Ripening winter wheat fields in Oregon. Both developed and developing country growers stand to gain from the collaborative spring x winter research program described in this article.

**CIMMYT TODAY No. 12**

**probing the gene pools**

**SPRING X WINTER CROSSES IN BREAD WHEAT**
probing the gene pools

Twenty-one new lines of bread wheat—among 465 grown at 58 locations across all continents—averaged over 4 tons of grain per hectare in CIMMYT’s 1979 international bread wheat screening nursery.

Nine of those 21 lines would not have existed without the ingenious helping hand to nature given by wheat breeders of CIMMYT and Oregon State University (USA).

That helping hand is a workable, field-based method for crossing spring wheat with winter wheat—the two great pools of genes among the world’s bread wheats.

For reasons we’ll go into later, it takes ingenuity to cross these distinctively different plants from the same species. The act of crossing spring and winter wheats isn’t new—that had been done in greenhouses for decades before the OSU and CIMMYT cooperation got under way. In fact, some early improvement in disease resistance came from laboratory crosses of spring and winter wheats. One noteworthy result of spring x winter crossing was the short-statured Norin 10 x Brevor; when CIMMYT’s Dr. Norman Borlaug bred the dwarfing genes from that variety into Mexican spring wheats, he laid the base for semidwarfs that triggered the Green Revolution in wheat.

The new element brought onto the scene by the OSU-CIMMYT project was a system adaptable to the extensive crossing and selection methods that permit breeders to probe more widely and deeply into the genetic resources from which improvement comes. That system is of recent origin. The key motive point came in the mid-1960s from the creative work of the late Dr. Joseph A. Rupert.

Now the spring x winter crossing program is a basic part of wheat improvement efforts at both CIMMYT and OSU. More than 1,500 new spring x winter crosses are made each year, and the contributions of genes from one pool to the other are to be seen in higher yields and improved disease resistance in selections in each type of wheat.

same species but different growth habits

Spring and winter bread wheats belong to the same species, *Triticum aestivum*. But they are different physiologically. They have different growth habits.

The name “spring wheat” applies to those wheats sown at the start of a growing season (spring or autumn, depending on climate). Their continuous growth cycle brings them to harvest in three to five months. They cannot survive freezing temperatures.

“Winter wheat,” on the other hand, must have the interruption in growth brought on by continuous periods of low temperature. Planted in autumn, winter wheat is ready for harvest the following fall.
Co-leaders of the Spring x Winter program visit a breeding plot at Oregon State University's research farm at Hyslop, Oregon. At left is Warren Kronstad, professor of crop science at OSU, with Glenn Anderson, director of the wheat program in CIMMYT.

summer, 10 to 11 months later. Without the intervening cold these plants will not tiller nor produce flowers, heads and seeds.

Natural crossing—which happens only infrequently in wheat—and most wheat improvement efforts have been mainly confined within the respective spring or winter group. The gene pools thus represent different evolutionary systems.

Winter wheats, as a pool of genetic inheritance, generally have:
- Superior resistance to diseases caused by Septoria species and also better resistance to powdery mildew, stripe rust and leaf rust.
- Greater tolerance for cold and possibly more tolerance for drought.

Spring wheats are considered to have genes for:
- Resistance to stem rust and leaf rust.
- Better breadmaking qualities.

Also, both wheats are believed to represent different genetic characters for yield—providing the opportunity for new combinations for yield that may surpass the best of either gene pool.

It is clear on balance that the best qualities of each gene pool, if selectively imparted to the other, would improve both.

the problem of crossing spring and winter wheats

In usual agricultural environments, spring wheat and winter wheat do not flower at the same time. So crossing isn’t feasible. Two solutions were conceived and instituted by CIMMYT:

- When winter wheat is sown in November at the central Mexico station at Toluca (2,640 m elevation), cold temperatures of December and January achieve naturally the vernalization of the plants necessary for them to tiller and to produce heads. By planting spring wheats at several dates in January and February at the same site, it can be assured that both groups will flower at the same time in May. Then plant breeders can make their crosses and observe first generation progeny, which they refer to as “F1” plants.
- With some artificial interventions, a separate spring x winter crossing program is carried
At CIMMYT, winter wheat seedlings are vernalized in a controlled temperature cabinet (45 days at 3°C to 4°C) to simulate natural "winter" conditions.

An OSU research assistant makes selections of winter-habit lines grown for OSU by CIMMYT at Ciudad Obregón.

Out at the Ciudad Obregón site, 39 m elevation, in the northwestern state of Sonora, Mexico. Seedlings are raised in pots and vernalized through 45 days in cold chambers (3°C to 4°C) under 12 hours of artificial light daily. After further preconditioning at 8°C, the seedlings are transplanted by hand to an outdoor nursery, where electric lamps add up to 6 hours extra light per day. Under these conditions, the winter wheats flower concurrently with spring lines, permitting crossing.

CIMMYT’s breeding stations at Ciudad Obregón and Toluca differ in physical characteristics, as recorded here. Also, the different growing seasons permit two cycles of crossing and selection in a single calendar year:

<table>
<thead>
<tr>
<th></th>
<th>Ciudad Obregón</th>
<th>Toluca</th>
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<tbody>
<tr>
<td>Altitude</td>
<td>39 m</td>
<td>2,640 m</td>
</tr>
<tr>
<td>Latitude</td>
<td>27°N</td>
<td>19°N</td>
</tr>
<tr>
<td>Temperatures: Min.</td>
<td>0°C</td>
<td>-15°C</td>
</tr>
<tr>
<td>Max.</td>
<td>40°C</td>
<td>20°C</td>
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exploiting the spring x winter crosses

Since CIMMYT breeders have the conditions for field-based crossing, that phase of the OSU-CIMMYT cooperation is carried out in Mexico. About 1,500 crosses are made each year.

First-generation progeny at Ciudad Obregon grow with epidemic exposure to leaf and stem rust. At Toluca the disease exposures are stripe rust plus leaf and stem rust.

The seeds of these first generation plants are shared half-and-half between CIMMYT and OSU. Since the OSU side of the program seeks to improve winter wheat, they cross the F₁ with some of their winter wheat lines or make crosses between two F₁s, the second being a winter x winter or another winter x spring. (Such crosses assure production of large numbers of lines with the winter growth habit.)

CIMMYT breeders also have the option of crossing F₁ spring x winter progeny with spring
wheats or of producing a new hybrid by crossing F₁ to F₁. And there is a third option open to CIMMYT: an outstanding F₁ from spring x winter cross can be maintained and carried through to produce segregating lines without further crossing.

spring x winter
in Oregon

Several factors qualify Oregon State University as an ideal partner with CIMMYT in this program to improve both winter and spring wheats. The university’s crop sciences faculty is highly regarded for its research and its success in training young plant scientists from all areas of the world. Winter wheat leads all other cereals in importance in the state which sponsors the university—Oregon wheat growers support wheat improvement efforts with check-off funds as well as personal and organizational backing. The university’s experiment stations provide a range of winter wheat growing conditions, which increases the probability that lines selected there will prove to have wide adaptation.

Each of OSU’s testing sites contributes a rigorous environment. Rainfall of about 1,000 mm per year characterizes the Hyslop Agronomy Farm near Corvallis, home of the university campus. The high winter rainfall in this “Mediterranean” climate facilitates strong disease pressure for screening reaction to Septoria tritici, Puccinia striiformis (stripe rust), P. recondita (leaf rust), Erysiphe graminis tritici (powdery mildew), Ophiobolus graminis, Cercosporella herpotrichoides and barley yellow dwarf virus.

The Pendleton Experiment Station is at 500 m altitude and receives annual rainfall of about 450 mm. The Sherman station is on the eastern side of the Cascade Mountains, with annual rainfall of about 250 mm. At these two stations wheats are screened for stripe rust and Cercosporella herpotrichoides plus two species of common smut, Tilletia caries and T. foetida. Both stations provide conditions to evaluate winterhardiness with winter temperatures down to -20°C; Sherman normally exposes winter wheat to further rigors of high winds and blowing snow.

Drought stress is applied by low annual rainfall at the Sherman station. Commercial wheat produc-

(Text continues on p.8)
FROM CROSS TO A POTENTIAL NEW VARIETY

In the spring of 1973, pollen was taken from the Mexican Spring Wheat Buho “S” and put on Kavkaz, a winter wheat from the USSR. (Seeds that grew from that simple cross can be called for our purposes, Kavkaz-Buho.) 

F₁ Kavkaz-Buho seeds were planted in the spring wheat season at CIMMYT’s Ciudad Obregon nurseries that same year. At flowering time early in 1974, a topcross was made by hand between plants of Kavkaz-Buho and a line that combined parentage of Kalyansona and Bluebird. (A topcross means a mating between a first-generation hybrid—Kavkaz-Buho in this case—and a plant from a line or variety that has been through several generations of homogeneous true-breeding.) Bluebird is a sister of several Mexican varieties released about five years earlier; Kalyansona, released in India, is one of many variety names given to progeny from the historic CIMMYT cross number 8156, from which came certain of the Green Revolution wheat varieties.

F₂ Seeds of that topcross—now known as Cross 33027—were planted at Toluca in the next season. Parentage is now complete, with no further crossing. Wheat is self-pollinated, with pollen from male organs fertilizing the female parts of the same plant. Breeders systematically observe all plants in the line to find those whose genetic combinations yield the most desired progeny. They look primarily for disease resistance and for desirable growth and plant characteristics. One of the plants chosen from the progeny in this season was labelled “Plant No. 12.” It was advanced for further attention.

F₃ Seeds of Plant No. 12 went to Ciudad Obregon for the next growing season. In this—and all other generations—breeders again carefully observed performance in relation to disease and plant type. Plant No. 1 from this plot was selected; the seeds passed visual and laboratory checks (for gluten strength, a factor in breadmaking quality) and were advanced for planting in the next season at Toluca.

F₄ Seeds from Plant No. 1 in F₃ were evaluated at Toluca, and Plant No. 1 from that plot was advanced.

F₅ Seeds from Plant No. 1 in F₄ were grown at Ciudad Obregon—it is now 1976. And the first plant chosen from this generation was advanced.

F₆ Seeds from the F₅ Plant No. 1 were grown at Toluca in the summer season. The first plant chosen from this generation was harvested and advanced. Critical field and laboratory evaluations continued.

F₇ At Ciudad Obregon—the time is now 1977-78—breeders were satisfied with the uniformity of plant type

story of one
very selection
and disease reaction. So they marked this plot for bulking. All of the plants were harvested, and all of the seeds were saved. It was given the breeding name, Veery.

F₈ The bulked seeds were planted at Toluca a few weeks later in a PC (parcela chica, Spanish words for “small plot”). The quantity of seed harvested in 1978 became the material for the serious business of putting this advanced line to test. Some seed was sown at Ciudad Obregon in CIMMYT yield trials; some was put into the 13th International Bread Wheat Screening Nursery for trials in locations worldwide.

F₉ In 1980 this line is an entry in the Second Elite Spring Wheat Yield Trial nursery. This worldwide test of yield performance will measure the range of its adaptation.

Soon a released variety? CIMMYT does not release varieties directly for multiplication and distribution to farmers. National program leaders are responsible for that. They are now growing this Veery selection under their own country conditions. Some may find that the line shows sufficient superiority to justify the time- and cost-consuming process of moving from a handful of seed to thousands of kilograms required when a significant number of farmers plant a given variety. From the time of a decision to release a new variety, several years may be needed before it can be said to be available to any farmer who may wish to grow it.
The Oregon team makes a similar visit to Toluca in July. They evaluate and make selections among plants grown from seeds of some of their own crosses of spring x winter crossed with winter. Although 12 major wheat diseases occur in Oregon, stem rust is absent. So CIMMYT grows segregating material for OSU where it will be exposed to stem rust and other races of leaf and stripe rust. Thus the Mexican connection serves as an off-season nursery for OSU, adding another breeding cycle each year.

CIMMYT breeders also utilize the staggered growth cycles to make observation trips to Oregon. They gather information on factors that help in CIMMYT’s crossing and evaluation programs.

The winter wheats with spring genes enter international testing in the same way as CIMMYT’s improved spring wheats, through international nurseries. OSU originated its International Winter x Spring Wheat Screening Nursery (IWSWSN) in 1973-74. Today that nursery includes about 250 entries grown by 97 cooperators in nearly 50 countries. International collaborators return observations on diseases, yield and adaptation. Computer-produced tables, based on the OSU analyses, go back to collaborators prior to their next crossing season.

OSU breeders put together their first international yield nursery of spring x winter types in 1979 for distribution in 1980. Those 25 advanced lines carry good general adaptation established through previous screenings in the IWSWSN. (A yield nursery specifies how entries should be planted and managed, with replications that permit scientific analysis and comparison with results from other trials.)
Chilean wheat growing environments range from winter wheats in the cold highlands to short-season spring wheats in the central coastal region— with transitional environments between these extremes. Dr. Rupert set about, on a small scale, to bring together the gene pools of Chilean winter and spring wheats. His work validated the concept. In fact, several varieties based on his spring x winter crosses are widely grown in Chile today.

In 1968 the Rockefeller Foundation moved to strengthen and exploit further the work he had begun. Dr. Rupert was transferred to the University of California-Davis in the United States to direct a new spring x winter wheat crossing program in collaboration with the then new CIMMYT. Subsequently the North American base for the program was moved to Oregon State University, Corvallis, Oregon. Growing conditions there offered more rigorous screening pressures—winterhardiness tests over a variety of soil and climate conditions plus exposure to a greater variety of disease organisms.

Four years after the collaborative program for spring x winter crossing was launched, Dr. Rupert succumbed to cancer. His association with agricultural development efforts in Latin America had spanned a quarter-century, beginning in 1947 after he received his doctorate from West Virginia University.

A native of Minnesota, in the USA, Dr. Rupert’s influence reached deeply into the professional lives of men and women working to improve agriculture. Under his leadership in Chile, for example, more than 60 prospective agricultural scientists were granted scholarships for advanced study abroad; he had a role in the organization in 1964 of Chile’s Instituto Nacional de Investigaciones Agropecuarias (INIA).

These scientists, the INIA, the spring x winter wheat program of CIMMYT and OSU—plus a myriad of unrecorded interactions—are the continuing productive legacy of this man whose associates knew him affectionately as “Uncle Joe” Rupert. His death in 1972 was reported in newspaper articles in such widely separate points as Santiago, Chile, and New York, in the United States.

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**spring x winter in CIMMYT**

CIMMYT’s winter crossing block for 1979—sources of winter genes—included 463 entries from widely scattered locations: Australia, 2; Soviet Union, 12; Turkey, 14; South America, 37; Western Europe, 68; Eastern Europe, 72; Far East, 75; and the United States, 183. All had already been screened for diseases under Mexican conditions. This crossing block provides one winter parent for each spring x winter cross.

The F1 spring x winter seeds harvested and kept at CIMMYT enter the regular routine of crossing and selection from F2 through F8 generations. They are evaluated in the field for disease reaction and agronomic characters; the seed of plants that meet field criteria must pass the visual standards for color, size and plumpness. In the laboratory a few grams of F3 seed are milled and put through a screening test for strength of gluten—an important factor in breadmaking quality.

Survivors of these tests move on for either additional crossing or to be grown through successive generations of selection against these same rigorous standards.

Some seeds of F2 (the second filial generation) are made available to other breeders. Countries with conditions where the spring x winter germ plasm may be especially useful include: Argentina, Chile, Algeria, Iran, Afghanistan, Turkey, South Korea and the People’s Republic of China. All have regions where spring wheats must have cold tolerance. These countries have received spring x winter F2 nurseries, as have many European countries and the USA. CIMMYT distributed 110 sets of the F2 spring x winter nursery in 1979.

**spring x winter:**

**some basis of promise for spring wheat**

Results of the introduction of winter germ plasm into spring wheats are increasingly promi-
From tens of thousands of spring x winter crosses come materials with a wide range of qualities (some excellent and some poor). This genetic diversity, breeders believe, should produce a few distinctly superior lines with the sought after high yield, disease resistance and tolerance for certain problem environments.

nent in CIMMYT materials. No fully developed lines have yet been increased and released, but performance of a number as advanced lines gives indications of what is to come from these crosses:

- More than one-fourth of the high yielding lines in the 13th International Bread Wheat Screening Nursery carry winter genes. While not technically yield trials, these results from worldwide tests can identify performance trends.

- Veery is the name CIMMYT has given to a cross that includes winter germ plasm from the USSR variety Kavkaz. These selections have been advanced to yield trials, and have been among the highest yielding lines at Ciudad Obregon. The average yield for these Veery sister selections was 2 t/ha higher than the average of all lines in the trial and 1 t/ha higher than the well-established check varieties, Nacozari 76 and Pavon 76.

- In the 15th International Spring Wheat Yield Nursery—with data returned from 74 trials around the world—a Veery selection had the highest average yield across all locations. It was the highest ranking entry in three of 12 regions—in East Africa and the Andean and Southern Cone regions of South America—and it ranked near the top in other regions. Another entry led two regions, but no other line led more than a single region.

- The IBWSN also includes analyses of disease reaction. Spring x winter lines were prominent among the top 10 per cent of lines for resistance to stripe rust and Septoria tritici reported for 1978-79.

- Spring x winter crosses form the foundation of efforts to develop spring wheats that are superior for facultative type plants that remain longer in the vegetative stage. This character may be important through not being in flower at the time of frost in high plateau regions, and it may be useful in parts of central India where, for example, it could be sown at the end of the monsoon but would not head until late January or early February.

- Influence of winter wheat genes is being picked up in the quality laboratory. Several
spring x winter crosses have yielded flour with protein levels over 13.3 per cent; one line with Kavkaz in its parentage had 14.7 per cent protein in the flour—and its loaf volume of 850 cm\(^3\) was further evidence of good baking quality.

### spring x winter: some basis of promise for winter wheat

Winter wheats that carry spring wheat genes have traveled the world for several years in OSU screening nurseries. Reports back from breeders who have grown the crosses—in some cases making further crosses of their own—give some measure of performance.

In Turkey, for example, six varieties have been named, one at Ankara and five in the area of Edirne. At Vanderhave, The Netherlands, two lines are under consideration for possible release. And in Yugoslavia, at Zagreb, two lines are in multiplication for possible release. All carry spring x winter parentage.

Advanced yield trials provide data useful in reaching decisions about which lines to advance toward naming and release as varieties. Among 22 countries from which reports came back to OSU last year, 14 had from two to ten spring x winter lines already in advanced yield trials. These represent such widely separated points as Pakistan, Australia and Chile.

Comments and observations of the national program reporters indicated considerable evidence that disease resistance seems to have been improved in spring x winter lines. Five countries noted good winterhardiness: Chile, in South America, and four European countries, France, Hungary, Poland and Romania. Tolerance to drought stress, another potential contribution from spring wheats, was noted by breeders in Algeria and Jordan. A notation from Algeria cited several lines with longer vegetative period and shorter time from reproduction to maturity, characteristics that should improve performance under conditions of late frost and early hot desert winds (sirocco).

As a preliminary judgment on the merits of introducing spring x winter crosses into winter wheats, the Oregon breeders believe there has already been improvement in resistance to leaf rust and improvement in earliness; and with many of these selections outyielding straight winter lines, they are hopeful that higher and more stable yields are on the way. The challenge remains, however, to combine both earliness and high yield in winter wheat.

### conclusion

More than 10,000 crosses have been made between the gene pools of winter and spring wheats since the CIMMYT-Oregon State University cooperative program began. Few of those crosses could have occurred in nature—and then they would have been random, not the strategically planned crosses involved here. Only a fraction of 10,000 crosses could have been made by an ambitious laboratory effort.

These cooperating scientists have ingeniously utilized and manipulated environments to give nature a helping hand. CIMMYT breeders have reason to believe that these spring x winter crosses are ushering in the first significant lifting of the plateau of yield potential of spring wheats since Cross 8156 made its remarkable impact on the wheat-producing world more than a decade ago.

No spring wheat variety has yet been pulled out directly from spring x winter crosses; some winter wheats of the same origin have been named, but their performance in farmers’ fields is not yet known. So the ultimate record has not yet been written. But it appears that the spring x winter crossing of wheats is rapidly approaching its payoff.

K. Robert Kern

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