores throughout the wheat season in six genotypes with different levels of HLB resistance. In this study, the amount of air-borne conidia was monitored on a weekly basis during 17 weeks from plant emergence using a Rotorod® Model 20 sampler (Multidata LLC, St Louis, USA) installed in trial plots to investigate the correlation with conidia formation on wheat leaves.

Since disease severity increases very quickly in the field and small differences indicating partial resistance need to be observed, disease evaluation is usually based on the area under the disease progress curve (AUDPC) calculated from a minimum of three field observations. For each disease rating, the percent diseased leaf area (%DLA) can be assessed on the flag (F) or penultimate (F-1) leaf, but this method is time consuming. Alternatively, HLB severity in each plot can be visually scored at weekly intervals using the double-digit scale (00-99) developed as a modification of Saari and Prescott's severity scale to assess wheat foliar diseases (Saari and Prescott, 1975; Eyal et al. 1987). The first digit (D_1) indicates the disease progress in height; the second digit (D_2) refers to severity measured as diseased leaf area. For each score, %DLA was estimated based on the following formula:

$$\%DLA = ((D_1/9) \times (D_2/9) \times 100)$$

Individual scores are recorded over a three-week period. The AUDPC is calculated using percent severity estimates corresponding to the three to four ratings as outlined by Das et al. (1992) and shown below:

$$AUDPC = \sum_{i=1}^{n-1} [(x_i + x_{i+1})/2] (t_{i=1} - t_i),$$

where, x_i = disease severity on the *i*th date, t_i = *i*th day, and n = number of scoring dates. The AUDPC measures the amount of disease as well as the rate of progress, and has no units.

Because the sustainability of the rice wheat system is being questioned, foliar blight severity was also assessed in a long-term trial in Bhairahawa (Nepal), where different fertilizer levels have been used. Similarly, because sowing time can be advanced by up to 15 days when a resource conserving technique such as zero tillage is used, the effect of sowing time on yield and disease is analyzed to assess the potential impact of changing cropping practices. In a study conducted in two locations in Nepal to assess the effect of stress on disease development, disease severity was compared under optimum and low fertility (Sharma and Duveiller, 2002).

Pre-breeding is conducted at selected hot-spot locations in Nepal and Bangladesh. This includes evaluating local and exotic sources of foliar blight resistance in unreplicated trials to assess genetic stocks. Recent introductions include doubled haploids, exotic materials from warmer areas (e.g., China, Zambia, and Brazil), and wide cross derivatives. After validating resistance, the materials are made available to cooperators as parental lines for new crosses and included in CIMMYT's germplasm bank. Another aspect of pre-breeding is the Helminthosporium Monitoring Nursery (HMN), which is proposed on regional basis to evaluate resistance stability (genotype x environment). The nursery includes parental materials of different geographical and genetic origins that may not have the proper agronomic type for the region, synthetic hexaploids resulting from crossing tetraploid wheat with *Ae. squarrosa* (syn. *T. tauschii*), and a few advanced lines produced by breeders in South Asia. A core of entries remains the same over years to assess any change in resistance but several lines are changed every year.

Due to the need for increasing wheat production in marginal areas where the yield gap between farmers' fields and experiment stations is still very high, a new regional breeding effort was initiated to specifically promote materials targeted towards warmer areas. The Eastern Gangetic Plain Screening Nursery (EGPSN), organized in 1997, includes a set of 150 entries proposed by national programs breeders who share their best advanced lines for testing across hot-spot locations. Data are summarized by CIMMYT's regional office and returned to cooperators (Ortiz-Ferrara et al., 2003). After evaluation, the best entries are recycled into national breeding programs or become part of the Eastern Gangetic Plain Yield Trial (EGPYT) before being proposed for release or evaluated directly by farmers through participatory varietal selection (PVS) at the village level. This method is very effective, as small farmers are able to give their input and choose among a set of advanced materials before new varieties are released; this increases the chance that they will adopt the improved genotypes (Ortiz-Ferrara et al., 2001). Lastly, although fungicide treatments are not a viable option, we also assess the benefits of seed treatments on plant establishment by comparing several chemicals available on the local market.

Results and Discussion

Field surveys conducted over several years showed that tan spot is largely overlooked. This was particularly well documented in Nepal, where *P. tritici-repentis* was isolated easily during four years from samples collected not only in the mid-hills, where the climate is cooler, but also in the warmer lowland areas (Sharma et al., 2002b). *Bipolaris sorokiniana* isolates, unlike rusts, do not show clear virulence patterns and consist of a continuum of strains differing in aggressiveness (Maraite et al., 1998). The epidemiological study conducted at Rampur showed that *B. sorokiniana* could be isolated from plant tissues sampled as early as the seedling stage, whereas *P. tritici-repentis* was isolated on lesions observed at near-booting stage, 10 weeks after sowing. This observation suggests that seed or soil is probably an initial source of inoculum for *B. sorokiniana*, whereas *P. tritici-repentis* infection might result primarily from air-borne spores possibly coming from alternate hosts (Sharma et al., 2002a). Later in the season, air-borne conidia caught in the spore trap are predominantly *B. sorokiniana* due to the profuse multiplication of this fungus during secondary infection cycles.

In South Asia it is crucial to favor resource conserving technologies that allow farmers to sow wheat early and avoid post-anthesis heat stress and drastic yield reductions. As indicated, early wheat sowing can be promoted by a range of options such as zero tillage or reduced tillage. Zero-tillage allows wheat to be sown up to 15 days earlier, which on average increases yields 10-25% over conventional practices. However, early wheat sowing seems to be characterized by higher HLB severity, probably due to the high relative humidity and residual soil moisture that prevail early in the wheat season. In 2002, we observed that AUDPC could increase by as much as 30% in varieties sown 15 days earlier. Thus, even though yield increases with early sowing when adopting resource conserving technologies, there might be trade-offs due to a lack of HLB resistance. The effect of seeding date was significant ($P<0.01$), and AUDPC was lower in late planting (Sharma et al., 2002a).

Recent studies of a long-term trial in Nepal showed the importance of potash in reducing foliar blight severity. The AUDPC decreased by 50% when 40 kg of K_2O was applied in a deficient soil (Regmi et al., 2002). Potassium prolongs the canopy's stay-green character. Many locations in South Asia present potassium deficiencies, yet most farmers do not apply this nutrient for several socio-economic reasons. Similarly, when farm-yard manure (FYM) is applied (10 t/ha), the AUDPC drops by 30%, suggesting not only that FYM contains a significant amount of potassium, but that copious levels of organic matter are beneficial and reduce disease severity. The study, conducted at two locations in Nepal in 2002 (Table 1), showed that foliar blight

Table 1. Mean AUDPC and reduction in grain yield and thousand-kernel weight due to foliar blight under optimum and low soil fertility, averaged over three genotypes at two sites (Rampur and Manara) in Nepal, 2001-2002.

Applied fertilizer (kg/ha)		Reduction due to foliar blight					
		Grain yield (kg/ha)			1000-kernel weight (g)		
$N:P_2O_5:K_2O$	AUDPC	Non-sprayed	Sprayed	Loss (%)	Non-sprayed	Sprayed	Loss (%)
120-60-40	414	2583	3144	17.8**	35.0	42.3	17.4**
0-0-0	544	1050	1602	34.5**	30.4	41.0	25.9**
Loss (%)		59.3**	49.0**		13.2**	3.2	

** = $P<0.01$.

severity (AUDPC) and yield losses (grain yield and thousand-kernel weight) are higher when soil fertility is low, confirming that non-specific pathogens causing foliar blight are favored when the crop is under stress.

Genetic stocks are currently being tested at specific hot-spots such as Bhairahawa, where the Nepal national wheat research program is located, to confirm the resistance of parental lines. Some of the best entries are given in Table 2.

Sources of resistance include wheat materials from China, Zambia, and Brazil, and novel germplasm such as synthetic hexaploid wheats derived from *Ae. tauschii* x tetraploid wheat crosses. In China, genotypes from Heilongjiang, Sichuan, and the Yangtze River Valley are characterized by a very short, efficient grain-filling period resulting from the warmer conditions occurring at the end of the growing season in these areas. This trait may explain the high resistance to foliar blight and again underlines that resilience to stress conditions is important to limit the disease.

An analysis of the performance of 17 common genotypes included in the HMN over three cropping seasons (2000-2002) is presented in Figure 1 showing a biplot based on decreasing average resistance (higher AUDPC) compared to an ideal genotype computed from field observations (Yan and Kang, 2002). Results confirmed the superiority of entries from China and novel sources of resistance such as derivatives from synthetic hexaploid wheats and Ae. squarrosa crossed to Chinese or CIMMYT materials. It also indicates the degree of similarity between testing locations which, in turn, can help scientists to decide on the relevance of testing materials at each of the sites and reduce unnecessary research costs.

Interestingly, the best grain yield performance is not necessarily obtained by entries scoring a low AUDPC, as shown in recent EGPSN results (Ortiz-Ferrara et al., 2003). This observation underlines the importance of general environmental adaptation, particularly to abiotic stresses such as heat. It also confirms that foliar blight resistance is still moderate and needs further improvement. No source of resistance gives high resistance in early maturing genotypes, although there are several materials combining high yield and low disease infection (Table 3). Better resistance levels in adapted genetic backgrounds may be obtained through the use of careful crossing and selection methods (Sharma and Duveiller, 2003).

Table 2. Wheat genotypes among genetic stocks observed in Bhairahawa (Nepal) in 2001 with particularly low HLB levels, ranging from 51 to 72 (00-99, double-digit scale).

Parentage	Days to heading date	Diseases March 15 2001 HLB	Leaf rust
MILAN/SHA7	1-Mar	51	0
SW89-3060	8-Mar	51	TMS
SW89-3064	5-Mar	51	0
SW89-5422	1-Mar	51	5MR/MS
TURACO/CHIL//PRINIA	4-Mar	51	0
UP 2472	13-Mar	51	0
CHIRYA-7	1-Mar	52	0
Mayoor = CS/A.CURV.//GLEN/3/ALD/PVN	6-Mar	52	TS
DL153-2	4-Mar	71	0
GISUZ/SABUF	3-Mar	71	0
K9606	8-Mar	71	0
SERI82//VEE"S"/SNB"S"/3/ LAJ3302/TURACO//TURACO	6-Mar	71	0
TRAP#1/BOW//CBRD	9-Mar	71	0
WEAVER/JAKANA	9-Mar	71	0
BL2047 =DANIAL88/HLB25//NL297	27-Feb	72	0
CHIRYA-3	28-Feb	72	0
DOVIN-2	3-Mar	72	TMR
NING8201	28-Feb	72	10MS
RR21 (Syn. Sonalika) (Local Check/Susceptible)	25-Feb	99	40S

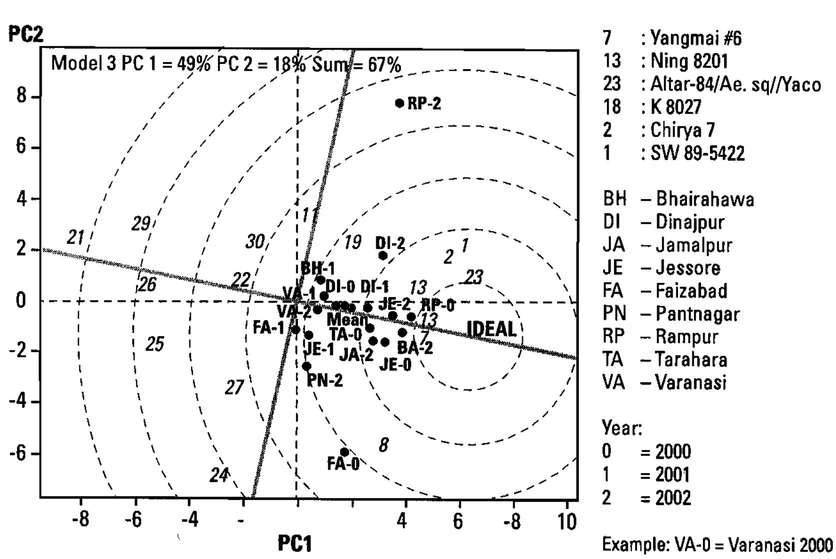

Figure 1. Biplot comparing 17 genotypes to an ideal cultivar based on decreasing resistance to foliar blight (AUDPC) in 19 environments of South Asia.

Since the primary source of foliar blight inoculum is not exactly known, appropriate management practices that enhance crop establishment and plant health at an early stage are critical. Options for controlling tan spot and spot blotch include sowing disease-free seed. Preliminary results using fungicide seed treatments indicate that the effect of these treatments on the number of infected seedlings per m^2 was not significant. However, there was an effect ($P<0.01$) on plant establishment and tillering vigor, suggesting that these options should be considered. But due to the overwhelming importance of airborne inoculum of this polycylic disease, this effect does not translate into a significant increase in grain yield (Table 4).

Conclusions

As presented in this paper, foliar blight control in South Asia is based on a combination of epidemiology, pre-breeding efforts, breeding, and crop management. Further epidemiological studies are needed to understand factors promoting disease outbreaks and causes of increased severity in the rice-wheat system of South Asia. Recent studies suggest that tan spot incidence, though overlooked, is not negligible. Germplasm is paramount. Since the disease is rather new, the genetic basis of host resistance to HLB is relatively narrow and presently limited to Chinese materials and derivatives of wide crosses combined with CIMMYT materials. There is a need to broaden the sources of variability and identify new resistant materials. Very little is known on the inheritance of resistance genes effective against spot blotch and tan spot, and field genetic studies are highly needed. The task is complicated by the similarity of symptoms induced by the two pathogens, which most probably trigger different resistance genes, and the limited areas where these studies can be conducted on one disease (tan spot or spot blotch) at a time. The role of crop rotation and fertilization seems equally important, but the long-term effects of using new resource conserving cultural practices will need to be monitored. In summary, controlling foliar blight in wheat is complex and requires a holistic approach. It must be included in technological packages aimed at making small-scale wheat production more cost-effective and sustainable, particularly in warmer areas.

Table 4. Effect of seed treatment observed in susceptible genotype Sonalika in Rampur, Nepal, during the 2001-2002 crop season.

Treatment	Emergence/m²	+ %	Infected seedlings/m² 12/23/2001	Number of tillers per 2-m row	Grain yield (t/ha)
Vitavax-200	50.7	43.2	2.6	72.9	2.63
Bavistin	41.3	16.3	2.0	69.4	2.44
Simonis Carbendazime	52.9	49.2	2.9	69.4	2.48
Check (untreated)	35.4		2.1	59.9	2.44
	P<0.01		NS	P<0.01	NS

Table 3. Top 20 entries showing high grain yield and low disease infection in the 5th EGPSN sown at 13 locations of the Eastern Gangetic Plains (2001-2002).

Genotype	GYP*	Rank	TKW	Rank	DH	Rank	HDS%	Rank	AUDPC	Rank
Shatabdi (=MRNG/BVC//BLO/PVN/3/PNB 81)	413	1	41	21	76	101	65	40	320	46
CHIRYA-3 (HLB Resistant Check)	411	2	36	109	77	110	65	4	293	28
NL 724/NL 750	398	3	38	61	78	114	71	21	292	27
DANIAL88/CHILERO//BHRIKUTI	397	4	36	109	70	25	62	78	394	90
90B57/4/R37/GHL121//KAL/BB/3/JUP/MUS/5/SW 90.1057	386	5	36	109	78	116	72	57	319	44
HPO/TAN//VEE/3/2*PGO/4/CROC-1/AE.SQ (213)//PGO	385	6	40	36	74	86	58	51	283	25
PBW 475	384	7	38	61	83	148	68	2	195	1
HW 90.1057/3/HE 1/3*CNO 79//2*SERI	383	8	36	109	80	129	75	13	253	10
BL 1048*/BB/TOB//CNO 67/3/HUAC/4/TIRESEL/4/BB/PL*/5/SX	379	9	41	21	69	21	49	123	503	138
HUW 542	378	10	35	132	82	144	77	39	262	13
PBW 343/CHIR 3	376	11	40	36	78	115	65	29	317	42
PBW 343 (Improved Check from India)	376	11	37	84	81	139	70	7	214	5
CATBIRD	375	13	36	109	83	146	67	45	308	36
DL 784-3/VEE#7//PRL/UP 262/3/CHIRYA -7	372	14	42	10	77	102	67	61	372	78
NAC/VEE'S'//ATTILA	372	14	40	36	72	50	54	42	351	67
PEWIT 3	370	16	39	47	78	119	70	70	415	99
RAYON F 89	369	17	38	61	77	108	60	34	311	39
KANCHAN (Improved Check from Bangladesh)	368	18	41	21	72	54	59	133	443	120
LOCAL CHECK	367	19	38	61	71	45	56	60	379	80
BCN*2/4/SHA7//PRL/VEE#6/3/FASAN	366	20	35	132	77	111	65	28	273	19

* GYP (g/plot); days to heading (DH); 1000-kernel weight (TKW); highest disease score (% diseased leaf area); AUDPC: area under the disease progress curve; and rank: ranking out of 150 lines.

Farmers are increasingly involved in this research process, and the whole production system must be considered. More than ever, controlling foliar blights requires a multidisciplinary team effort.

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Utilization of *Thinopyrum* spp. in Breeding Winter Wheat for Disease Resistance, Stress Tolerance, and Perennial Habit

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The genus *Thinopyrum* (tribe Triticeae) consists of perennial species that are widely distributed geographically, many of which are relatively easily crossed to both *Triticum aestivum* and *Triticum durum*. Stable amphiploids and partial amphiploids can be produced at high frequency. These features have allowed *Thinopyrum* spp. to be exploited as an important source of disease resistances in wheat breeding programs (reviewed in Jones et al., 1995). Here we report on the successful integration of a new resistance to *Cephalosporium gramineum* (causal agent of Cephalosporium stripe) from *Th. ponticum* into adapted winter wheat germplasm. We also report on our ongoing efforts to integrate with more complex traits from *Thinopyrum* spp., such as perennial habit, stay-green trait, drought tolerance, emergence, stand establishment, and more quantitative disease and pest resistances and tolerances.

Cephalosporium stripe, caused by the fungus *Cephalosporium gramineum* Nisikado and Ikata, is one of the most important diseases of winter wheat (*Triticum aestivum* L., 2n=6x=42) in the U.S. Pacific Northwest (PNW). Yield losses caused by this disease can be as high as 78% (Johnston and Mathre, 1972). There is no chemical control available for Cephalosporium stripe. Cultural practices, such as crop rotation, straw residue destruction, and delayed seeding, provide some measure of disease control (Martin et al., 1983). However, these control measures are not always effective and practical under the PNW conditions. The preferred method to control Cephalosporium stripe would be the use of resistant cultivars. However, no resistance genes to the disease have been identified in wheat or species in the *Triticum* complex.

The wild perennial relatives of wheat, *Thinopyrum ponticum* (Podp.) Barkworth & D.R.Dewey [syn. *Lophopyrum ponticum* (Podp.) A. Love, *Agropyron elongatum* (Host) Beauv, 2n=10x=70] and *Th. intermedium* (Host) Barknorth & D. R. Dewey [syn. *Agropyron glaucum* Roem. et Schult., *A. intermedium* (Host) Beauv., *Elytrigia intermedia* (Host) Nevski, 2n=6x=42], are highly resistant to Cephalosporium stripe (Mathre et al., 1985). These two *Thinopyrum* species have been extensively hybridized to wheat and many wheat-*Thinopyrum* amphiploids, addition, substitution, and translocation lines have been produced from those crosses (Larson and Atkinson, 1970; Dvorak, 1976; Shepherd and Islam, 1988; Jiang et al., 1993; Friebe et al., 1994; Xu et al., 1994; Zhong et al., 1994; Chen et al., 1995; Cai et al., 1996; Zhang et al., 1996). These wheat-*Thinopyrum* derivatives are useful intermediates for transferring desirable traits from these two *Thinopyrum* species to wheat. The partial wheat-*Th. ponticum* amphiploid "AT 3425" (2n=56) was identified to be highly resistant to Cephalosporium stripe (Mathre et al., 1985) and carry seven pairs of *Th. ponticum* chromosomes, three pairs of wheat-*Th. ponticum* translocated chromosomes, and eighteen pairs of wheat chromosomes (Cai et al., 1998). In the present study, we used the partial wheat-*Th. ponticum* amphiploid AT 3425 that has a high crossibility with wheat to transfer the resistance of *Th. ponticum* to Cephalosporium stripe into wheat. *Th. ponticum* chromatin conferring the resistance to Cephalosporium stripe was successfully incorporated into wheat and characterized cytogenetically.

Materials and Methods

Plant materials and hybridization

The wheat-*Thinopyrum* amphiploid AT 3425 was identified to be a partial *T. aestivum-Th. ponticum* amphiploid (2n=56) (Cai et al., 1998). The two advanced winter wheat breeding lines, J99C0009 and J99C0010, were derived from the cross between AT 3425 and the adapted winter wheat cultivar Madsen. The winter wheat cultivar susceptible to Cephalosporium stripe Stephens and the winter wheat breeding line showing resistance to the disease PI 561033 (Cai et al., 1996) were used as controls for disease resistance evaluation.

Madsen was used as a female parent to cross with AT 3425 by the conventional hybridization technique in the greenhouse. Madsen was then used as a recurrent parent to backcross once to the F_1 hybrid. After that, BC_1 individuals were allowed to self-pollinate for six generations. The resistant lines to Cephalosporium stripe, J99C0009 and J99C0010, were selected from the BC_1F_4 generation.

Disease evaluation and selection

Disease evaluation started at the BC_1F_2 population by inoculating the field using oat kernels (approximately 318 kg ha^{-1}) colonized by *C. gramineum*. Visual assessment of disease resistance was carried out to select resistant individuals from the BC_1F_2 population. A relative scale based on reaction of the controls to the disease was used. Seeds from the selected BC_1F_2 individual plants resistant to Cephalosporium stripe were planted in plots in the BC_1F_3. Heads of the BC_1F_3 individuals showing less disease than Madsen were selected and planted as head rows. Continuous selection for resistant individuals was performed to the segregating head rows. Resistant and uniform head rows were harvested and planted as plots.

The selected resistant lines were planted in the field in a randomized complete block design with four replicates (2.4 x 4.9 m; eight-rows with 0.3 m between rows). All the plots were inoculated by oat kernels (approximately 318 kg ha-1) colonized by *C. gramineum* in October (Bruehl et al., 1986). Incidence and severity of Cephalosporium stripe were determined after anthesis by removing stems in 0.5 m sections of a row from each plot. Individual stems were rated for the severity of Cephalosporium stripe symptoms with a 0-4 scale; where 4 = stems with stripes in the flag leaf, or extending to the head, 3 = stems with stripes in the leaf subtending the flag leaf, 2 = stems with stripes in the second leaf down, 1 = stems with stripes in the third leaf down, and 0 = stems with no symptoms in the upper four leaves (Specht and Murray, 1990). Disease incidence (DI) was calculated as the percentage of stems with symptoms in the uppermost four leaves. Disease severity (DS), which represents the extent of colonization of the plant, was the mean severity of the symptomatic stems (Murray et al., 1992; Specht and Murray, 1990). A disease index was calculated as [(DI x DS)/4] x 100 to reflect both components of disease. Disease incidence, severity, and index were subjected to analysis of variance. Fisher's least significant difference ($P = 0.05$) was used to differentiate genotype mean values.

Genetic analysis

Chromosomes in the F_1 hybrid of Madsen with AT 3425 and the BC_1F_2 were counted using the method described by Cai and Liu (1989). Both fluorescent genomic *in situ* hybridization (FGISH) and C-banding were used to analyzed chromosome constitutions of the lines resistant to Cephalosporium stripe. For FGISH, total genomic DNA of *Th. ponticum* was labeled as the probe with biotin-16-dUTP by nick translation (Enzo Diagnostics Nick Translation). Total genomic DNA of CS sheared by boiling in 0.4 M NaOH for 40-50 min was used as blocking DNA for FGISH. The hybridization and signal detection of FGISH were carried out as described by Mukai et al. (1993). The C-banding technique employed in the present study followed the procedure of Gill et al. (1991).

Results

The partial wheat-*Th. ponticum* amphiploid AT 3425, which is highly resistant to Cephalosporium stripe, was used as an intermediate to transfer the disease resistance of *Th. ponticum* into wheat. The BC_1F_2 population showed a significant variation of disease resistance to Cephalosporium stripe among the individuals.

Four hundred and sixty-seven BC_1F_2 individual plants resistant to the disease were selected and planted in plots in the fall of 1996. From 467 BC_1F_3 plots, 1278 single heads from the resistant plants were selected and planted as head rows in the fall of 1997. Starting from 1998, uniform and resistant head rows have been harvested in bulks and placed in the yield trial for further evaluating their resistance to Cephalosporium stripe and other agronomic characteristics. In 2000 and 2001, the line J99C0009 resistant to Cephalosporium stripe showed the highest yield and best end-use quality among the 24 resistant breeding lines and 4 controls, including Madsen, Stephens, PI 561033, and AT 3425. J99C0010 highly resistant to the disease also showed desirable yield and end-use quality. Disease resistance levels of both J99C0009 and J99C0010 were significantly higher than the controls Madsen and Stephens. The yield trial in the second year of these two lines with other lines resistant to Cephalosporium stripe is being carried out in the field.

Both J99C0009 and J99C0010 were found to have 42 chromosomes that pair as 21 bivalents during meiosis (data not shown). One pair of wheat- *Th. ponticum* translocated chromosomes were detected from these two lines using FGISH. Only a small piece of *Th. ponticum* chromatin translocated with the terminal region of one of the wheat chromosomes in these two lines. The translocated chromosomes in both of the two lines showed a similar FGISH pattern and physical characteristics. Moreover, FGISH patterns of the translocated chromosomes are similar to the wheat-*Th. ponticum* translocated chromosome 3DS·3DL-3TL in AT 3425 (Cai et al., 1998). C-banding of mitotic chromosomes in J99C0009 showed the regular common wheat (*T. aestivum* L.) chromosome constitution. The chromosome 3D in J99C0009 exhibited a similar C-banding pattern to the translocated chromosome 3DS·3DL-3TL in AT 3425 (Figure 1 and Cai et al., 1998).

Figure 1. Fluorescent Genomic *in situ* Hybridization of line J99C009 using a *Thinopyrum ponticum* genomic DNA probe. The results show that the line is euploid (2n= 42) and carries a terminal translocation of *Thinopyrum ponticum* chromatin on a pair of wheat chromosomes.

Several of the historic amphiploids utilized in the Cephalosporium breeding effort were found to be perennial under field conditions in Washington State. We have initiated a breeding program to perennialize wheat utilizing these lines, as well as many newly produced amphiploids and partial amphiploids between adapted annual winter wheat varieties and accessions of *Thinopyrum* spp. that have been found to be highly adapted to Washington State conditions (Scheinost et al., 2001). Such lines may prove to be valuable tools for combating the severe water erosion associated with annual cropping on the steep hills of the Palouse region of the PNW and the wind erosion associated with summer fallow cropping systems in extremely arid regions. Such lines typically stabilize as octaploids maintaining the majority of the *T. aestivum* genome and a complete complement of seven homoeology groups from the *Thinopyrum* spp. donor (Cai et al., 2001). We are currently characterizing crosses to adapted wheats utilizing *Thinopyrum* species as the recurrent female parent. These lines typically stabilize as decaploids and show considerable promise for use in arid dryland farming regions of the PNW (under 250 mm annual percipitation).

Lines from these programs display novel traits associated with high degrees of resistance and tolerance to biotic (Cox et al., 2002) and abiotic stresses. We are investigating a number of back-crossed lines with significantly altered senescence patterns ("stay-green" traits), a trait associated with drought tolerance in sorghum, maize, and the *Festuca/Lolium* complex. The stay green trait has been introduced into annual wheat from two separate sources: partial amphiploids between wheat and *Th. ponticum,* and partial amphiploids between wheat and *Th. intermedium*. Other workers have found that the most common cause of stay green phenotypes is a lesion in the chlorophyll catabolic pathway. Such mutations are not correlated with drought tolerance.

To confirm that the trait present in our lines represents an actual alteration in the timing of the onset of senescence, flag leaves subtending ripening heads at the point of physiological grain maturity were fixed for histochemical analysis from stay green and wild-type siblings. Mesophyll cells from wild-type plants showed the presence of oil droplets and failed to stain for the presence of starch granules within chloroplasts, signs associated with the onset of normal senescence associated with physiological maturity. In contrast, the stay green plants showed no oil droplet formation, and stained strongly for starch granules, indicating that the leaves remain photosynthetically active in these plants at a time when wildtype flag leaves are senescing. We are therefore currently working to determine the chromosomal basis of this phenotype using GISH, and to establish the degree of drought tolerance in these lines.

Conclusions

AT 3425 is a partial *T. aestivum-Th. ponticum* amphiploid with 56 chromosomes and highly resistant to Cephalosporium stripe. Seven pairs of *Th. ponticum* chromosomes and three pairs of wheat-*Th. ponticum* translocated chromosomes were identified in the amphiploid in addition to 18 pairs of wheat chromosomes (Cai et al., 1998). The large amount of *Th. ponticum* chromatin in the amphiploid carries genes conferring desirable traits, such as resistance to Cephalosporium stripe, and also genes conferring undesirable traits, such as late maturity and unsatisfactory end-use quality. Therefore, this amphiploid cannot be used directly in wheat production. However, AT 3425 is a useful "bridge" to transfer the resistance of *Th. ponticum* to Cephalosporium stripe to wheat because this amphiploid carries wheat genomes besides *Th. ponticum* genome and has high crossibility with wheat. In the present study, the Cephalosporium stripe resistance of AT 3425 was successfully transferred to wheat by crossing AT 3425 to the adapted winter wheat cultivar Madsen. Advanced breeding lines resistant to the disease were developed.

Advanced winter wheat breeding lines J99C0009 and J99C0010 were identified as being highly resistant to Cephalosporium stripe and possessing desirable performance of yield and end-use quality (Table 1). FGISH indicated that J99C0009 and J99C0010 carry a small piece of *Th. ponticum* chromatin involved in the terminal wheat-*Th. ponticum* translocation. No genes for Cephalosporium stripe resistance have been found within wheat genomes (Mathre et al., 1977). Therefore, it can be concluded that the small piece of *Th. ponticum* chromatin in these two lines carries resistance gene(s) to Cephalosporium stripe.

Alien genes can be introduced to wheat from the relatives of wheat by producing wheat-alien species amphiploid, chromosome addition, substitution, and translocation lines (Shepherd and Islam, 1988; Jiang et al., 1994; Jones et al., 1995). Chromosomal translocation between wheat and alien species is the most desirable approach to transfer alien genes to wheat because less amount of alien chromatin is incorporated into wheat through wheat-alien species translocations than amphiploids, additions, and substitutions. Wheat-alien species translocation allows introduction of an alien chromosome fragment that carries the target gene(s) to wheat, which reduces the chance of bringing in unwanted genes to wheat by linkage drag. The terminal wheat-*Th. ponticum* translocation in J99C0009 and J99C0010 just carries a small piece of *Th. ponticum* chromatin. No undesirable genes have been identified from this piece of *Th. ponticum* chromatin in addition to the resistance gene(s) to Cephalosporium stripe. Thus, the resistance gene(s) to Cephalosporium stripe was successfully transferred to wheat, and the unwanted genes of AT 3425, such as those conferring late maturity and unsatisfactory end-use quality, were eliminated.

Table 1. Yield and test weight of control and test lines in a *Cephalosporium* inoculated field.

	bu/a	lbs/bu
Madsen	79.3	58.1
Stephens	51.0	54.5
J99C0009	90.6	61.3
J99C010	98.2	63.4

Madsen and Stephens are *Cephalosporium* sensitive varieties, and J99C009 and J99C010 carry a small translocation of *Thinopyrum ponticum* chromatin. Yield is expressed as bushels per acre, and test weight is expressed as pounds per bushel.

The wheat-*Th. ponticum* translocated chromosome in J99C0009 and J99C0010 C-banding showed an FGISH pattern similar to the translocated chromosome 3DS·3DL-3TL in AT 3425 (Figure 1 and Cai et al., 1998). There is no mutation induction factors involved in the development process of these two lines and homoeologous chromosome pairing between wheat and *Th. ponticum* chromosomes is very rare (Cai et al., 1997). Thus, the possibility of spontaneous translocation occurring between wheat and *Th. ponticum* chromosomes is very low in the cross of AT 3425 with Madsen. Furthermore, the wheat-*Th. ponticum* translocated chromosome in J99C0009 showed a C-banding pattern similar to the translocation 3DS·3DL-3TL in AT 3425 (Figure 1 and Cai et al., 1998). All these results indicated that the wheat-*Th. ponticum* translocation in J99C0009 and J99C0010 may be the same as the translocation 3DS·3DL-3TL in AT 3425.

We have successfully integrated a new source of Cephalosporium stripe resistance from *Th. ponticum* into lines of soft white winter wheat that are highly adapted to the PNW. This resistance is associated with a small terminal translocation of *Th. ponticum* chromosome. This program has yielded a number of new amphiploids and partial amphiploids with perennial growth habit, and phenotypes associated with drought and other stress tolerances.

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Water Use Efficiency of Winter Wheat in Irrigated Areas of Central Asia

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Water use efficiency in irrigated winter wheat requires special attention given the growing water shortage in the region. Water has become a key factor determining the future of wheat in irrigated areas. At the same time, only an integrated approach that takes into consideration all grain production factors and potential negative impacts can ensure sustainable winter wheat cropping under irrigated conditions. Because irrigated winter wheat causes significant changes in water and salt levels in the soil and in the seasonal distribution of drainwater, land reclamation practices need to be corrected.

By analyzing the present status of agricultural development and water management, results achieved in grain production can be evaluated and plans for the future drawn up. At present agricultural development includes: (1) the establishment of small farms and low probability of large investment projects; (2) the replacement of cotton/alfalfa crop rotations with winter wheat and cotton fields; and (3) the use of cotton/wheat rotations, as in the last cropping cycle. For example, in Tajikistan the wheat area in 1990-2000 increased from 143.4 to 343.1 thousand hectares; in Turkmenistan from 187.3 to 727.0 thousand hectares; and in Uzbekistan from 456.7 to 1144.9 thousand hectares. These increases were achieved mainly by reducing the area sown to fodder crops (including alfalfa). In addition to grain produced under rainfed conditions, wheat now covers a quarter of the irrigated area in the region.

At present the status of water management in the region is as follows: (1) water shortages mid- and downstream in the rivers; (2) a sharp reduction in financing; and (3) the gradual establishment of a new type of water management: water user associations. These features of current agricultural development and water management, based on inefficient technologies for water and soil resources use, have resulted in some negative processes. These processes have specific characteristics in sloping upstream areas and in flat areas located mid- and downstream in river basins. Characteristics in sloping areas are:

- Under semi-humid rainfed conditions on brown carbonate soil, erosion increased to 1.6 and soil losses exceeded 4.0 t/ha because of replacement of perennial grasses with winter wheat.
- Soil erosion also increased on irrigated typical sierozem. Soil losses exceeded 3.0-4.0 t/ha because irrigation dominates in intensely sloping areas. Soil erosion can reach 8.0 t/ha and more when maize is grown for silage after winter wheat. High winter wheat yields in sloping areas may not be sustainable because of the gradual reduction in soil fertility, and urgent measures are needed to halt soil erosion.

In flat areas they are:

- Salt content in the soil has increased in irrigated areas. Salt-affected areas exceeded 53% of total irrigated land in Uzbekistan, and 89% in Turkmenistan. Winter wheat cropping complicates maintenance of favorable salt regimes on moderately and highly saline soil. This needs to be taken into account when determining the cropping pattern.
- The amount of fresh water for irrigation decreased, while the amount of brackish water increased. In Turkmenistan alone, drainage flows with less than 2.0 g/l total dissolved solids (TDS) are equal to 225.0 million m≥/year, and with 2.0-3.0 g/l TDS are equal to 1.46 km≥/year. In Uzbekistan, the volume of drainage water with less than 3.0 g/l TDS comes to 3.51 km≥/year in the Amudarya River Basin and to 10.8 km≥/year in the Syrdarya River Basin.
- The quality of river water mid- and downstream has deteriorated. The TDS of irrigation water mid- and downstream reach 1.2-1.5 g/l. These levels, combined with excess salt in the soil, reduce potential winter wheat yields.

The goal of this study was to identify agro-ecological areas with low water use efficiency in irrigated wheat and to propose technologies and measures for its improvement.

Methodology

Under conditions of growing water shortages, water use efficiency can be assessed based on the following indicators: water use efficiency(WUE), water productivity (WP), and recovery efficiency (REW). Water use efficiency is defined as the ratio of biomass to all available water:

$$WUE = Y / Wa,$$

where Y is the crop yield in kg/ha, and Wa is the total amount of water (in m^3/ha) available for crops. All available water (Wa) includes irrigation water, precipitation, reduction of soil moisture during vegetation season, and upward flow. The upward flow is originated by deep losses from irrigated areas and canals. When the upward flow is not included in the amount of available water, this may lead to the overestimation of WUE. The indicator identifies efficiency of irrigation technologies to provide water for crops.

Water productivity is the biomass produced per unit of cropped area, per unit of water evaporated and transpired:

$$WP = Y / ET,$$

where ET = evapotranspiration in m^3/ha. This indicator characterizes the crop's physiological efficiency in utilizing water.

Recovery efficiency is the ratio of water used (ET or T) to all available water.

$$REW = ET \text{ (or T)}/ Wa.$$

Assessment of soil erosion, salinization, drainwater volume, and nutrient use efficiency leads to an integrated approach for evaluating the efficiency of grain production in irrigated areas. Evaluation of water and salt balances allows monitoring the values of the indicators.

Study areas

The studies on water use efficiency were conducted under sub-humid rainfed conditions in Tajikistan on brown carbonate soil; under irrigated conditions on typical sierozem in Uzbekistan; and under irrigated conditions on sandy soil in Turkmenistan. Along with these results, data from other ICARDA experimental sites were also used.

Faizabad site is located 1200 m above sea level (masl) in the sub-humid rainfed area. Despite considerable rainfall, there is poor crop growth due to substantial wind erosion. Landscape is mainly hilly, with 5 to 20° sloping gradient. Precipitation is 750-850 mm and occurs mainly in winter and spring. Soil is moderately eroded brown carbonate soil. Originally, brown soils have a humus horizon of 30-35 cm, with 3-5% humus content. Due to soil erosion humus content is now 1.00-1.59%.

Boikozon farm is located in Tashkent province, Uzbekistan, at 525 masl, in a predominantly hilly area. Climate is extremely continental, with an average annual temperature of 14.3°C. Mean annual precipitation is about 500 mm. Soil is typical sierozem, mainly moderate and heavy loam with low and intermediate nutrient content. Humus content in the topsoil is 1.1-1.5%.

Vatan farm is located in an arid desert climate with an average temperature in July of 30.7°C. Annual precipitation is 150-220 mm, and the evaporation rate from water surface is over 1500 mm. Duration of the frost free period is up to 286 days with the sum of positive temperatures around 5800°C. The soil is sandy, slightly saline, as thick as 1.5 m with soil bulk density of 1.25 g/cm^3. Ground water table is at about 2 m, with water salinity of 2.5-3.0 g/l, whereas TDS of irrigation water is below 1.0 g/l. The research was conducted on 1.4 ha.

The effect of strip cropping on runoff, erosion, and soil fertility was studied at Faizabad experimental site in 2000-2002. Treatments were as follows:

- Winter wheat
- Winter wheat (top) and alfalfa (bottom) strips
- Alfalfa (top) and wheat (bottom) strips
- Chickpea (top) and sainfoin (bottom) strips
- Fallow
- Alfalfa

The experiment was conducted in an area with 8-12° slope gradient in three replications. Plot size was 200 m^2 (20 m x 10 m). Strip cropping was studied in a hydrologic experimental plot. Flow and soil erosion were measured during the rainy season, mostly in April and May. The following furrow irrigation technologies were tested at the Boikozon site:

- Traditional irrigation along the slope (control).
- Irrigation along the slope using polymer K-9.
- Joyak (zigzag) furrow irrigation technology for winter wheat.
- Contour irrigation for winter wheat.

Joyaks are zigzag furrows cut across the maximum slope. The furrows were 20-22 cm deep and 1.4 m wide. The length of the horizontal section of zigzag varied from 2.0 m to 2.5 m and 3.0 m. Contour furrows were 0.7 m wide and 22-25 cm deep and cut across the maximum slope. The following drainwater reuse treatments were studied at the experimental site in Vatan farm:

- Irrigation of winter wheat with surface water.
- Irrigation of winter wheat using surface water in fall and drain water in spring and summer (alternating water sources).
- Irrigation of winter wheat with drain water.

Pre-sowing irrigation using surface water was applied to all treatments. In fall of 2001 land was plowed to a depth of 25-27 cm. After soil leveling pre-sowing irrigation was applied at a rate of 1500-1600 m^3/ha. Manure was applied prior to planting at a rate of 30 t/ha. Nitrogen was applied twice at a rate of 60 kg/ha each time. Seed rate was as high as 180-200 kg/ha. Furrows were cut 90 cm wide.

Results

Water use efficiency in sloping areas

Strip cropping in sub-humid rainfed areas. Replacement of perennial grasses by wheat sharply increased erosion processes and created an area of ravines. A group of scientists from the Tajik Soil Science Institute, in collaboration with ICARDA, studied the influence of strip cropping on erosion processes. Received dependence of runoff and soil erosion from growing crops is presented in Figure 1.

Obtained data indicate that surface runoff and erosion were 150 m^3/ha and 2.85 kg/ha, respectively, under alfalfa and other perennial grasses. Under continuous wheat, surface runoff and erosion increased by 85% and 48%, respectively, compared to the alfalfa treatment. Under wheat/grass strip cropping, soil erosion was at the same level as with the alfalfa treatment. These data indicate that strip cropping can significantly reduce soil erosion in sloping areas with winter wheat.

At the experimental site, low content of mobile nutrients was another factor limiting crop yields. Under strip cropping there was higher nutrient concentration compared to under continuous wheat. In dry 2001, precipitation during the wheat growing season was 215 mm. Ammonification and nitrification processes slowed down due to the shortage of soil moisture. The dynamics of nitrogen under different cropping systems in 2002 revealed that in early spring there was low nitrogen availability in the 0-50 cm soil layer under continuous wheat (61 kg/ha) and high availability under strip sowing (135 kg/ha).

In May, because of high consumption, nitrogen content in the topsoil decreased considerably under strip cropping and under

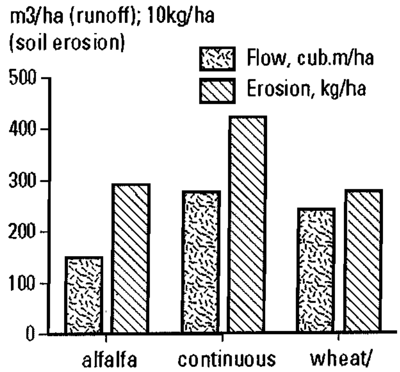

Figure 1. Runoff and soil erosion under different cropping options at Faizabad site.

alfalfa (up to 33-37 kg/ha). Nitrogen content was high only on fallow land (up to 129 kg/ha). In wet 2002, nitrogen levels reached 55 kg/ha under alfalfa, 69 kg/ha under strip cropping, and 166 kg/ha under fallow. To the end of the crop growing season, there was more mineral nitrogen under strip sowing than under continuous cropping. Thus, nitrogen content was higher under strip cropping of winter wheat/alfalfa than under continuous wheat.

Improved furrow irrigation in sloping areas. Joyak furrow irrigation technology was tested at experimental site of Boikozon farm, in the sloping areas of Uzbekistan. Joyaks are zigzag furrows cut across the slope. Furrow depth was 20–22 cm; the furrows were cut 1.4 m apart. In the winter wheat experiment the length of the horizontal section of zigzag was tested: 2.0, 2.5, and 3.0 m. Zigzag furrows 1.4 and 2.0 m wide were tested only in the 2000-2001 season. Soil is heavy clay loam. Soil moisture in the root zone was monitored during the vegetative period to determine irrigation needs.

Portable chutes were designed to improve the uniformity of jets into furrows in the sloping area. Adjustable outlets allowed optimizing the jet discharge into each furrow depending on the slope. Portable, light 1.5-m long plastic chutes allow farmers to apply irrigation easily.

Two of the three study years were dry for growing winter wheat. Precipitation was 416 and 345 mm in 1999-2000 and 2000-2001, respectively. Winter wheat yields in many areas depend on availability of irrigation water. That is why three irrigations (1,200-1,300 m^3/ha each) were applied (Table 1).

The data obtained found that traditional irrigation along the slopes does not result in high returns to water supplied, because significant water and soil losses were observed. Surface runoff was 28% of irrigation water. Using joyaks 2.8-3.0 m wide helped reduce irrigation rates by 14-15% due to reduction of surface runoff. Winter wheat yield increased by 40-45% compared to the control. At the same time, WUE increased by 51-55% over the control.

The WUE index was an average of 20% higher under rainfed conditions than under traditional furrow irrigation along the maximum slopes. Soil erosion was reduced up to five times and more using joyak furrows. During the rainy 2001-2002 season, 592 mm of precipitation was recorded. Irrigation was required only in the beginning of June (Table 2).

Obtained data revealed that the use of joyak and contour irrigation increased winter wheat yields by 20-25% compared to the control. Water use efficiency increased by 24-29%. High precipitation resulted in significant surface runoff from the area; that is why WUE index was lower under rainfed conditions compared to the control. Remarkably, soil losses due to erosion decreased from 1.2 t/ha under the control option to 0.02-0.08 t/ha under joyaks and to 0.10 t/ha under contour irrigation.

Joyak irrigation technology greatly reduced losses of fertile soil layer. The soil moisture profile was uniform over the entire furrow. Irrigation continued without tail water, and WUE increased. Irrigation during the night also became easier. The optimum width of a joyak was 2.0 m in 1999-2000 and 2.8-3.0 m in the last two years. This appears to be a consequence of making joyaks 20 cm deep manually in 1999-2000 season and 25-27 cm deep with a tractor the following years.

Thus joyak furrow technology and contour irrigation practically controlled soil erosion. The lack of joyak-making mechanisms appears to be a major factor limiting the adoption of this technology. The use of light portable plastic chutes for water distribution in contour furrows increased the uniformity of irrigation in sloping areas.

Table 1. Water use efficiency of winter wheat (average of the 1999-2000 and 2000-2001 seasons).

Parameter	Rainfed	Control	Joyak furrow irrigation				
			2.0 m	2.5 m	3.0 m	2.8 m	1.4 m
Yield (t/ha)	1.94	3.04	5.10	4.80	4.71	4.65	3.54
Precipitation (m^3/ha)	380	380	380	380	380	345	345
Irrigation (m^3/ha)	0	3695	3343	3559	3442	2900	3055
WUE (m^3/ha)	1.94	3.04	5.1	4.8	4.71	4.65	3.54
Soil erosion (t/ha)	-	5.88	0.72	0.63	0.66	0.25	0.33

Table 2. Water use efficiency of winter wheat in the rainy 2001-2002 season.

Parameter	Rainfed	Control	Joyak furrow irrigation			Contour irrigation
			2.0 m	2.5 m	3.0 m	
Yield (t/ha)	3.23	4.99	5.68	6.07	6.27	6.05
Precipitation (m^3/ha)	5920	5920	5920	5920	5920	5920
Irrigation,(m^3/ha)	0	1186	1135	1050	1038	1028
WUE (m^3/ha)	0.55	0.7	0.81	0.87	0.9	0.87
Soil erosion (t/ha)	-	1.2	0.08	0.04	0.02	0.1

Table 3. Surface and drainwater use at the Vatan experimental site (m^3/ha).

Season	Parameter	Treatment		
		Surface water	Alternate surface and drainwater	Drainwater
2000-2001	Applied surface water	5160	3410	1650
	Applied drainwater		2150	4140
2001-2002	Applied surface water	5280	3500	1850
	Applied drainwater		2180	4520

Table 4. Winter wheat yields and water use efficiency at Vatan experimental site.

Parameter	Treatment		
	Surface water	Alternate surface and drainwater	Drainwater
Yield (t/ha)	2.7	2.2	2.0
Precipitation (m^3/ha)	1920	1920	1920
Irrigation rate (m^3/ha)	5220	5620	6080
WUE (m^3/ha)	0.38	0.29	0.25
WP (m^3/ha)	0.41	0.34	0.30

Water use efficiency in flat areas

Using drainwater for irrigation on sandy soil. Drainwater is an important source of water when there are water shortages. Alternative uses of surface and drainwater were tested at the experimental site in Vitan farm, Turkmenistan. Salinity of drainwater was 2-3 g/l during spring and early summer, and exceeded 3.0 g/l in fall and winter. Salinity of surface water in the Karakum canal was 0.7-0.8 g/l. Four irrigations were applied. Surface runoff accounted for 5-17% of irrigation rate. Use of drainwater reduced surface water requirements (Table 3).

The data presented reveal that in the drainwater treatment, drainwater requirements decreased by 64-68%, and in the alternating water sources treatment, by 33-34%. Use of drainwater affected winter wheat yields (Table 4).

Obtained data indicate that WUE and WP were low using drainwater for irrigation of winter wheat on sandy soil due to low fertility and low water holding capacity of soil. Using drainwater for irrigation reduced winter wheat yields by 26%, while WUE and WP indexes decreased by 27-34% compared to the control. Alternating surface and drainwater increased winter wheat yields by 9%, and the value of WUE and WP by 10% compared to the drainwater treatment.

Thus, despite relatively low winter wheat yields, in years with water shortages, alternating water sources increased available water. Significant water losses were recorded for irrigated winter wheat on sandy soil in Turkmenistan because of the soil's low water-holding capacity, which was 425-475 m≥/ha, while furrow irrigation rates exceeded 900 m≥/ha. Research using sprinkler irrigation under similar conditions found that the sprinkler system on sandy soil increases WUE from 0.36-0.47 to 0.60-0.65 kg/m≥.

Timing of irrigation on saline soil. Soil salinity is one of the factors limiting water use efficiency in winter wheat. At the Kushman-ota experimental site in Syrdarya Province, where the soil has a moderate level of salinization, and ground water is 1.5-2.0 m deep, WUE in winter wheat did not exceed 0.3 kg/m≥. Irrigation timing did not significantly improve water use efficiency.

Double cropping

On heavy loamy soil on typical sierozem at the Akkavak experimental site in Tashkent Province, growing green gram after winter wheat increased water use efficiency from 0.58 kg/m≥ to 0.66 kg/m≥.

Crop diversification on saline soil

On the saline soils of Karalang experimental site in Vahsh Valley, Tajikistan, WUE in cotton, wheat, and barley was compared. Applied irrigation water was 6800, 2100, and 2000 m^3/ha, respectively, for cotton, barley, and wheat. Precipitation totaled 120 mm during the vegetative period of cotton and 250 mm during the vegetative period of barley and wheat. Upward flow was 1700 m^3/ha with shallow groundwater under cotton, and 360 and 315 m^3/ha under barley and wheat, respectively. Values for water use efficiency are presented in Table 5.

The saline, shallow, ground water table had a very significant effect on cotton yields (a 44% reduction) compared to a 3-m deep water table. Grain yields of wheat and barley were affected to the same degree by slight and moderate salinity. Water was used more efficiently by barley than by wheat, which indicates barley's higher salt tolerance. Saline, shallow ground water at the site was the reason for cotton's low water use efficiency. Thus, barley has higher water use efficiency in saline areas.

General Overview of the WUE Problem

Data obtained from different experimental sites were used to build a generalized graph of water use efficiency in winter wheat (Figure 2).

The data obtained indicate that starting from about 7600 m^3/ha of total water available to the crops under the studied soil and climatic

Table 5. Water use efficiency of different crops at the Karalang experimental site, Tajikistan, 2002.

Crop	Salinity level/ saline ground water level	Yield (t/ha)	Yield reduction (%)	Total water available for crops (m^3/ha)	WUE (kg/m^3)
Cotton	>3 m	2.5	0	8000	0.31
Cotton	< 1.0 m	1.4	44	9700	0.14
Barley	Non-saline	4.3	0	4960	0.87
Barley	Slightly saline	3.8	12	4960	0.77
Barley	Moderately saline	2.83	34	4960	0.57
Wheat	Non-saline	2.7	0	4815	0.56
Wheat	Slightly saline	2.37	12	4815	0.49
Wheat	Moderately saline	1.98	27	4815	0.41

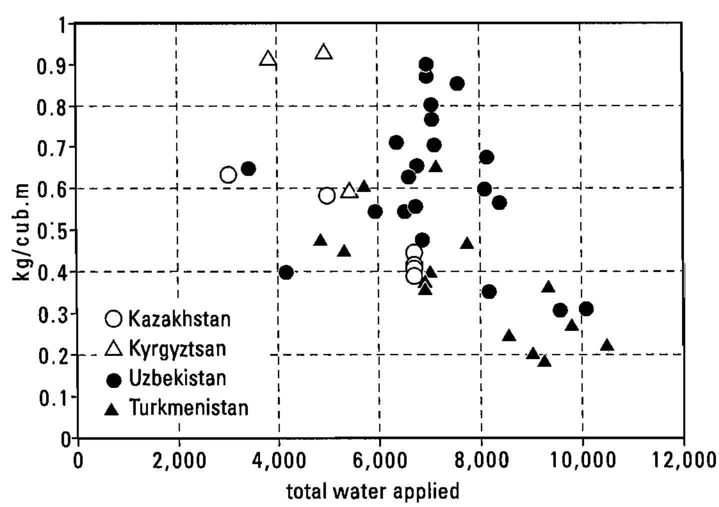

Figure 2. Correlation between water use efficiency and water available to the crop at experimental sites located in Kazakhstan, Kyrgyzstan, Turkmenistan, and Uzbekistan.

conditions, both winter wheat yields and WUE index are reduced. Low water use efficiency was observed mainly in sloping areas of Tashkent Province, where the crop is irrigated by traditional methods along the maximum slopes; in Syrdarya Province, where soils are from moderately to highly saline; and on sandy soil in Turkmenistan, where furrow irrigation is applied. Contour irrigation, or joyak technology, combined with conservation tillage on the sloping areas of Uzbekistan and with low-cost sprinkler systems on the sandy soils of Turkmenistan could be widely used by farmers to increase water use efficiency.

Conclusions

Research results indicate that along with increased winter wheat yields and higher grain production in rainfed and irrigated areas, the following negative processes are occurring:

- Increased soil erosion and the forming of ravines in sloping areas with brown carbonate soil in the semi-humid rainfed zone;
- Increased soil erosion in sloping areas of typical sierozems where irrigation along the maximum slopes is practiced, especially where there is intensive land use;
- Low water use efficiency on sandy soils under traditional furrow irrigation;
- Low water use efficiency in soils with moderate and, especially, high salinity levels. The amount of water used to irrigate winter wheat is not sufficient to guarantee sustainable salt balance in areas with moderate and high salinity levels.

The following options were found promising to increase water use efficiency:

- Strip cropping in semi-humid rainfed conditions on brown carbonate soil;
- Contour irrigation with portable plastic chutes for uniform water distribution could be widely used in sloping areas. A combination of supplemental irrigation of winter wheat with zero- or minimum tillage could increase the feasibility of contour and joyak irrigation and promote the adoption of these technologies by farmers. This technology requires extensive on-farm testing;
- Micro sprinkler irrigation of winter wheat on sandy soil requires extensive on-farm testing;
- Growing summer crops, especially drought tolerant legume crops, after winter wheat increases water use efficiency;
- Replacement of winter wheat by other, salt-tolerant crops on moderately and highly saline soil. The research found that barley has higher water use efficiency than winter wheat on saline soils.

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Conservation Agriculture for Irrigated Production Systems: Permanent Bed Planting Technologies

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The adoption of conservation agriculture technologies has dramatically increased in many countries over the past 25 years. They are characterized by minimal soil disturbance (tillage) before seeding (ultimate aim: zero-till seeding) and by diverse strategies to increase crop residue retention on the soil surface and ensure full ground cover (leading essentially to biological tillage) over time. For example, there are now over 28 million ha of zero till seeding in Latin America, with the bulk concentrated in the Southern Cone countries (Brazil, Argentina, and Paraguay) (Derpsch, 2001). Table 1 lists the adoption of zero-till in the world up to 2001 (Derpsch, 2001). Much of this acreage is zero-till with residue retention. However, upon closer inspection, reduced/ zero till seeding combined with surface crop residue retention in the countries mentioned above and in other large area adopters (such as the USA, Canada, and Australia) and particularly for wheat production systems, has been adopted mainly by large-scale farmers and nearly universally for rainfed production systems (with a few exceptions, e.g., where sprinkle irrigation is used). The apparent exclusion of small-scale farmers in general and essentially all surface irrigated production systems (especially where irrigated wheat is a major crop) has several explanations.

Table 1. Global adoption of zero-tillage.

Country	Million hectares
United States	21.1
Brazil	17.3
Argentina	11.7
Australia	9.0
Canada	4.1
Paraguay	1.3
Rest of the World	1.4
Total	**66.0**

Source: Derpsch (2001).

There are clear-cut differences between developed and developing countries regarding both how wheat and other crops are grown and who grows the crops. Less than 5% of the total wheat produced in developed countries (and also in Argentina, Brazil, and Paraguay) comes from irrigated systems, whereas large-scale farmers are by far the most important wheat producers. In contrast, well over 50% of wheat production in developing countries (especially large producing countries in South Asia and China) comes from irrigated systems, and the vast majority of these farmers are very small-scale (Byerlee and Moya, 1993). These divergent circumstances have led to serious shortages of appropriate reduced/ zero till seeding implements for small- and medium-scale farmers since machinery development has largely focused on large farms. Furthermore, since there is so little irrigated wheat in the developed world, there have been insufficient efforts expended to develop appropriate crop management technologies to reduce tillage and ensure retention of crop residues for surface irrigated systems, in particular, those involving wheat.

One of the main constraints for reduced tillage and crop residue retention for surface irrigation, especially in wheat, is linked to the widespread use of solid stand planting on the flat combined with flood and basin irrigation systems. They are commonly used throughout the world but especially by the major, irrigated wheat producers in South Asia and China. Flood irrigation can lead to extreme difficulty in irrigation water distribution within the field when loose residues are left on the surface. In some areas (western USA, West and Central Asia, where irrigated wheat is grown in rotation with row crops like cotton, dry beans, and maize) it is common to find wheat planted as a solid stand on the flat following tillage. Then shallow furrows are made (60-100 cm apart) and used for irrigation. In this system of planting, most wheat plants are located on top of a bed formed between the irrigation furrows. When tillage is reduced and some crop residues are left on the surface, serious water movement problems through the furrows can occur. This paper will discuss the development of appropriate raised bed planting systems for irrigated systems in various parts of the world.

Evolution of Raised Bed Planting Systems in Mexico: The First Step

The Yaqui Valley, located in the State of Sonora in northwest Mexico, includes about 255,000 ha of irrigated land, where the most widely grown crop is wheat.

Gravity irrigation systems are used to transport water through the fields from either storage reservoirs (over 90%) or deep tube wells (around 10%). Over the past 25 years, more than 95% of farmers have changed from the conventional technology of planting most of their crops on the flat with flood and basin irrigation to planting all crops, including wheat, on beds. Irrigation water is distributed through the fields by furrows between the beds (70-100 cm wide from furrow to furrow, depending on the distance between tractor tires). Wheat yields in the Yaqui Valley have averaged over 6 t/ha for the past several years (Aquino, 1998).

A single row is planted on top of each bed for row crops like maize, soybean, cotton, sorghum, safflower, and dry bean, and 1-2 rows per bed are planted for crops like chickpea and canola. However, 2-4 defined rows, spaced 15-30 cm apart depending on bed width, are used for wheat. Even though most farmers still use conventional tillage, remaking the beds for each new crop, those that now grow wheat on beds obtain about 8% higher yields, use approximately 25% less irrigation water, and save at least 25% on operational costs compared to those still planting conventional tilled wheat on the flat, using flood irrigation (Aquino, 1998).

Based on positive interactions through visits of scientists from developing countries to the CIMMYT base agronomy program, bed planting of wheat has also been introduced in various other countries in the last five years. Table 2 lists the benefits of planting wheat on beds in irrigated systems in terms of yield and water savings from various collaborating countries. Work has also started in South Africa, Morocco, Sudan, Iran, Kyrgyzstan, Uzbekistan, and Nepal, but data were not available for this paper.

Water savings, as indicated in Table 2, are significant (25-35%); this is an extremely crucial issue in these countries, as competition for irrigation water between urban and industrial uses intensifies. Table 3 presents more detailed information on wheat biomass and grain yield to allow comparisons of zero till bed planting using furrow irrigation with tilled flat planting using flood irrigation for the Shandong data, which supplement the data from China presented in Table 2. These results are from trials that form part of a collaborative program with CIMMYT to extend wheat bed planting to China and other countries. It is extremely interesting to observe the marked reduction in two serious wheat diseases, sharp eyespot and powdery mildew, with bed planting which is likely the consequence of modest plant canopy micro-climatic differences resulting from the change in plant orientation. Similarly, plant height and crop lodging were reduced with bed planting (Table 3). Dr. Wang Fahong, the principal scientist in China for this collaborative project, has also reported a 25% reduction in irrigation water use for bed planting in these trials.

In South Asia, bed planting has also been used to increase the diversity of crops grown in the Indo-Gangetic Basin. Success has been shown with vegetables, maize, legumes (chickpea and pigeonpea), oilseeds, cotton and sugarcane. Table 4 presents further information on different crops for which comparisons between bed planting with furrow irrigation versus conventional planting on the flat

Table 2. Benefits of bed planting for bread wheat in various parts of the world.

Country	Location	Yield on beds (kg/ha)	Yield on flat (kg/ha)	Extra yield bed vs flat (kg/ha)	Water savings, bed vs flat (%)
Bangladesh	Dinajpur	4710 a	3890 b	820	25
Pakistan	Punjab	4530 a	4220 b	310	24
	Punjab	4470 a	4020 b	450	32
India	Punjab	5750 a	5460 b	290	33
	Haryana	5290 a	5010 b	280	46
	UttarPradesh	4750 a	4550 b	200	30
China	Shandong	7070 a	6110 b	960	25
	Gansu-Hex Corridor	8770 a	7110 b	1663	26
Turkey	Achakale	5500 a	5750 a	-250	20
	Diyarbakir	5380 a	5230 a	150	na
	Eskishehir	5070 a	5020 a	50	na
Kazakhstan	Almaty	5080 a	4900 a	180	29
Average		5531 a	5106 b	425	29

Means in rows followed by different letters are significantly different by LSD at the 0.05 level.
Source: Personal communications from scientists in these countries. Data to be published.

Table 3. Effect of planting method on different wheat traits, disease incidences, and lodging rate for two wheat varieties averaged over four crop cycles, Jinan, Shandong, China, 1998-2002.

Variety	Planting method	Plant height (cm)	Biomass yield (kg/ha)	Grain yield (kg/ha)	Incidence, sharp eyespot (%)	Powdery mildew index (%)	Lodging rate (%)
Jimai 19	Bedplanting	73	15570**	6195**	8	8	0
	Flat planting	77*	14109	5630	33**	20**	10**
Yannong19	Bed planting	76	16134**	6765**	2	9	5
	Flat planting	83**	14550	5965	51**	23**	70**

* and ** indicate differences within varieties at the 5 and 1% levels of probability.
Data provided by Dr. Wang Fahong, agronomist/soil scientist, Shandong Academy of Agricultural Sciences, Jinan, China.

with flood irrigation have been made in numerous farmer fields in northwestern India. In all cases, yields are higher and considerable irrigation water was saved with bed planting.

Most farmers in the Yaqui Valley and other countries listed in Table 2 have taken only the first step in bed planting but are now working on shifting to reduced tillage with appropriate management of crop residues by making the change to permanent beds. They largely continue to practice conventional tillage and destroy the beds after harvesting each crop. They do several tillage operations before new beds are formed for the succeeding crop. This tillage is accompanied by burning of crop residues, although some maize and wheat straw is baled-off for fodder and, when turn-around-time permits, some crop residues are incorporated during tillage (Meisner et al., 1992). However, there has been intense farmer interest in the development of new production technologies that will allow marked tillage reductions combined with residue retention. These may lead to reductions in production costs, improved input-use efficiency, and more sustainable soil management while allowing continued use of the gravity irrigation system. In the early 1990s, CIMMYT wheat agronomists and their Mexican research colleagues, in collaboration with farmers, began to address this issue. Scientists who visited CIMMYT returned home and also started to look at permanent bed planting with their farmers.

Permanent Bed Planting Systems: The Second Step

The bed planting system offers easy field access that can improve the effectiveness of many field operations, including placement of fertilizers, especially N fertilizers, when and where they can be used most efficiently, easier application of herbicides (tractor wheels follow the furrows) and ease in rouging for seed multiplication. Bed planting provides an opportunity for natural, controlled traffic when tillage is reduced. Since all implements can be designed to track in the bottom of the furrows with little soil disturbance on the surface of the bed during the seeding operation. This concentrates soil compaction in the furrow bottoms and reduces compaction on top of the beds, where crops are seeded. The seeding of 2-4 defined rows of wheat on top of the bed, as opposed to the solid seeding pattern normally associated with wheat and other small grains, makes including wheat in the system far more feasible. However, it was soon established that not all wheat varieties were appropriate for bed planting, and cooperation with wheat breeders helped to identify appropriate wheat plant types for bed planting (Sayre and Ramos, 1997). Seed rates could also be reduced by a third, saving the farmer the cost of this valuable input.

Table 4. Yield comparisons between diverse crops planted in beds with furrow irrigation and in conventional, flat planting with flood irrigation, and irrigation water savings associated with bed planting in farmers' fields, Ghaziabad, Uttar Pradesh, India.

Crops	Farmers (no.) 2000-2002	Yield (kg/ha)	
		Beds	Conventional
Maize	10	3,270 a† (35.5%) ‡	2,380 b
Urd bean	10	1,830 a (26.9%)	1,370 b
Mung bean	10	1,620 a (27.9%)	1,330 b
Green pea	15	11,910 a (32.4%)	0,400 a
Pigeon pea	10	2,200 a (30.0%)	1,500 b
Gram	8	1,850 a (27.3%)	1,580 b
Carrot	15	3,630 a (31.8%)	2,860 b
Okra	10	3,440 a (33.3%)	2,910 b
Rice	20	5,620 a (42.0%)	5,290 b
Wheat	22	5,120 a (26.3%)	4,810 b

‡ Average percent savings in irrigation time with bed planting.
Source: R. Gupta, Facilitator for the Rice-Wheat Consortium (pers. comm., 2002).

The next step to reduce tillage and retain crop residues on the surface was to simply reshape the beds as needed between each crop cycle, following some chopping and even distribution of the previous crop's residue. By eliminating tillage (except for reshaping the beds before planting the next crop), the beds solidify, so that when irrigation water is channeled in the furrows, even in the presence of high amounts of crop residues resulting from high-yielding irrigated crops, it advances evenly without cutting across the beds. Such beds are referred to as permanent beds or permanent raised beds. In some soils the compaction in the furrow bottoms from machine traffic helps to enhance lateral water infiltration and forward water advance. If residues are chopped, it is important not to chop them too finely in order to minimize floating residue particles as the water advances in the furrows.

Obviously there has been important implement modification and development activity associated with the evolution of the permanent bed planting technology. The furrow-makers that farmers were already using to make beds with tillage were easily modified to reshape the permanent beds, by attaching cutting disk coulters ahead of the furrow openers for residue management. Similarly, existing zero till planters for row crops like maize and soybean could be easily adapted for planting on permanent beds into crop residues. However, no commercial zero till wheat drill was readily available to plant 2-4 rows of wheat without tillage on top of 70-100 cm wide beds and into high levels of crop residues. Many modifications were needed.

Once the underlying ideas for the permanent bed planting system were developed, long-term experiments were initiated in the Yaqui Valley in 1992 to compare the new permanent bed system with the bed planting system based on extensive tillage currently being used by farmers. The main objectives of these trials were: 1) to fine-tune the machinery and management practices, 2) to determine the effects of planting method on crop productivity, emphasizing wheat, but including maize and soybean, and 3) to monitor relevant soil parameters.

Materials and Methods

The main long-term experiments have been conducted at the CIANO/CIMMYT experiment station located near Cd. Obregon, Sonora, Mexico (lat. 27.33° N long. 109.09° W, 38 m above sea level). Soil type is described as coarse, sandy clay, mixed montmorillonitic typic calciorthid, low in organic matter (<0.8%) and slightly alkaline (pH 7.7-8.2). Long-term weather data for the wheat growing period (November to May) are as follows: maximum and minimum temperatures are 26.7 and 8.7°C respectively, average growing season rainfall is 49.3 mm, and average daily pan evaporation is 4.9 mm.

The principal long-term experiment was initiated in the summer of 1992 and involves a two-crop, annual rotation, with wheat planted in late November and harvested in early May and either maize or soybean planted in late May-early June and harvested in October. Since the initiation of the experiment, 10 wheat crops have been planted and harvested in the winter season. Nine maize crops (1992, 1994, 1995, 1996, 1997 1999, 2000, 2001 and 2002) and two soybean crops (1993 and 1998) have been planted and harvested in the summer season, which makes a total of 21 crops.

The five tillage/residue management treatments included in the trial were:

- Conventional tillage with formation of new beds for each crop; all crop residues incorporated
- Permanent beds; all crop residues burned
- Permanent beds; crop residues baled-off for fodder, leaving around 30% in the field
- Permanent beds, maize residues baled off for fodder and wheat residues retained
- Permanent beds; all crop residues retained

All crop residues were chopped before incorporation or when retained on the surface, depending on the treatment. When residues were baled-off for fodder, the maize residue was chopped before baling but the wheat residue was not chopped. Only the wheat residue cut by the combine harvester was baled for fodder, leaving the standing stubble intact. Whenever soybean was grown, however, its residue was not removed/burned because of the comparatively low amount of residue (2-3 t ha^{-1}).

The trial also included treatments concerning rates and timing of N applications for the wheat crop (data not presented). When summer maize was grown, 150 kg N ha^{-1} was uniformly applied across the whole experiment. No N was applied when soybean was planted in the summer. All N was banded either in the center of the bed or in the bottom of the furrow, through surface residues. Similarly, 20 kg P ha^{-1} was applied uniformly over the trial area prior to planting any crops. Bed width was 75 cm, and two rows of wheat, 25 cm apart, were planted on top of each bed. One row of maize or soybean was planted in the center of each bed.

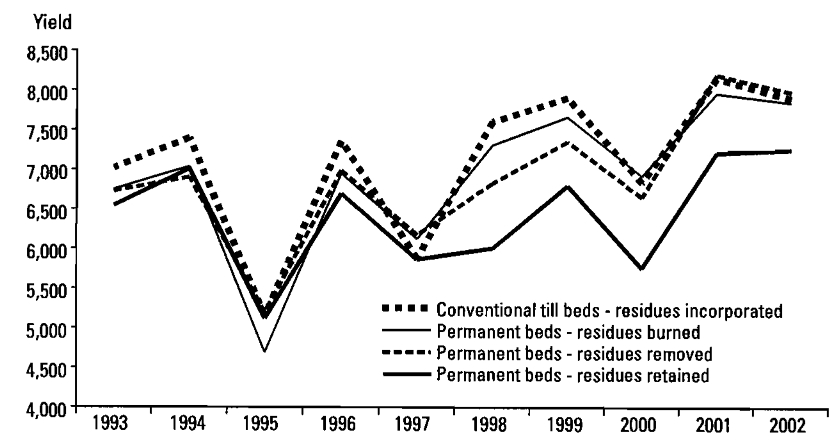
Each crop was seeded into moisture following a pre-seeding irrigation. This is a common strategy used by farmers in the region as part of their weed control strategy. At the time of planting, usually 13-17 days after irrigation, the first flush of weeds are controlled by a shallow tillage at planting time with the conventional tillage system but for the permanent bed treatments, weeds were controlled applying 1.5-3.0 l ha^{-1} glyphosate immediately after planting. In most years, no further weed control was needed but appropriate post-emergence, selective herbicides were used when required. Normally four to five post-emergence irrigations were applied to wheat.

Results

It is common that conversion from conventional tillage to a reduced/zero tillage system with residue retention may require several crop cycles before potential advantages/disadvantages become apparent (Blevens et al., 1984). Results from this long-term trial confirm this observation. Figure 1 presents the wheat grain yield trends and associated year effects for the 10 wheat crops harvested since 1993 for the five tillage/residue management treatments when 225 kg N/ha was applied at the first node stage. Only small albeit significant yield differences between the tillage/residue managements occurred from 1993 to 1997 (5 summer crops and 6 wheat crops), but beginning with the 1998 wheat crop, large and significant differences between the management options occurred; year-to-year yield effects were also large (Figure 1). From 1998 onwards, the permanent bed treatment with continuous crop residue retention has had, on average, the highest yield, closely followed by conventional tillage with residue incorporation, permanent beds with full removal for fodder by baling and, considerably inferior, permanent beds with residue burning.

A number of soil chemical, physical, and biological parameters have been regularly monitored throughout the experimental period. Table 5 presents a brief summary of some of these parameters measured during the 2002 wheat-growing season. Samples that were taken at the onset of the experiment in 1993 indicated uniformity for these parameters across the trial area (data not shown). Soil samples taken in 2002 indicate that, while pH was not different for the tillage/residue management treatments, Na content and electrical conductivity were significantly less for permanent beds where part or all of the crop residues had been left on the soil surface as compared to both tilled beds and especially permanent beds with residue burning. This is an exceedingly important result because it indicates that in soils that tend to develop salinity problems, the use of permanent beds with retention of crop residues on the soil surface may help ameliorate this tendency by reducing the potential concentration of salts in the surface layers. Organic matter and total N levels were lowest for conventional tillage with residue incorporation and highest for permanent beds, increasing with levels of crop residue retention (Table 5).

Table 5 also presents values for average soil aggregate size which was similar for all treatments except for permanent beds with all residue removed for fodder (moderately less) and for permanent beds with residue burning which had strikingly smaller soil aggregates. Soil strength/compaction on top of the beds (data not shown) has demonstrated a similar trend with only permanent beds with residue burning being significantly inferior to the other treatments, which had similar levels. The addition of residue mulch plays a significant role in reducing compaction at the soil surface and also improving the infiltration of water into the profile.



	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
LSD (0.05)	205	ns	ns	ns	ns	537	813	476	525	627

Year LSD (0.05) = 310 Kg/ha; Tillage/residue LSD (0.05) = 166 Kg/ha; Year * tillage LSD (0.05) = 539 kg/ha

Figure 1. Effect of tillage and residue management over ten years on wheat grain yield (kg/ha at 12% H_2O) when 225 kg/ha N are applied at the 1st node stage at CIANO/Cd. Obregon.

Table 5. Effect of tillage and crop residue management (averaged over 4 nitrogen treatments) on soil properties in a long-term bed-planted trial initiated at Cd. Obregon, Sonora, in 1993.

Tillage/Residue Management	$P_H(H_2O)$ 1:2	% C	% Total N	Na ppm	EC* dS m^{-1}	Soil Aggregates MWD'mm	SMB^{β}C mg Ckg^{-1}soil	SMB^{Ψ}N mg Nkg^{-1} soil
Conventional Tillage /Incorporate Residue	8.13	0.71	0.069	564	1.14	1.32	464	4.88
Permanent/Beds Burn Residue	8.10	0.77	0.071	600	1.21	0.97	465	4.46
Permanent Beds/Remove Residue For Fodder	8.12	0.77	0.074	474	0.94	1.05	588	6.92
Permanent Beds/Retain Residue	8.06	0.83	0.079	448	0.90	1.24	600	9.06
Mean	8.10	0.77	0.073	522	1.05	1.14	529	6.33
LSD (0.05)	0.02	0.01	0.001	9	0.01	0.03	13	0.16

* -Electrical conductivity.
' -Mean weight diameter by dry sieving.
β -Soil microbial biomass – C content.
Ψ -Soil microbial biomass – N content.
Note: Results reported here are from 0-7 cm soil samples taken in the 2002 crop cycle, 10 years after trial initiation.

Soil microbial biomass C and N levels in Table 5 are clearly superior in permanent beds with some or all residue retention compared to permanent beds with residue burning or conventional tilled beds with residue incorporation. This measure of potential soil health favors the permanent beds with residue retention and correlates with the observations that have been made on root disease scores and pathogenic nematode levels which have been consistently higher for the permanent bed treatment with residue burning (data not shown). It seems evident that the inferior grain yield performance of the permanent bed treatment with crop residue burning is strongly linked with the unremitting soil degradation that has occurred.

In 2000, a large-scale demonstration module (covering 8 ha) conducted with farmer participation was initiated to compare wheat performance with conventional tilled beds versus permanent beds with full residue retention for both planting systems. Crop performance and yield as well as variable production costs are being monitored. Figure 2 presents a comparison of the average wheat grain yields, variable production costs and economic returns over variable costs for both planting systems for the 2001 and the 2002 wheat crops. It seems abundantly clear that the permanent bed planting system has shown both higher grain yield and a marked economic advantage. Average returns over variable costs were 75% higher for the permanent bed planting system. Farmers are now more convinced and confronting the issue of modifying wheat seeders to function on permanent beds with crop residue retention.

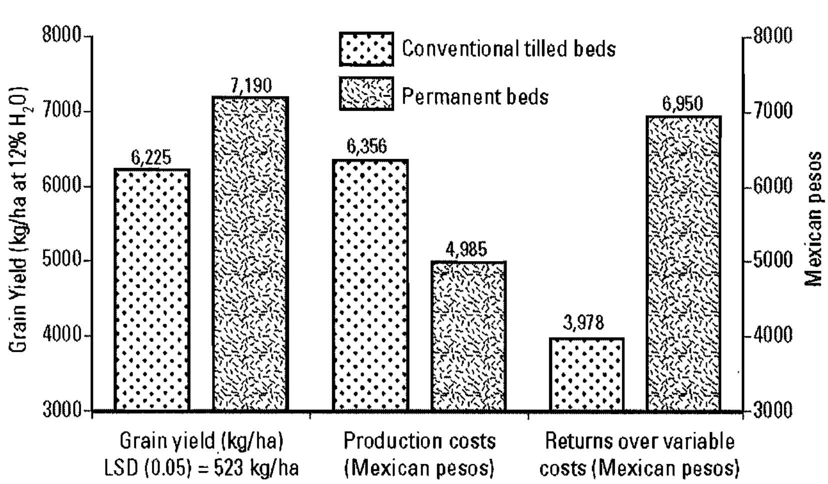


Figure 2. Comparison of average wheat grain yields, variable production costs and returns over variable costs for wheat produced on conventional tilled beds versus permanent beds at CIANO, Cd. Obregon for the 2000/01 and 2001/02 crop cycles.

Conclusions

The permanent raised bed irrigated planting system for wheat and other crops that is being developed in Mexico and elsewhere may finally provide a coherent technology to extend marked tillage reductions with appropriate management of crop residues for surface irrigated production systems including those where wheat is a major crop. It is not a zero till system per se since some soil disturbance occurs by the occasional reshaping of the bed in the bottom of the furrows between the beds but it can be seen as a zero till system on the top of the bed where the crops are seeded.

The results presented here indicate that tillage reduction in surface irrigated production systems resonates in the same positive way in terms of production profitability and sustainability as in rainfed production systems. They also indicate that retention of crop residues will be essential to ensure that the required enrichment of critical levels of the chemical, physical and biological soil parameters, which are crucial to ensure long-term production sustainability, can be achieved. Irrigation farmers must realize that some residue retention will be essential if they attempt to adopt permanent bed planting systems even though their primary goal may be simply to realize lower production costs.

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Advantages of Rotating Winter Wheat with Commercial and Forage Crops in Various Regions of Tajikistan

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Agricultural land in Tajikistan, especially arable land, is a very scarce resource. Including pastures, agricultural land totals only 4.57 million ha, of which arable land totals 0.7 million ha, or 0.11 ha per capita. That is why the major problem is the access of peasants to land and its fair distribution.

Efficient use of, and fair access to, land and water resources is one of the sector's priorities in fighting poverty. Others include creating a positive environment for agriculture related to private activity and reducing government intervention in decision making.

Agriculture in Tajikistan is significantly exposed to unfavorable weather. The drought of 2000-2001, whose adverse impact was also felt in 2002, has led to a decline in grain production, especially wheat grain. Given the arid climate, the key issue for agricultural development in Tajikistan is pumping water. This has led to the problem of maintaining the water supply and irrigation facilities. Large expenditures are required every year to keep them in good condition. With the transition of the country to a market system, a fee on water consumption was introduced, starting in 1996.

However, farmers are able to cover only a small part of the maintenance costs. The resulting deterioration of the water supply and irrigation complex reduced the efficiency of the system, considerably affected the condition of irrigated land, and caused the flooding of pastures. The main concern is the state of pumping stations covering almost 300,000 ha, or 40% of irrigated land. A rural population of about 2 million resides and earns a living in this area.

The agricultural sector is important in the national economy due to its contribution to the GDP, employment, and exports. Considering that three quarters of the population live in rural areas, the agriculture sector will play a crucial role in poverty alleviation. While arable land is scarce, experience in recent years, based on the ongoing restructuring of the large state-owned, cooperative farms, has shown that the transition to private farms can substantially raise yields.

Food security is a big issue for Tajikistan. It is a landlocked country, and the Government has confirmed that self-sufficiency in wheat production is a national priority, flour being the single staple food. Therefore we increased the area of wheat production 2.5 times, from 143,000 ha in 1991 to 343,000 ha in 2000. Today around 200,000 ha of irrigated land are used for wheat production.

Materials and Methods

Research was conducted in three agroecological zones.

- Northern Tajikistan: Zerafshan Valley. Mountainous area, 1300 m above sea level (masl); soil: calcareous cinnamon. Cropping system: irrigated, wheat-tobacco, wheat-buckwheat, and wheat-millet. Annual rainfall: 350 mm; annual average temperature: 12.2 °C. Days without frost: 230. Wheat planting time: 15-20 October; second crop: 20 June.
- Central Tajikistan: Hissar Valley. 700 masl; soil: dark serozem. Cropping system: irrigated, wheat-maize, wheat-peas, and wheat-soybean. Rainfall: 600 mm; annual average temperature: 13.6 °C. Days without frost: 260. Wheat planting time: 15-20 October; second crop: 5 June.
- Southern Tajikistan: Nignekafernihan Valley. 500 masl; soil: light serozem. Cropping system: irrigated; wheat-cotton, wheat-maize, and wheat-rice. Rainfall: 200 mm; annual average temperature: 16.4 °C. Days without frost: 310. Wheat planting time: 15-20 October; second crop: 1 June. Additional application of 100 kg/ha N on second crop.

Results and Discussion

Productivity in northern Tajikistan

The results of three years of research in the foothills of Zerafshan Valley have demonstrated the advantages of alternating a winter wheat variety (Jagger) with tobacco, buckwheat, and millet.

The application of 100 kg/ha of nitrogen on a background of 160 kg/ha phosphorus and 100 kg/ha potassium promoted a one-ton increase in winter wheat yield (i.e., 10 kg grain produced per kg of nitrogen applied). Tobacco, buckwheat, and millet yields also tend to increase on a background of these fertilizers. When 200 kg/ha N were applied, winter wheat yield increased by 1.5 t/ha, tobacco by 1.7 t/ha, buckwheat by 0.5 t/ha, and millet by 0.2 t/ha, compared with the treatment without N fertilizer. Given the limited availability of fertilizers, application of 200 kg/ha nitrogen is inexpedient, but repeated crops such as buckwheat, tobacco, and millet guarantee food security for the population in the foothills and mountain areas under conditions of limited land resources such as Tajikistan.

It should be noted that, with fertilization, biomass accumulation of the second crop doubled, and according to our research results, the amount of soil microorganisms and their activity doubled as well. This cropping system is now very popular in the northern part of the country. Farmers previously grew only tobacco, but now they plant tobacco after harvesting wheat (15-20 June). With fertilization tobacco yield is around 2.4 t/ha (Table 1).

Productivity in central Tajikistan

Results of studies on the conditions of Hissar Valley have shown that applying mineral fertilizers for producing high yields of winter wheat (7-10 t/ha) and maize (8-10 t/ha) is a promising method for managing plant and soil processes. Inclusion of leguminous crops in the system by annual alternation has shown that they promote fixation of biological nitrogen in the soil. This allows reducing mineral fertilizer applications, leading to the more sustainable use of soil and water resources (Table 2).

Productivity in southern Tajikistan

Research carried out in southern Tajikistan, where winter wheat is rotated with cotton, maize with a grain and rice have shown that by managing soil conditions it is possible to achieve yield stability for these crops.

Application of 100 kg/ha of nitrogen on a background of 160 kg/ha phosphorus and 100 kg/ha potassium, plus the direct planting of winter wheat into the cotton crop led to a winter wheat yield of 3.8 t/ha. Through the additional application of 100 kg/ha of N to rice and maize, we increased yield by 0.6 t/ha. By applying 200 kg/ha N, winter wheat yield increased by 2.2 t/ha, rice yield by 1.4 t/ha, cotton yield by 0.2 t/ha, and maize for grain by 0.2 t/ha over the yield of the non- N fertilized nitrogen treatment (Table 3).

Growing two crops a year in the different agroecological zones of Tajikistan while applying increasing doses of mineral fertilizers has been very favorable to the farmer. Calculations of the economic efficiency indicate that cropping tobacco, millet, and buckwheat has produced most benefits for farmers in the foothills of Zerafshan Valley; cotton, rice, and maize for grain for farmers in the south; and soybean, peas, and maize for silage for farmers in Hissar Valley. The most economically profitable cropping system in the south appears to be wheat-rice; in Hissar, wheat-maize; and in the foothills of the north, wheat (Table 4).

Table 3. Productivity of double cropping systems in southern Tajikistan.

	Yield (t/ha)			
Treatments	Wheat	Rice	Cotton	Maize
160K100	2.66	5.24	2.24	6.84
F1+N100	3.84	5.83	2.62	7.21
F1+N200	4.83	6.61	2.42	8.27
$LSD_{0.05}$	0.67	0.63	0.14	0.46

Table 1. Productivity of double cropping systems in northern Tajikistan.

	Yield (t/ha)			
Treatments	Wheat	Tobacco	Buck-wheat	Millet
160K100(F1)	2.72	1.78	1.25	0.86
F1+N100	3.78	1.92	1.45	0.96
F1+N200	4.28	2.42	1.76	1.02
LSD 0.05	0. 26	0.13	0.14	0.05

Table 2. Productivity of double cropping systems in central Tajikistan.

Treatments	Wheat yield (t/ha)	Fertilizers for second crop	Maize yield (t/ha)
Control	2.99	0	2.06
$N_{230}P_{230}K_{120}$	7.44	N323P268K120	7.20
Control	2.99	0	0.81
$N_{230}P_{230}K_{120}$	7.44	0	2.07
Control	2.99	0	0.61
$N_{230}P_{230}K_{120}$	7.44	0	1.62

Table 4. Farmers' benefits from double cropping systems.

Cropping system	Income (US$)
Wheat-tobacco	741
Wheat-buckwheat	891
Wheat-millet	808
Wheat-cotton	1013
Wheat-maize	823
Wheat-rice	1938
Wheat-maize-ST	800
Wheat-soybean	770
Wheat-pea	637

Conclusions

Wheat-commercial crop, wheat-maize, wheat-legumes, and wheat-forage cropping systems during one year are sustainable, productive, and profitable. These cropping systems will improve soil and water use efficiency and generate economic benefits for farmers.

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Zero Tillage Grain Crop Rotation in Central Kazakhstan: Preserving Soils from Water Erosion

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Adoption of subsurface tillage methods developed by the Baraev VNIIZKH has reduced soil losses due to wind erosion on fields used for grain crop production, especially where imprudent tillage of virgin lands has occurred. However, the reduced use of conventional tillage has not solved the problems of water erosion on sloping land.

In areas of central and northern Kazakhstan, as much as 45% of grain crops are grown on slopes, the majority of which have a gradient of 3 to 5°. A distinctive agro-climatic feature of this region is that most precipitation occurs as snow. Current cultural practices allow the melt water to wash away the fertile layer of soil, particularly on southern slopes. Applying deep tillage in the autumn offers better moisture absorption for melting snow in the spring and greater soil moisture storage capacity, which in turn contributes to high yields.

Studies were conducted by TSNIISKH and CIMMYT in 2000 to determine the effectiveness of zero tillage and direct planting on different agricultural landscapes. The scheme of the experiment included the following check options:

1) Mechanical fallow: Four mechanical tillages at 10-12 cm and one deep cultivation at 25-27 cm
2) Reduced fallow: Two mechanical tillages at 10-12 cm, two herbicide treatments (glyphosate at 3 L/ha), and one deep cultivation at 25-27 cm

The options for fallow preparation under trial conditions were:

1) Chemical fallow: Three glyphosate applications, each 3 L/ha
2) Green-manure fallow: One glyphosate application of 3 L/ha, oats planted as a green manure crop (in the phase of panicle formation, soil packing)
3) Anti-erosion fallow: Two glyphosate applications of 3 L/ha, oats sown in the second week of July

During the four plot rotation in the first option, a total of 7 mechanical tillages 10-12 cm in depth and 3 tillages 25-27 cm in depth were carried out. The second option offers two less shallow tillages. Spring wheat was planted using stubble seeders equipped with sweep shovels. Chemical herbicide treatment was applied at the tilling stage, when the second and third crops were sown after fallow.

For the test options of fallow, spring wheat was planted by direct sower, with the help of a disc seeder. If necessary, chemical weed control was employed during the tilling stage. Also, the straw was left on the surface after harvest to improve the moisture reserve.

The experiments were set up on three contrasting agricultural landscapes: a southern slope, which is warmer in the spring; a northern slope, which is the most productive; and a watershed plateau, where no moisture run-off was observed during thawing, which was taken as the control.

On the northern slope, yields were practically the same for both technologies, whereas on the southern slope zero tillage resulted in lower yields. The advantage of zero tillage is increased soil resistance to water erosion. The extent of its washout after the snow thaws showed that with the mechanical fallow treatment, losses were 10 times higher than with the chemical treatment; this was apparent on both the northern and southern slopes. Table 1 presents first-year, baseline production results.

Table 1. Influence of fallow and field cultivation upon the productivity of spring wheat as the first crop in the rotation, 2001.

Options of fallow preparation	Productivity (t/ha)
Check	
Mechanical	1.73
Reduced	1.76
Tested	
Chemical	1.81
Green-manure	1.07
Anti erosion	1.62

After snow thawing and the washout of soils from the mechanical treatment in 2002, losses of the most fertile soil reached 0.47 t/ha, and with the chemical treatment, 0.4 t/ha (Table 2). A similar fallow preparation pattern was observed in 2003; however, the soil washout that year was significantly lower.

As soil fertility preservation is the main indicator of technology effectiveness, zero tillage deserves attention because it increases soil resistance to water erosion.

The second question for the evaluation of systems effectiveness is increasing soil impermeability to water. When the snow thaws, mechanical tillage creates the best conditions for moisture absorption. The options of chemically treated fallow were less efficient in terms of water conservation and depth of water penetration into the soil (Table 3). In these options, moisture was better preserved in upper layers, especially when oats were planted. In options with mechanical tillage, moisture loss was very significant due to the unleveled surface.

Table 2. Soil washout (t/ha) by thawing waters, depending on the fallow preparation method, 2002.

Options of fallow preparation	Northern slope	Southern slope
Check		
Mechanical	4.9	4.7
Reduced	4.6	4.2
Tested		
Chemical	0.6	0.4
Green-manure	0.4	0.3
Anti erosion	0.7	0.6

In the fallow field, nitrification processes were intensive, due to good aeration created by mechanical tillage (Table 4). This, in turn, determined the level of nitrogen nutrition of spring wheat plants. In the chemical fallow, the accumulation of nitrate nitrogen was insignificant and the plants experienced a lack of nitrogen nutrition, which could be clearly observed in the development and color of the wheat. The main elements of nutrition in vegetative organs of wheat during heading evidenced a lack of nitrogen. Studies show that the efficiency of nitrogenous fertilizers depends on minimization of soil tillage.

The main reason for leaving a field fallow is purification of weeds, especially perennial root-sucking weeds. A highly weed-infested plot was chosen for the experiments (Table 5). Observations of weeds, undertaken during fallowing, showed that their death occurred primarily after chemical treatments. Some weeds, such as abthinthium (*A. abthinthium*) and vine spurge were highly resistant to herbicides. Annual weeds, namely wild oats, were efficiently destroyed by herbicides in the fallow field. However, due to a moist spring, a significant number of weed shoots emerged before the first crop in rotation was planted. Presowing treatment controlled these weed shoots.

This research concluded that in Central Kazakhstan zero tillage can be an effective way to improve soil resistance to water erosion. However, nitrogenous fertilizers should be applied, and methods for improving soil permeability should be developed. Crosswise groove creation is a possible solution to this problem.

Table 3. Productive moisture content (mm) before the first crop planting after fallow.

	Options of fallow preparation				
Soil horizon (cm)	Mechanical	Reduced	Chemical	Green-manure	Anti-erosion
0-100	192.3	190.2	169.1	178.1	180.8
0-50	88.3	84.1	95.5	108.3	99.2
50-100	104.0	106.1	73.6	69.8	80.2
0-20	28.2	28.3	31.7	35.2	37.3

Table 4. Macronutrient content (%) in plants, depending on the type of fallow treatment.

Options of fallow preparation	Nitrogen	Phosphorus	Potassium	Calcium
Check				
Mechanical	1.82	0.26	1.66	0.95
Reduced	1.77	0.25	1.63	0.90
Tested				
Chemical	1.66	0.23	1.45	0.80
Green-manure	1.71	0.22	1.33	1.71
Anti erosion	1.63	0.23	1.45	0.88

Table 5. The influence of fallow treatments upon weed density (pieces/m²) before the first crop planting.

Options of fallow preparation	Total weeds	Total root suckers
Check		
Mechanical	121.4	12.4
Reduced	97.4	6.8
Tested		
Chemical	5.4	1.2
Green-manure	325.4	15.0
Anti erosion	80.1	6.9

Creating a Collaborative Advantage for Crop Improvement: The Asian Maize Biotechnology Network

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Abstract

The Asian Maize Biotechnology Network (AMBIONET) is a collaborative research, training, and information network, whose goal is to help build an enabling environment for Asian national agricultural research systems (NARS) to use modern science and biotechnology tools to address maize production problems. Co-financed by the Asian Development Bank (ADB), NARS of partner countries, and CIMMYT, the network emphasizes the application of molecular markers in the development of improved maize varieties. AMBIONET provides a unique mechanism for institutions in developing countries to build capacity for biotechnology research and create synergies. Network activities are geared towards building capacity through workshops and exchange visits, supporting collaborative research through the provision of funds and scientific/technical support, and promoting the sharing of research results, technologies and materials. By providing regional connectivity, AMBIONET facilitates access to the global maize science and technology resources through CIMMYT.

AMBIONET member countries–China, India, Indonesia, Philippines, Thailand, and Vietnam–already have significant maize biotechnology efforts underway. AMBIONET's approach for biotechnology collaboration was to build upon previous investments in the region by the Rockefeller Foundation's International Rice Biotechnology Program and the International Rice Research Institute's Asian Rice Biotechnology Network, and to complement and strengthen existing national capacity. Through a collaborative research program implemented by multidisciplinary teams of scientists, progress is being made towards the development of locally adapted, high-yielding, stress-tolerant maize varieties. Research efforts are targeting higher yields through genetic diversity studies; resistance against downy mildews (DM), banded leaf and sheath blight (BLSB), and the virus disease sugar cane mosaic virus (SCMV); tolerance to drought and low soil nitrogen; and nutritional enhancement through quality protein maize (QPM). The application of molecular markers serves as the common theme in three main areas of the collaborative work involving the targeted traits.

Understanding the complex interactions between genes and the environment, and the effective application of this knowledge for crop improvement is a challenging task. Research that addresses multifaceted crop production problems requires a multidisciplinary approach that combines knowledge and methodologies from breeders, biotechnologists, and other scientists. This and the substantial resources required, underscore the need for networking and working effectively in collaborative relationships. This need is vital in developing countries, where national agricultural research systems (NARS) which seek to incorporate biotechnology in agricultural research, are unable to build the necessary capacity by themselves. To exploit modern science and new technologies, researchers in crop improvement programs need to know the science and adopt the tools, to work across disciplines, and to build effective linkages with others.

While the promise of biotechnology in agriculture is now being realized in developed countries, this is not generally so in developing countries. Most of them still face challenges on how best to build capacity that would enable them to exploit the rapid advances being made, and to take advantage of available information and products.

"Collaborative advantage" in networks

Asia has some of the most highly developed NARS, as well as others with varying levels of capacities and resources. The rationale for forming linkages and engaging in partnerships is driven by considerations for improved effectiveness and efficiency. Bringing different partners to bear on common problems brings on board the advantages of economy of scale and scope relevant to regional agriculture.

Collaborative partnerships are advantageous and sustainable when there is a clear value added as a result of the relationship. This synergy, referred to as "collaborative advantage", is achieved when something innovative is created that no organization could have achieved on its own, and when each organization is able to achieve its own objectives better than it could alone (Huxham, 1996). A collaborative network serves as a mechanism for creating an enabling environment that allows common issues to be addressed without duplicating efforts, ensures judicious use of resources through sharing, and facilitates technology diffusion and spillover over from country to country. The opportunities for interactions in a network open the door for sharing information and experiences so countries avoid reinventing the wheel, for complementarities to be exploited while considering the strengths and needs of individual countries, and for breaking the isolation of NARS researchers, allowing them to join the mainstream of the global research community. Advances in information and communication technologies now greatly facilitate collaborations, allowing intensive and extensive interactions to take place electronically across national barriers. However, partnerships are complex and challenging to manage, and effective collaborations are not easy to achieve.

This paper provides an overview of the Asian Maize Biotechnology Network (AMBIONET) as an example of a regional network for crop improvement, with a specific focus on research results that demonstrate the value of a coordinated, collective effort.

The Asian Maize Biotechnology Network: A Case Study

Maize is the third most important crop in Asia, where it is mainly grown in marginal production environments, often in rainfed uplands characterized by shallow and infertile soils. With the exception of China, most maize farms in Asia are small-scale and subsistence-oriented, where yields are generally low. Maize demand in Asia is projected to rise from 138 million metric tons in 1993 to 241 million metric tons in 2020. Although production varies among the maize producing countries, on the whole, production has not been sufficient to keep up with the growth in demand. How to meet this rising demand is a pressing challenge.

Advances in maize biotechnology

Biotechnology has the potential to contribute to agricultural production by revolutionizing the way plant breeding is carried out, making germplasm improvement efforts faster, cheaper, and more precise (Knapp, 1998; Ribaut and Hoisington, 1998; Stuber et al. 1999; Warburton and Hoisington, 2001). Over the past few years, significant advances have been made in maize biotechnology:

- Highly saturated molecular maps of maize have been constructed, and the location and effect of major genes and QTL (quantitative trait loci) controlling a variety of traits determined.
- The arrangements of genetic and DNA markers on the chromosomes of major cereals such as maize, rice, wheat, barley, and rye, have been found to be similar. This concept of genome colinearity means that the location of a gene can be inferred from one map to another, extending the usefulness of molecular maps.
- "Gene machines," which are large collections of maize plants whose genomes contain transposon-induced mutations, have been developed. Transposons constitute powerful tools for identifying, tagging, and ultimately isolating almost any gene of interest.
- Genetic engineering of maize has become a routine technology for introducing novel gene sequences and/or expression.
- Efforts are underway to produce complete genomic sequences of the gene-rich regions of maize and once the information is available, gene function can be correlated to phenotypes.

The challenge is to apply these scientific breakthroughs in maize improvement programs. or scientists in the developing world, it is difficult to reap the benefits of these advances if they are not capable, equipped and resourced to capture them as they come.

Application of biotechnology tools in maize improvement in Asia

AMBIONET was established in 1998 as a collaborative research, training, and information network whose goal is to help build an enabling environment for NARS in China, India, Indonesia, Philippines, Thailand, and Vietnam to use modern science and biotechnology tools to address maize production problems. Co-financed by the Asian Development Bank (ADB), NARS of member countries, and CIMMYT, the network emphasizes the application of molecular markers in the development of improved maize varieties. The network was built upon previous investments in the region by the

Rockefeller Foundation's International Rice Biotechnology Program and the International Rice Research Institute's Asian Rice Biotechnology Network, complementing and strengthening the existing national capacity. Network activities are geared towards building capacity through workshops and exchange visits, supporting collaborative research through the provision of funds and scientific/technical support, and promoting the sharing of research results, technologies and materials. Training activities done in CIMMYT Mexico, in the region, and in-country have benefited NARS scientists, enhancing the scientific and technological capacity of the national programs. By providing regional connectivity, the network facilitates access to the global maize science and technology resources through CIMMYT.

Collaborative Research under AMBIONET

Collaborative research under AMBIONET is presently focused on the application of molecular marker technology to problems of national and regional importance, such as the molecular characterization of locally important maize lines, mapping of QTLs for resistance to major diseases—downy mildews, sugar cane mosaic virus and banded leaf and sheath blight—and tolerance to abiotic stresses (drought and low nitrogen conditions), and the integration of MAS in national breeding programs (Table 1). AMBIONET teams engage in country-specific research, at the same time that they work collaboratively with others in network-wide research involving common themes. Two examples of such collaboration are given below.

Fingerprinting and genetic diversity of maize germplasm. DNA fingerprinting and genetic diversity analyses allow the efficient management of germplasm collections (Warburton and Hoisington, 2001). Accurate assessment of genetic diversity is helpful in maize breeding for maintaining/broadening the genetic base of elite germplasm; for assignment lines to heterotic groups; and for selecting appropriate parental lines for hybrid combinations. As a predictive tool, genetic distance between inbred lines is of particular value in crops like maize where substantial resources are devoted to the field-testing of lines in various cross combinations to identify those with superior combining ability.

A network-wide effort was made for fingerprinting and characterizing the genetic diversity of the maize germplasm in Asia using simple sequence repeats (SSRs) or microsatellites. Molecular profiling of 102 inbred lines, including tropical/subtropical lines from the national programs in China, India, Indonesia, Philippines, Thailand, Vietnam, and CIMMYT (Asian Regional Maize Program and Maize Program) as well as temperate lines from the US and Europe, revealed that breeding activity in Asia has not caused a decline in the overall amount of diversity in the region. The mean polymorphism information content of the 76 SS markers used in the study was 0.59 (range of 0.15 to 0.84). Diversity at the gene level showed an average of 5.4 alleles per locus and a range of two to 16 alleles per locus, with a total of 409 alleles. About half of the alleles in the Asian lines had frequencies of 0.10 or less, and only 2 % had frequencies > 0.80, indicating the presence of many alleles, and thus a high level of diversity.

A dendrogram was constructed and distinguished lines from the US, Germany, and China which comprised three clusters of temperate maize, and those from India, Indonesia, Philippines, Thailand, Vietnam, and CIMMYT which comprised seven indistinct clusters of tropical and subtropical maize. Bootstrap values for the branches of the temperate cluster are high, indicating that the groupings are robust, but those of the branches in the subtropical/tropical cluster were low (Figure 1). Lines from each country were clustered in at least two of the seven groups, with lines from Thailand being the most diverse, occurring in five of the seven clusters. The CIMMYT lines were dispersed in the clusters within the subtropical/tropical group of Asian lines, reflecting the common germplasm sources of these lines. The average

Table 1. Summary of AMBIONET research activities (1998-2003). Each activity is focused on the improvement of locally adapted lines for country-relevant traits. A research component relevant to all engaged in a particular research is conducted as a network activity.

Country	NARS*	Maize diversity	Virus	DMR	BLSB	Drought	Low N	QPM
China	CAAS	x	x			x		x
	SAU	x			x	x		
India	IARI	x		x	x	x		
Indonesia	ICERI/IABGGRI	x		x	x	x		x
Philippines	USM	x		x		x		x
Thailand	DOA	x		x		x	x	x
Vietnam	NMRI/AGI	x				x		x

* CAAS, Chinese Academy of Agricultural Sciences; SAU, Sichuan Agricultural University; IARI, Indian Agricultural Research Institute; ICERI, Indonesian Cereal Research Institute; IABGRRI, Indonesian Agricultural Biotechnology and Genetic Resources Research Institute; USM, University of Southern Mindanao; DOA, Department of Agriculture; NMRI, National Maize Research Institute; AGI, Agricultural Genetics Institute.

genetic similarity among the lines in the subtropical and tropical group (GS = 0.29) was not very different from that of all the lines (GS = 0.28), or to that of the lines in the temperate group (GS = 0.31). On a per country basis, there was a range of GS from to 0.29 (Thailand) to 0.45 (India).

Studies in China (Yuan et al., 2001), India (Pushpavalli et al., 2001), and Indonesia, Philippines, Thailand, and Vietnam (unpublished data) provided valuable information about genetic relationships of breeding materials in the individual countries. A high level of SSR heterozygosity in some lines, possibly due to inadequate cycles of inbreeding, uncontrolled pollination, contamination of seed stocks, mutations at diverse SSR loci, or amplification of similar sequences in different genomic regions, was observed in these studies.

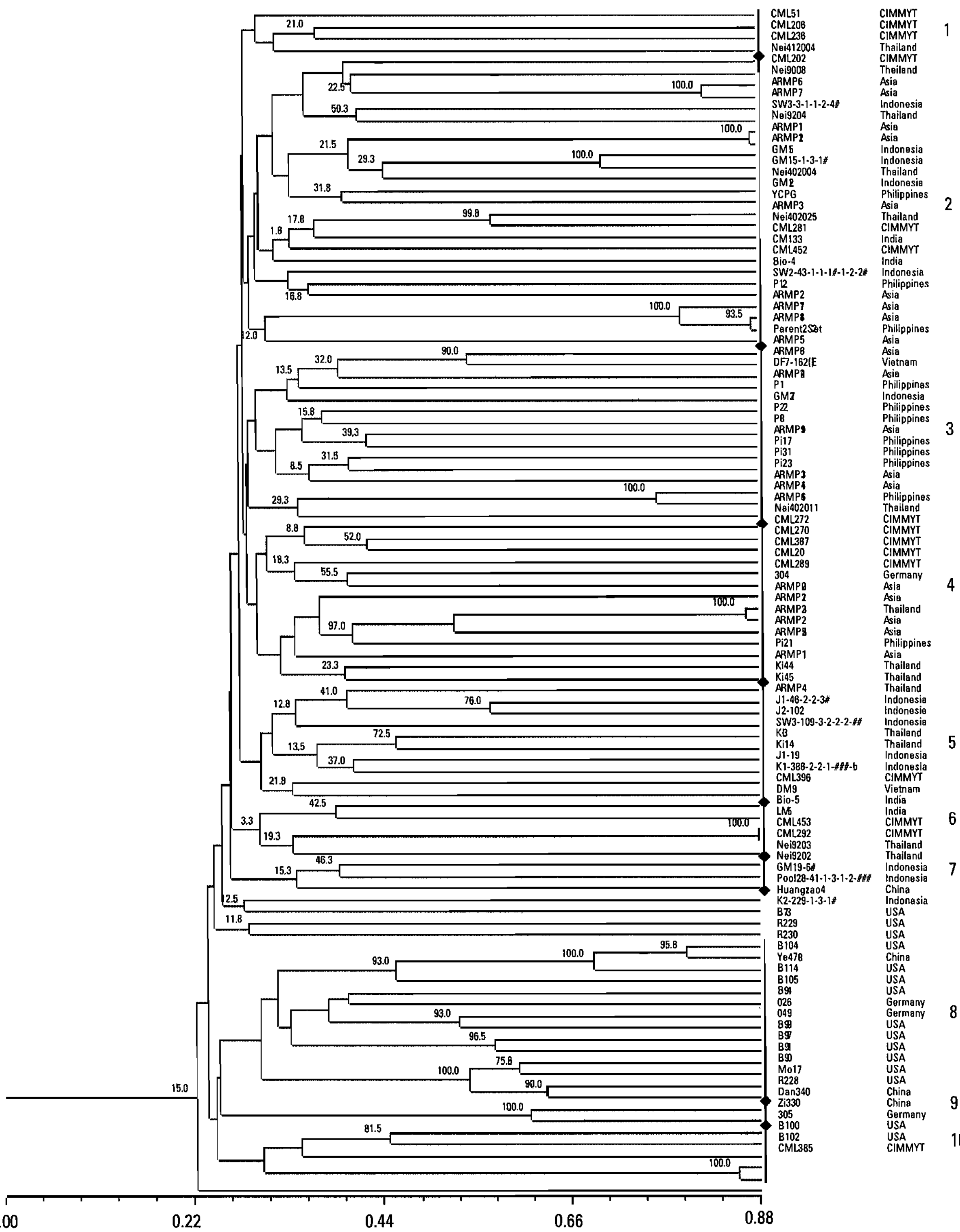

Figure 1. UPGMA dendrogram of 102 inbred lines based on 76 SSR markers. Genetic similarities were calculated using Jaccard's coefficient. Bootstrap values are indicated at the junction of the clusters.

To obtain a picture of the relationships between local lines and those in the regional and international breeding programs, a coordinated effort was made to develop and use a standardized methodology for genetic diversity studies. This allowed the merging of datasets from different countries, and the wide-scale analysis of maize diversity. An important aspect of this work is the standardization of the techniques to yield reproducible results across laboratories to allow multiple datasets to be compared and combined into a common database.

Mapping QTLs for resistance to downy mildews. A major emphasis in maize breeding in Asian countries has been the improvement for resistance to the downy mildews, a serious disease that causes significant yield losses. The mapping of QTLs and identification of molecular markers closely linked to the QTLs with major effect on a target trait permit marker-assisted selection. This is especially useful for traits that are otherwise difficult or impossible to select for by conventional means. A network-wide effort to map resistance genes for downy mildews, with CIMMYT contributing seeds and genotype data, and the AMBIONET teams contributing the phenotype data, resulted in the identification of resistance QTLs that is expressed in several Asian countries.

The QTL mapping study was based on a multi-environment evaluation of a set of recombinant inbred lines (RILs) derived from Ki3 x CML139 cross (George et al., 2002). The downy mildew resistant parent (Ki3) is a tropical yellow flint line with late maturity from Suwan 1, a cultivar developed in Thailand against sorghum downy mildew (*Peronosclerospora zeae*). The susceptible parent (CML139) is a subtropical yellow-red semi-flint line with intermediate maturity, developed from CIMMYT materials for tropical corn borer resistance. A molecular map was previously constructed from this cross (135 RILs with 143 RFLP markers) for QTL mapping of southwestern corn borer resistance (Groh et al., 1998). The same RIL families were evaluated for downy mildew reaction at Mandya in southern India against sorghum downy mildew (*P. sorghi*); at Udaipur in western India against Rajasthan downy mildew (*P. heteropogoni*); at Maros in Indonesia against Java downy mildew (*P. maydis*); at Farm Suwan in Thailand against sorghum downy mildew (*P. zeae*); and in southern Mindanao in Philippines against Philippine downy mildew (*P. philippinensis*). Composite interval mapping was carried out for joint analysis of data across environments to map QTL and estimate their genetic effects.

QTLs with significant effects on resistance to five important downy mildew diseases were identified (Figure 2). Three QTL, two on chromosome 2 and one on chromosome 7, significantly influenced resistance only to specific pathogen populations. The first QTL on chromosome 2 (position 158 cM), due to alleles from the susceptible parent CML139, was specific to sorghum downy mildew at Mandya in India. The second QTL on chromosome 2 (position 234 cM) and the QTL on chromosome 7, due to alleles from the resistant parent Ki3, were found to influence specifically *P. heteropogoni* at Udaipur in India. The most important genomic region, having the highest LR values in the analysis of data from individual locations as well as in the joint analysis, and having a consistent expression against the different downy mildews, was found on chromosome 6. Interestingly, this QTL is located in a region (bin 6.05) holding clusters of resistance genes in maize.

The five QTL identified in this study explained a range of phenotypic variation in disease susceptibility, from 24% (Thailand) to 54% (Udaipur, India). Most significantly, the QTL on chromosome 6 had the largest contribution, accounting for nearly 20% and 31% of the phenotypic variance for *P. sorghi* and *P. heteropogoni* disease susceptibility at Mandya and Udaipur, respectively. The same QTL explained more than half of the total phenotypic variance due to the five QTL in each of the four environments. Significant QTL x E interactions and large estimates of s^2_{ge} observed across the locations indicated major influence of the environment on the expression of downy mildew resistance. The AMBIONET study identified three SSR markers *umc11*, *umc23a*, and *umc113* tightly linked to the QTL on chromosome 6 (George et al., 2002), for possible use in MAS.

Conclusions

Prior to AMBIONET, national programs in Asia have made efforts to integrate biotechnology in maize improvement in isolation. Collaboration in AMBIONET has resulted in the systematic and region-wide application of molecular markers and their integration in national maize breeding programs. Significant factors that contributed to this enabling environment are efforts put into capacity building (laboratory and human resources), focused and sustained scientific and technical support, and a culture of sharing and interactions fostered in the network.

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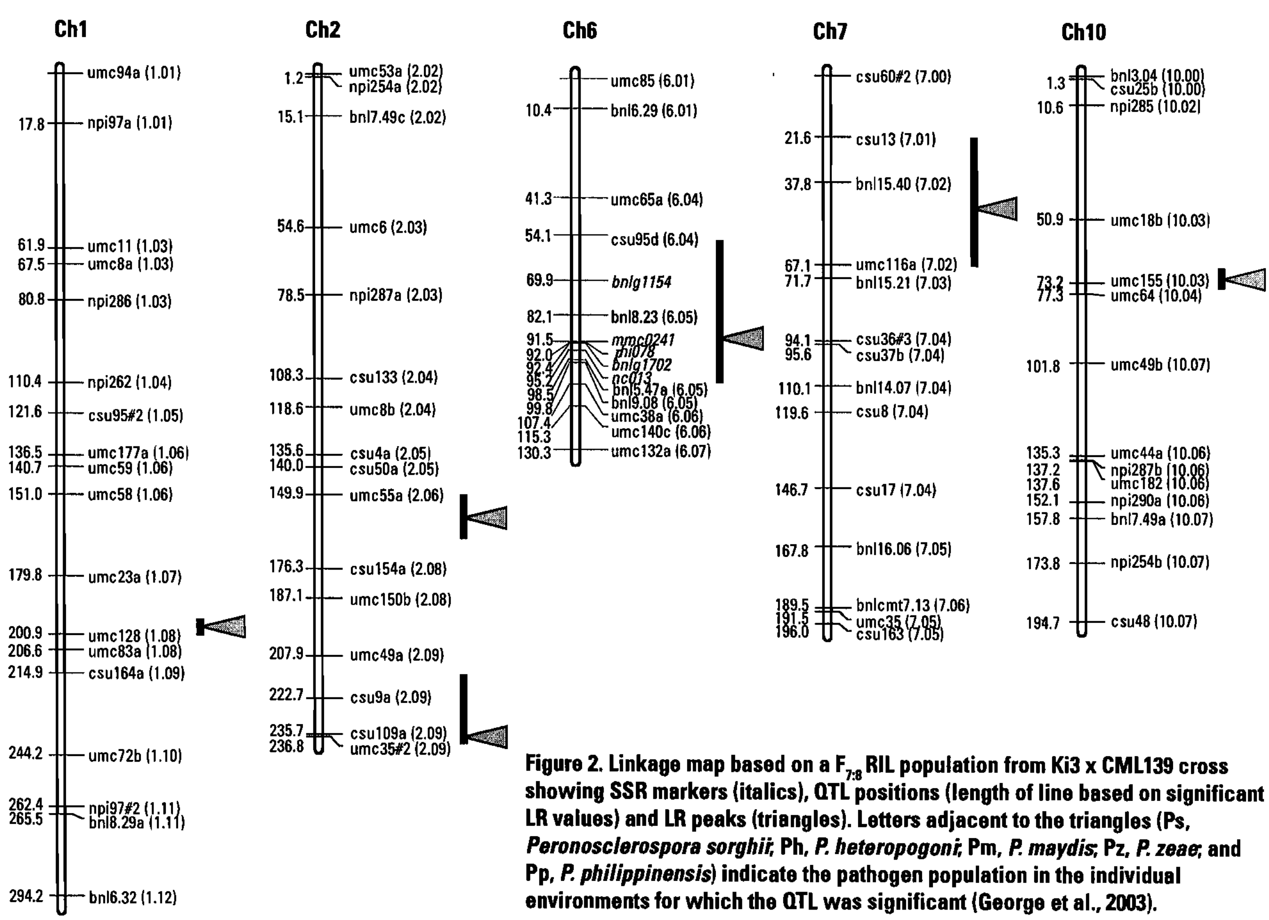

Figure 2. Linkage map based on a $F_{7:8}$ RIL population from Ki3 x CML139 cross showing SSR markers (italics), QTL positions (length of line based on significant LR values) and LR peaks (triangles). Letters adjacent to the triangles (Ps, *Peronosclerospora sorghii*; Ph, *P. heteropogoni*; Pm, *P. maydis*; Pz, *P. zeae*; and Pp, *P. philippinensis*) indicate the pathogen population in the individual environments for which the QTL was significant (George et al., 2003).

Breeding Spring Bread Wheat Adapted to Siberian Conditions

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Western Siberia is very rich in energy sources, and its potential for economic growth is great. Spring bread wheat is a very important crop in the region, and one of the goals of agricultural science here is to identify sources useful for increasing its yield and grain quality. Varieties have an essential role to play, since up to 60% of yield increases is controlled by genotype. As for grain quality, the input of genotype is even higher. Varieties are in many cases the only effective means of increasing agricultural production.

High variability in abiotic stress factors from year to year causes high variability in spring bread wheat yields. That is why wheat breeders are trying to increase the adaptive potential of newly bred varieties. An important goal of agricultural scientists is to develop cropping practices for wheat production that must be adapted to the biological requirements of each variety.

Wheat breeders have achieved some progress, especially in the last decades. Still, wheat producers usually do not use the biological potential of new varieties effectively. Here are some reasons for this. First, before the 1990s too much attention was paid to breeding wheat varieties for intensive cropping systems. Broad adaptation, which is highly important in many regions of Russia, was underestimated. Secondly, crop management practices have usually not been effective for combining local natural resources and the genetic potential of a variety. Thirdly, many farms grow crops under low-level agronomic practices, and this is harmful to intensive varieties.

Materials and Methods

There are some abiotic stress factors that should be considered in breeding:

- Regional danger of droughts. Atmospheric droughts in Siberia are not seldom even in its northern parts.
- Late spring and early autumn frosts. Great difference between day and night temperatures.
- Shortage and irregularity of rainfall.
- Alternation of dry and reasonably wet seasons.
- Wind erosion in southern parts of the region (steppe and forest-steppe zones).

Among the negative biotic factors for spring bread wheat one should mention:

- Insects that attack spring bread wheat: *Agriotes sputator* L., *Melolontha* L., *Phyllotreta vittula* Redt.,*Chaetocnema hortensis* Geoffr., *Mayetiola destructor* Say., *Oulema melanopa* L., *Psammotetlix striatus* L., *Macrosteles laevis* Rib., *Haplothrips tritici* Kurd., *Schizaphis graminae* Roud., *Macrosiphum avena* F., and *Apamea anceps* Schiff. Last season's locust invasions took place in the southern territories of Western Siberia, due to the radical increase of abandoned soils in Kazakhstan.
- Most harmful fungal diseases: *Helminthosporium sativum* Pam. Kung et Bakke, *Fusarium* Link; *Ustilago tritici* (Pers.) Jens; *Tilletia tritici* (Bjerk) Wint; *Puccinia triticina* Eriks. et Henn; *Puccinia graminis* Pers.; *Erysiphe graminis* DC; and *Septoria graminum* Desm.
- Among bacterial diseases one should mention *Xanthomonas campestris* and *Pseudomonas syringae.*
- The most harmful weeds; breeding to improve wheat plants' ability to compete against them being conducted:
  - annual: *Avena fatua* L., *Fagopyrum tataricum* L., *Convolvulus arvensis* L., *Galeopsis ladanum* L., *Galium aparine* L., *Setaria viridis* L., *Amaranthus retroflexus* L.;
  - perennial: *Cirsium arvense* L., *Sonchus arvensis* L., *Euphorbia waldstenii* (Sojak) Czer.

In accordance with ecological features of the region, the principal goals of wheat breeding are:

- breeding varieties of different maturity;
- resistance/tolerance to biotic and abiotic stress factors;
- production of high quality grain.

Accessions from the collections of the All-Russia Plant Development Vavilov Institute (St. Petersburg, Russia), CIMMYT (Mexico), and lines developed in the spring bread wheat breeding laboratory of the Siberian Agricultural Research Institute (SARI) in Omsk, Russia, were used as parents.

Breeding plots were 10 m^2 in size, with 3-4 replications. All evaluations of breeding materials in the field and laboratory after harvest were conducted following the State Variety Testing Commission's recommendations.

In vitro biotesting of breeding materials for tolerance to environmental stress factors, including drought, was done using the methods of Rosseyev (Roseev V.M., 2001). The recommendations of Eberhart and Russell (1966) and Tai (1971) were used for evaluating ecological adaptation.

Results and Discussion

For *in vitro* biotesting of breeding materials of cereal crops for tolerance to environmental stress factors, including drought, one needs: an assortment of explants and media; to fulfill a series of operations aimed at protecting cultivated cell systems from infection; to create an environment favorable for observing the whole spectrum of morphogenetic reactions in the materials under study and for distinguishing among genotypes. Tissue culture methods are used to test wheat genotypes for general (non-specific) tolerance based on the reaction of explants of mature embryos on calligenic media. The proportion of cultures with green sprouts at 30th day of explant cultivation is used as an indicator of resistance at early stages of plant development (i_21). The proportion of cultures (genotypes) with high regeneration capacity of cultured cells (i_1) and proportion of cultures with regenerants (i_2) are used as a measure of genotype resistance for the whole development period. These characteristics are evaluated on 90-day explants, as follows: $i_1 + i_2 > 0.5$ means improved or high resistance; $i_2 > 0.5$ = high. If the sums ($i_1 + i_2$) of two genotypes are the same, the genotype with higher i_2 index has higher resistance.

The correlation between biotesting results and abiotic stress tolerance is based on the assumption that high regeneration capacity of cells cultured *in vitro* in a medium suppressing such capacity demonstrates stability (resistance) of morphogenetic mechanisms; the loss of such capacity shows weak protection ability. *In vitro* biotesting allows identifying lines with high general (non-specific) tolerance to abiotic stress factors, including drought. Results of biotesting of some spring bread wheat varieties are presented in Table 1.

Breeders are developing varieties of the type and level of resistance needed in specific ecological areas.

In vitro biotesting has shown that new spring bread wheat lines Lutescens 322/93-2, Lutescens 181/95-5, and Lutescens 50/95-3 have improved levels of resistance (Table 1). The laboratory method proposed for evaluating plant tolerance to stress factors is not, unfortunately, an express method. Nonetheless, it can be used to evaluate the resistance of biological systems under short- and long-term effects of stress factors and to identify lines with different types of resistance (tolerance). This method can also be used to identify lines from heterogenic samples.

Biotesting and *in vitro* selection can be done at different stages of the breeding process. However, homogenic (or nearly homogenic) materials are normally used in biotesting, while heterogenic materials are necessary for *in vitro* selection.

Wheat grain yield losses due to epidemics of foliar diseases can sometimes reach 30%. In recent years farmers in the Omsk region have been introducing new wheat varieties with resistance to smut.

Table 1. Results of *in vitro* biotesting of spring bread wheat for resistance to abiotic stresses.

		Resistance index			
		In early stages	Adult plant		
Variety	Year of release	i_21	i_1	i_2	$i_1 + i_2$
Mid-to-early varieties					
Yertyshanka 10	1981	0.53	0.40	0.05	0.45
Omskaya 26	1998	0.56	0.37	0.04	0.41
Pamyati Azieva	2000	0.68	0.39	0.10	0.49
Omskaya 32	2001	0.54	0.43	0.03	0.46
Lutescens 322/93-2	-	0.63	0.47	0.09	0.56
Intermediate varieties					
Cezium 111	1929	0.58	0.30	0.02	0.32
Saratovskaya 29	1957	0.55	0.54	0.05	0.59
Thelinnaya 26	1986	0.56	0.49	0.08	0.57
Omskaya 29	1999	0.63	0.41	0.05	0.46
Omskaya 33	2002	0.57	0.45	0.07	0.52
Omskaya 35	-	0.59	0.53	0.06	0.59
Lutescens 181/95-5	-	0.61	0.51	0.09	0.60
Mid-to-late varieties					
Milturum 553	1940	0.54	0.43	0.06	0.49
Omskaya 9	1979	0.59	0.49	0.05	0.54
Omskaya 18	1991	0.57	0.50	0.09	0.59
Omskaya 24	1996	0.59	0.47	0.05	0.52
Omskaya 28	1997	0.65	0.50	0.05	0.55
Lutescens 50/95-3	-	0.64	0.53	0.07	0.60
LSD_{05}		0.06	0.05	0.03	0.04

These varieties were developed by breeders of Kurgan Agricultural Research Institute, Novosibirsk Cytology and Genetics Institute, and Omsk State Agrarian University (Tertsia, Sonata); SARI varieties with field resistance are Omskaya 20, Omskaya 29, Omskaya 30, Strada Sybiri, and Omskaya 33.

Breeding spring bread wheat varieties resistant to smut is complicated because of the high level of pathogen variability and the low number of resistance genes in parental lines. The genetics of smut resistance also needs careful study. There has been some research conducted in this field of science in recent years (Russell, 1982) that showed that the proportion of genotypes demonstrating resistance in the field and in the laboratory is low. Genes controlling adult plant resistance to smut are different from those determining resistance at early stages of plant ontogenesis.

Despite the introduction of smut resistant varieties, losses from the disease are increasing. This is associated with the genetic propinquity of cultivated varieties. Many researchers consider that varieties should be developed that, though susceptible, do not decrease yield significantly. Such varieties demonstrate stable yields at the expense of disease resistance. Some authors consider that the most effective, long-term resistance is secured by combining major and minor genes. Van der Plank (1972) mentioned that combining vertical and horizontal resistance in a plant has a positive effect.

We consider that as long as smut diseases appear in Western Siberia after mid July, intermediate to early maturing varieties need have only horizontal resistance; as for early varieties, they escape infestation with smut. Intermediate varieties, which are seriously affected by smut diseases, need vertical resistance as a rule. It is therefore reasonable to breed wheat varieties that can delay infestation, sometimes up to harvesting time. Of the mid-to-late varieties, those that delay infestation but demonstrate susceptibility in the last vegetative stages by speeding up maturity are most valued.

As a result of many planned crosses, some new varieties in 2002, an epidemic year for smut, proved to be more resistant than the checks in a nursery of our laboratory breeding scheme. In a group of mid-to-early varieties, Lutescens 45/94-2 and Lutescens 196/94-6 delayed smut development. In a first field trial, resistance of these varieties received scores of 5 and 7, respectively. In a second field trial where susceptibility to smut disease was assessed, when check varieties had dead leaves, these new varieties had 60 and 50% of infested leaves, respectively.

Nearly all the new test varieties in the intermediate-maturing group were at yield levels similar to or above those of the check varieties. Among the highest yielding varieties, Lutescens 242/97-2, Lutescens 261/97-4, and Lutescens 269-97/97-3 should be mentioned. Check varieties in this maturity group also restricted pathogen development.

Average grain yield in the mid-to-late group of test varieties was not high: 2.5 t/ha. This is connected with the long period of foliar disease development. While 100% of check varieties were overcome by leaf rust, most new test varieties demonstrated resistance to the pathogen. Of 11 varieties selected, 4 were assessed as resistant and 3 as susceptible; 4 varieties were infested only at the end of the vegetative period. The varieties that delayed pathogen development had the highest grain yield: from 3.82 (Lutescens 158/97-26) to 4.18 t/ha (Lutescens 149/97-4).

Although some breeders consider that the time for developing varieties with wide adaptation (Saratovskaya 29 type) is passed, the high liability and sporadic combination of abiotic and biotic stress factors in extended territories such as Western Siberia is reason enough for developing such varieties.

In selecting sources of adaptive traits, our laboratory invested a great deal of time studying the All-Russian Plant Development Vavilov Institute (St. Petersburg) and CIMMYT collections. Of most interest are such traits as maturity, resistance to harmful diseases, root system development, and adaptability of selected traits.

Determining the ecological adaptability of varieties makes it possible to predict their rate of adoption and to evaluate their commercial potential better. Parameters of ecological adaptability allow the breeder to evaluate the effectiveness and relevance of breeding in a region.

In 1989 the authors established an experiment for evaluating spring bread wheat varieties bred over the course of 75 years (1929-2003). Twenty-seven varieties were studied in SARI in 1996-2002. Results indicated genotype x environment interaction and significant influence of factors A (varieties) and B (years) on yield level. Varieties introduced from 49.49% (mid-to-late group) to 56.98% (intermediate varieties) of input; years – from 41.39% (intermediate group) to 48.59% (mid-to-late). Interaction of factors proved to be significant but not high: 1.63-2.45%.

In Table 2, b_i, S_d^2, α and λ parameters are shown for each maturity group of test varieties. In the intermediate group, old varieties Cezium 111 and Albidum 3700 were the weakest in their reaction to improved technology: at an experimental yield increase of 1 h/ha, theirs only increased 0.36 and 0.59, respectively. The most responsive variety in all test years was Omskaya 20 (1.44 h/ha). Regression lines obviously demonstrate reaction of test varieties to the environment. For example, average grain yield of Cezium 111, Albidum 3700, Sybiryachka 4, and DIAS 2 is lower than that of the experimental mean. Omskaya 20 is highly responsive to improved conditions. In stress situations it decreases its yield but not so drastically as old varieties. Omskaya 33 was the best in the trial: highly responsive to improved conditions, reasonably decreases yield in stress situations, and its average yield was the highest in the experiment.

Besides yield, we evaluated ecological adaptability parameters for yield components and selected physiological parameters (productive tillers, high internode length, number of grains per spike, productivity of head and plant, 1000-kernel weight, flag leaf area, dry matter surplus during grain-filling).

Table 2. Grain yield and adaptability parameters of spring bread wheat developed at SARI, 1996-2002.

Variety	Year of release	Yield (h/ha) Average	Limits	Ecological adaptability parameters bi	Sd	α	λ
Mid-to-early varieties							
Noe	1929	23.7	15.0, 28.4	0.83	10.98	-0.14	0.32
Smena	1938	22.9	18.4, 29.7	0.69	10.46	-0.25	0.35
Lutescens 956	1939	25.3	18.2, 31.2	0.88	9.66	-0.10	0.28
Yertyshanka 10	1981	24.8	16.2, 29.4	0.88	6.54	-0.10	0.19
Omskaya 12	1984	25.1	17.4, 32.9	1.03	9.83	0.03	0.27
Omskaya 21	——	29.9	23.6, 34.0	0.84	2.46	-0.13	0.09
Omskaya 26	1998	33.2	20.6, 44.4	1.68	14.61	0.55	0.71
Pamyati Azieva	2000	36.4	27.5, 44.0	1.28	1.94	0.23	0.11
Omskaya 32	2001	34.9	25.6, 39.7	0.90	5.26	-0.09	0.15
Intermediate varieties							
Cezium 111	1929	20.4	17.2, 23.4	0.36	2.74	-0.58	0.55
Albidum 3700	1940	22.2	17.4, 26.8	0.59	7.14	-0.38	0.43
Sibiryachka 4	1976	29.8	20.8, 37.0	1.05	12.97	0.05	0.42
Omskaya 17	1986	33.4	23.1, 40.3	0.95	7.79	-0.05	0.26
Omskaya 19	1989	33.6	25.1, 39.7	0.90	4.60	-0.10	0.16
Dias- 2	1992	28.3	17.3, 38.0	1.30	6.91	0.28	0.33
Omskaya 20	1993	36.2	20.8, 44.7	1.44	7.78	0.40	0.47
Omskaya 29	1999	37.6	25.3, 45.2	1.13	8.51	0.11	0.29
Omskaya 33	2002	42.6	27.8, 50.7	1.29	6.54	0.26	0.31
Mid-to-late varieties							
Milturum 321	1929	21.1	14.8, 29.6	0.53	14.04	-0.59	1.15
Milturum 553	1940	24.5	13.3, 29.0	0.85	4.09	-0.19	0.24
Cezium 94	1957	26.7	19.9, 30.7	0.65	4.65	-0.44	0.49
Omskaya 9	1979	33.1	23.0, 39.0	0.90	2.01	-0.13	0.11
Omskaya 18	1991	38.5	27.1, 49.0	1.06	3.78	0.07	0.18
Omskaya 24	1996	37.7	22.3, 53.7	1.53	32.1	0.67	2.10
Omskaya 28	1997	38.0	24.8, 49.7	1.29	3.28	0.37	0.35
Omskaya 30	2003	40.8	25.9, 52.4	1.17	10.8	0.22	0.56
Omskaya 35	LSD	40.5	23.6, 49.1	1.02	31.8	0.02	1.44

Some years ago old Siberian varieties (Mylturum 553, Mylturum 321, Skala, Lade a.o.), and varieties from the Volga river basin (Saratovskaya 29, Bezenchukskaya 98, Lutescens 758 a.o.) and Northern Kazakhstan (Pyrotrix 28) were very popular in Western Siberia. After 40 years of stagnation, wheat breeding was restored and improved with a return to traditional breeding methods, use of modern techniques and equipment, sensible organization of the breeding process uniting in one program specialists in different fields: breeders, seed growers, geneticists, immunologists, biochemists and physiologists, grain quality experts, agronomists, and economists. This work was concentrated at SARI's Plant Breeding Centre, established in 1970.

In 1976-2003, 17 spring bread wheat varieties developed at SARI were introduced in Russia and Kazakhstan. Most of these varieties combine drought tolerance, lodging tolerance, high yield potential, good grain quality, and wide adaptation. That is why they are grown on a large territory (Table 3).

The newly developed varieties are better in yield and grain quality, as compared to older ones. Being susceptible to stress factors, new varieties have higher minimal yield (Table 2).

Besides having high yield potential and good grain quality, modern varieties must be disease resistant, well adapted to crop management practices, and highly responsive to agricultural inputs. Developing different varieties that complement one another is an effective means of stabilizing grain production in any ecological zone. But this strategy is not always put into practice.

Conclusions

- Seventeen varieties bred by the Spring Bread Wheat Laboratory of the Siberian Agricultural Research Institute were registered in the List of Breeding Achievements of Russia in 1976-2003. Five of them (Yertishanka 10, Omskaya 18, Omskaya 20, Omskaya 32, Omskaya 33) are grown in three regions of Russia, and 10 are grown in Kazakhstan. This to some extent testifies to the effectiveness of breeding for adaptation.
- As a result of research conducted in the laboratory in the past decade, some genotypes are resistant to most harmful diseases.
- The effectiveness of *in vitro* biotesting methods for selecting genotypes of grain crops tolerant to abiotic stress factors (including drought) was demonstrated.
- In field experiment of 1996-2003, in which 17 spring bread wheat varieties, bred in 1929-2003, were compared, grain yield was very variable in all maturity groups. New varieties demonstrated higher level of maximal and minimal yield than the older ones.
- New varieties in all maturity groups were more responsive to agricultural inputs. As for stability, it tended to decrease in mid-to-early and intermediate groups of maturity.

Table 3. Origin of varieties developed by SARI breeding laboratory and released in 1976-2003.

Variety	Year of release	Target region*	Origin
Sibiryachka 4	1976	10	Sibiryachka 2 / Saratovskaya 29
Omskaya 9	1979	10, 11, RK**	Bezostaya 1 / Saratovskaya 29*
Yertyshanka 10	1981	7, 10, 11, RK	Skala / Saratovskaya 36
Omskaya 12	1984	10, 12	Lade (Norway) / FKN-25 (USA)
Omskaya 17	1986	7, 10, RK	Lutescens 1138-166 / Red River 68 (USA)
Omskaya 19	1989	RK	Lutescens 1138-70 / Lutescens 1210
Omskaya 18	1991	9 – 11, RK	Omskaya 11 / Geines
Dias-2	1992	10	Novosibirskaya 67 / Rang (Sweden)
Omskaya 20	1993	9 – 11, RK	Yertyshanka 10 / / Graekum 114 /Kavkaz
Omskaya 24	1996	10	Lut.1594 / Sibiryachka 8 // Krasnodarskaya 39
Omskaya 28	1997	10, RK	Lutescens 19 / hybrid (Canada)
Omskaya 26	1998	9, 10	Novosibirskaya 22 / W.W.16151 (Sweden)
Omskaya 29	1999	10, RK	Lutescens 204/80-1 / Lutescens 99/80-1
Pamyati Azieva	2000	7, 10, RK	Saratovskaya 29 / Lutescens 99/80-1
Omskaya 32	2001	7, 10, 11	Lutescens 162/84-1 / Chris (USA)
Omskaya 33	2002	7, 10, 11, RK	Lutescens 137/87-39 / Omskaya 28
Omskaya 30	2003	RK	Omskaya 20 / Lutescens 204/80-1

* Regions: 7 = Mid Volga; 9 = Urals; 10 = West Siberia; 11 = East Siberia; 12 = East.
** Varieties also grown in Kazakstan (RK).

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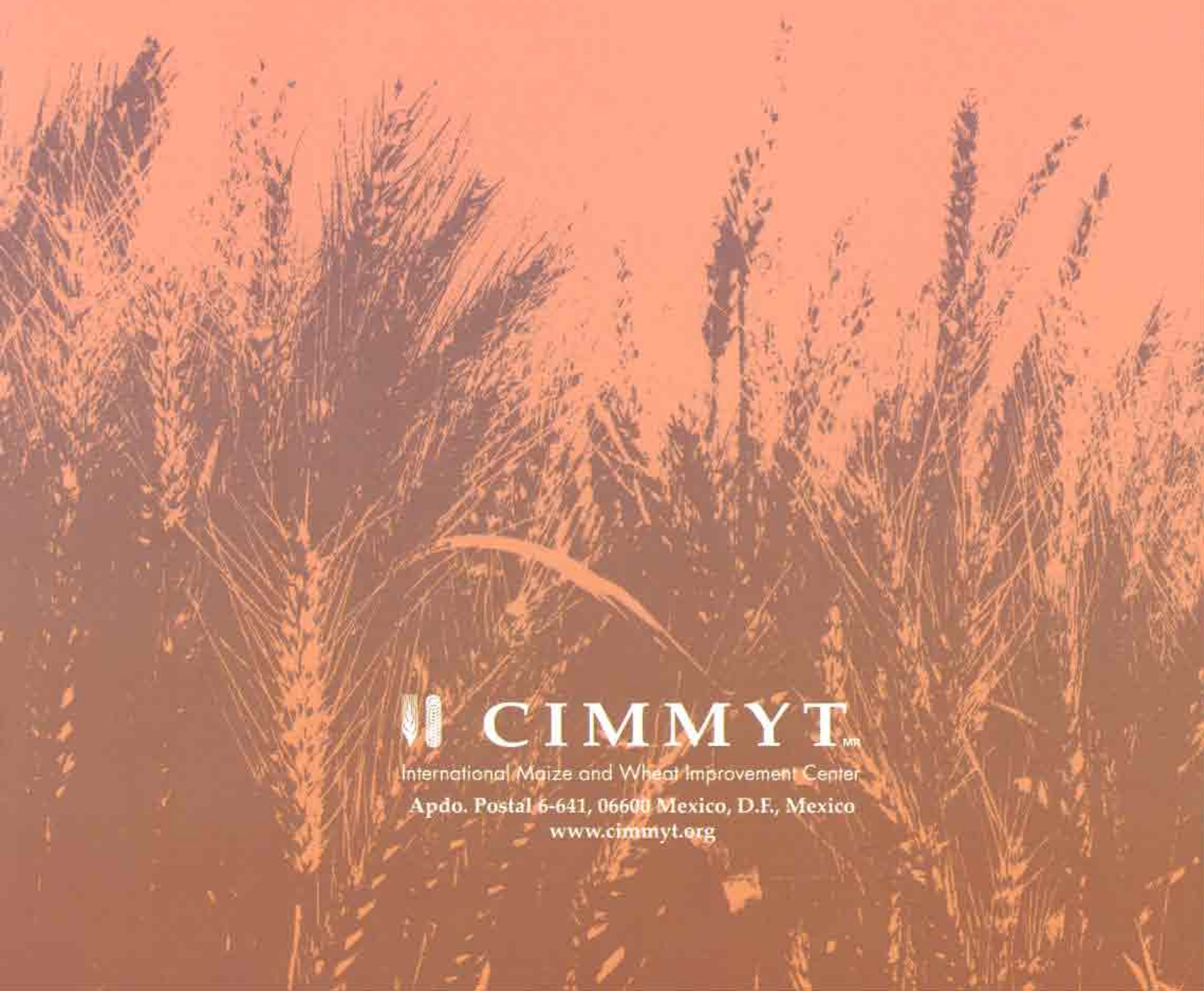

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