Wheat Special Report No. 1

Russian Wheat Aphid Research at CIMMYT

Current Status and Future Goals

In-House Review Meeting

June 7, 1991

CENTRO INTERNACIONAL DE MEJORAMIENTO DE MAIZ Y TRIGO
INTERNATIONAL MAIZE AND WHEAT IMPROVEMENT CENTER
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Contents

Note on Citing Sections in this Wheat Special Report

By sharing research information in this Wheat Special Report on the Russian Wheat Aphid, we hope to contribute to the advancement of RWA research and to the importance of shared technical knowledge. However, the working research information in this report is shared with the understanding that each item is not published in the sense of a refereed journal. Therefore, sections in this report should not be cited in other publications without the specific consent of the section author.

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Preface

G. Varughese, Associate Director, Wheat Program

A few years ago, CIMMYT started working on the Russian Wheat Aphid (*Diuraphis noxia*) on a very small scale. Reports on the spread and damage due to this aphid's attack are on the increase in both developed and developing countries. Hence, during the last two crop cycles in Mexico, our efforts have grown substantially and are showing good results. On June 7, 1991, select CIMMYT wheat staff members met at El Batan to review the current status of CIMMYT's RWA research and to define goals for the future. This report summarizes the presentations and discussions during that meeting.

Those attending the meeting included Peter Burnett, Lucy Gilchrist, Gene Hettel, A. Mujeeb-Kazi, Gene Saari, Bent Skovmand, S. Rajaram, Jonathan Robinson, Maarten van Ginkel, George Varughese, and Hugo Vivar.

The Appendices include some popular new releases emanating from Information Services, a brief mention of CIMMYT's RWA work in the August 19, 1991 issue of *Time Magazine*, and an up-to-date bibliography of recent scientific literature published on the RWA.

Distribution and Economic Importance of Russian Wheat Aphid

P.A. Burnett, virologist/entomologist

Distribution

The Russian wheat aphid (RWA), *Diuraphis noxia*, has only recently become a serious pest of wheat and barley. Its effects are being felt in many parts of the world. Originally collected and described in 1900 in the Caucasus area of the southern Soviet Union, it became a pest of wheat in South Africa in 1978. By 1980 it was recorded in Mexico and by 1986 it had reached Texas in the USA. Currently it is reported to be present in Canadian provinces of Alberta, British Colombia, and Saskatchewan and in most of the states of the western USA. It is also now found in Europe (Spain, France, Hungary), central Asia, the Middle East, Pakistan, Afghanistan, Africa (northern Ethiopia and South Africa), North America, and South America (Chile and Argentina). See the world map in Figure 1, which shows recorded occurrences of the aphid.

Potential locations

Hughes and Maywald (1990) used the CLIMEX computer model to forecast the favorableness of the Australian and other environments for the RWA. The model matches climate to the potential of a location to support population growth of a non-introduced species such as the RWA. As shown in Figure 2, RWA has the potential to cause severe losses to the wheat crop should it arrive in Australia.

Hughes and Maywald (1990) show, in Figure 1, areas of the world already infested with RWA and, using the CLIMEX model, indicate areas that, if they became infested, would support the pest. Figure 3 (Burton 1990) shows the area of the USA that was infested with RWA in 1990 and Figure 4, by comparison, shows Hughes and Maywald's CLIMEX distribution and the actual 1989 RWA distribution in the USA. Figure 5 shows the area of southern Africa delineated by the CLIMEX model as favorable for the growth and survival of RWA.

Biology

The RWA is a small pale green aphid about 2 mm in length with a supracaudal process, short antennae, and reduced cornicles, which make it distinct from other aphids. On depleting its food source, or under adverse environmental conditions, viviparous winged females are produced from RWA colonies. These winged forms can be borne long distances on wind currents to initiate new colonies. The RWA reproduces almost exclusively by parthenogenesis; very few males have been found.

Damage symptoms

RWA, which primarily infests wheat and barley but also rye, triticale, and a range of grasses, feeds within tightly rolled leaves. The location of the feeding site makes it difficult for predators and parasitoids to find the RWA and also provides a degree of protection against contact insecticides. Typically in the field, damage symptoms are observed before the aphid is seen. The leaves of infested plants become tightly rolled and the plants develop a prostrate growth habit. Longitudinal chlorotic streaks develop on the leaves and some purple discoloration and necrosis may be observed. The spikes, frequently trapped in the flag leaf because of its tight curling, are often deformed as a result. Plants infested by RWA often exhibit symptoms typical of drought stress when soil moisture is not limited.

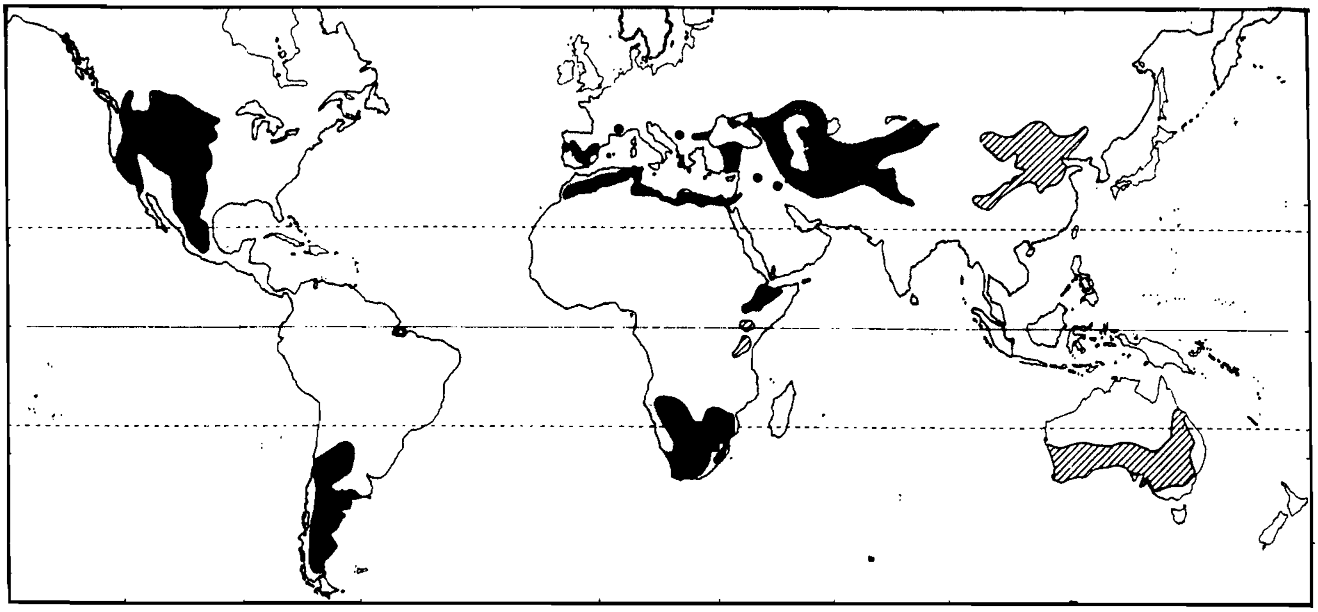

Figure 1. Areas of the world delineated by the CLIMEX model as favorable for the Russian wheat aphid (*Diuraphis noxia*). Source: Hughes ad Maywald (1990).

■ Delineated areas with recorded occurrences of the aphid.
● Aphid recorded, but not included in a delineated area.
▨ Aphid not recorded, but conditions considered favorable.

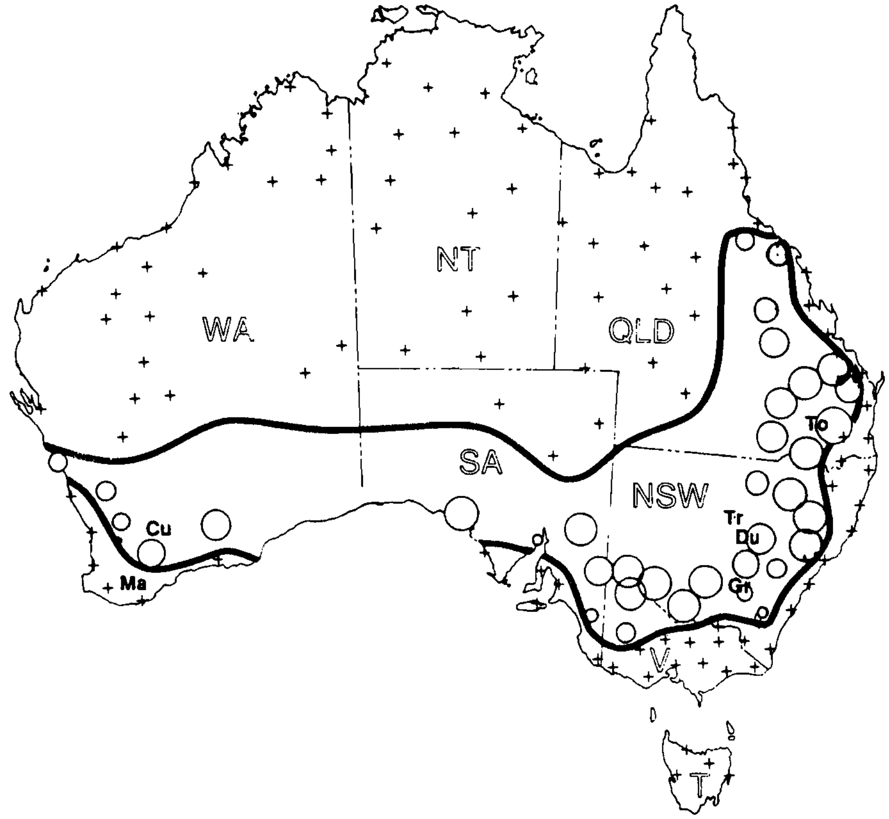

Figure 2. Region of Australia delineated by the CLIMEX model as favorable for *D. noxia*. Local favorableness levels at sites within the wheat belt are indicated by the sizes of the contained circles. Source: Hughes and Maywald (1990).

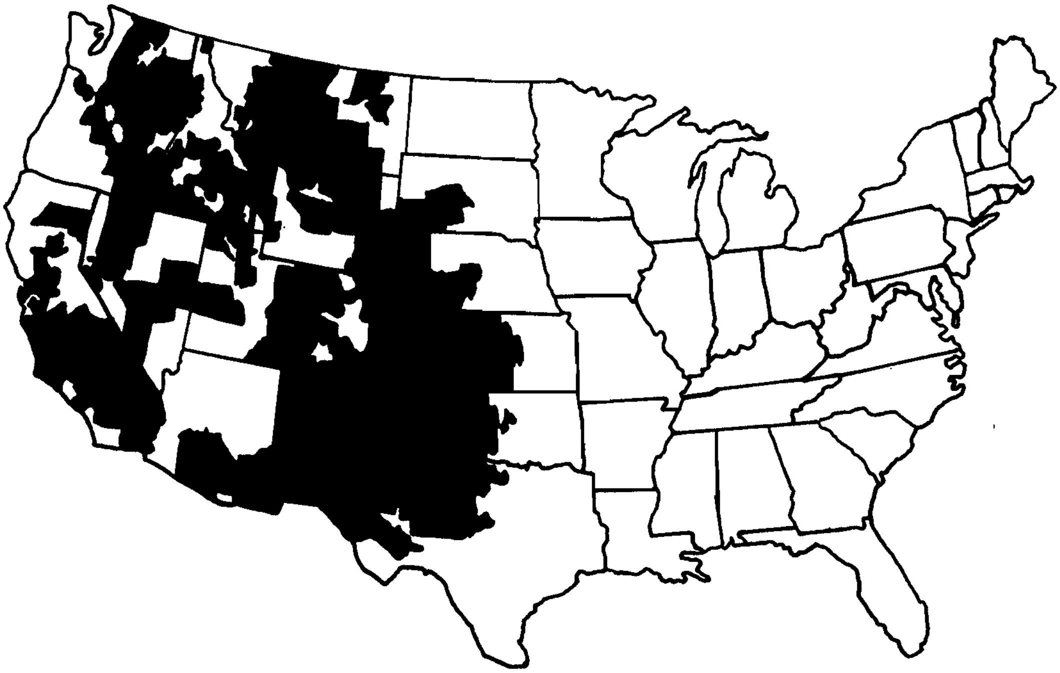

Figure 3. Russian wheat aphid distribution in the United States as of December 1990. Source: Burton (1990).

Figure 4. North American distribution of *D. noxia* up to 1989 (shaded) compared with fitted CLIMEX distribution based on long-term meteorological data. The size of contained circles indicates local favorableness for growth and survival of the aphid. Source: Hughes and Maywald (1990).

Table 1. Economic impact of the Russian wheat aphid on small grains production in the western U.S., 1987-89.

	1987	1988	1989
		millions	
Infested area (hectares)	6.8	11.6	8.3
Control costs (US$)	17	17	21
Losses from yield reductions (US$)	37	113	92
Total cost (loss)	54	130	92

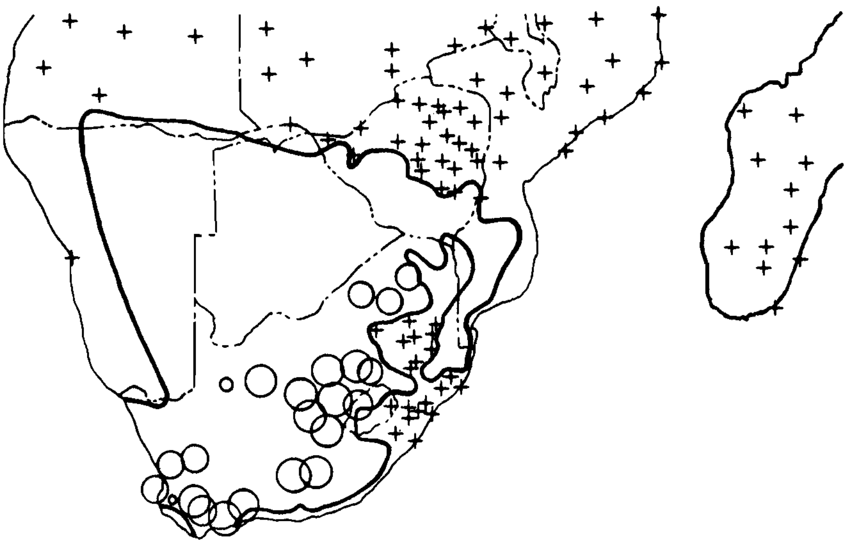

Figure 5. The area of southern Africa delineated by the CLIMEX model as favorable for the growth and survival of *D. noxia*. The size of the contained circles indicates the level of favorableness for the aphid in major wheat-growing areas of the Cape, Orange-Free State, and Transvaal. Source: Hughes and Maywald (1990).

Crop losses

Reported yield losses caused by RWA infestations have averaged around 50%:

- 30-60% in winter wheat in South Africa (Du Toit and Walters 1984).
- 40-70% in barley in Europe (Miller and Haile 1988).
- 70% in wheat in Ethiopia (Miller and Haile 1988).
- 50% of attainable yield in the U.S. (Johnson 1990)

In most regions of the world, there are few substantiated data, so we use here data from the USA (Johnson 1990). Approximately 7.7 million hectares (53%) of the winter wheat, 540,000 hectares (11%) of spring wheat, and 870,000 hectares (37%) of barley were RWA-infested in the western U.S. during 1989. In this same area in 1989, some 916,000 hectares of cereals were chemically treated for RWA control at a cost of US$21 million. Approximately 35% of the spring wheat, 8% of the barley, and 7% of the winter wheat were treated twice. Table 1 shows the total economic impact of the RWA in the western US.

The estimated cumulative costs of RWA as of 1991 is US$300 million for control plus loss of production (This does not include the ripple effect in the community).

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Review of Current Knowledge on RWA

J. Robinson, entomologist

Sources of Resistance to RWA

- There are numerous sources of resistance to RWA in winter wheats from Iran and the USSR (Smith et al. 1991).

- We have field-screened 32 winter wheats identified by Harvey and Martin (1990) as resistant in the greenhouse. There is very good correlation.

- Sources in spring wheat are few. We have identified some facultative types from Hakkari in S.E. Turkey. The USA, with the exception of California, is interested in winter wheat.

- Durum wheats appear generally very susceptible, but we have identified some *T. dicoccum* accessions that may be useful sources for getting resistance into durums.

- At CIMMYT, there are abundant sources of resistance in barley. Oklahoma's barleys (Iran) seem to be BYDV susceptible. Sources of resistance are also available in wild barleys.

- There are abundant sources of resistance in triticale, rye, and a range of pasture grasses.

- Sources of resistance have mainly been identified from greenhouse screening and await field confirmation.

- A potential problem is that of biotypes--resistance to one biotype (from a particular area/environment) may not hold in other places under different conditions.

Note: J. Robinson can supply a list of references for published results on sources of resistance.

Mechanisms of Resistance

Three mechanisms of resistance are involved with the RWA:

- Tolerance--the ability of a plant to yield satisfactorily in spite of injuries that would debilitate a susceptible plant. This is solely a plant response, but it can be a complex of physiological factors.

- Antibiosis--the tendency of a plant to injure or destroy insect life. This can be biophysical or biochemical and involves both plant and insect responses.

- Antixenosis--nonpreference: plant characteristics that lead insects away from a particular host. These can be allelochemic or morphological and involve both plant and insect responses.

The most useful mechanism for plant breeders is tolerance because it does not put selective pressure on the aphid to form new biotypes. It is permanent, but is modified by environmental conditions.

Resistance in wheat, barley, and triticale generally appears to be a combination of tolerance and antibiosis. We have demonstrated antixenosis with barleys, but its expression appears to be linked to preconditioning (the plant variety from which the aphid transferred). Oats are highly antixenotic.

Tolerance

Tolerance is measured in terms of % uninfested plant height/weight corrected by using weight of aphid colony to remove the antibiosis component (Table 1). S13 is tolerant to RWA in comparison with S16, but it is not known what the tolerance is attributable to.

Table 1. Tolerance to Russian wheat aphid in five barley genotypes.

	Means (±SD)			
Genotype	**Final % uninfested plant height**	**% uninfested dry leaf wt.**	**% uninfested dry root wt.**	**Aphid wt. per plant (mg)**
S4	80.52±5.70b	67.69±5.99bc	150.07±40.07	5.54±2.55
S6	96.92±8.72a	77.08±13.29abc	97.37±11.76	3.02±2.56
S8	96.64±11.41a	97.46±25.95a	84.42±42.10	3.16±1.26
S13	101.22±6.09a	92.06±23.91ab	117.50±30.94	5.38±1.73
S16	69.52±12.81b	57.27±18.15c	98.18±50.44	8.00±3.58
P	0.000	0.038	0.156	0.057

Means in a column followed by the same letter are not significantly different, P> 0.05; Tukey's test (SAS Institute, 1985).

Antibiosis

Using the barley genotypes S13 (Gloria/Come, relatively resistant to RWA) and S16 (Esperanza, susceptible), Figure 1 indicates that the antibiosis of S13 is specific to RWA (Dn, *Diuraphis noxia*). No antibiosis is shown by S13 to the other five aphid species (Rm, *Rhopalosiphum maidis*--Corn Leaf Aphid; Rp, *Rhopalosiphum padi*--Oat Bird Cherry Aphid; Md, *Metopolophium dirhodum*--Rose Wheat Aphid; Sa, *Sitobion avenae*--English Grain Aphid; *Schizaphis graminum*--Greenbug). Antibiosis is measured in terms of total nymph production over the complete lifespan of the aphid on whole plants.

The antibiosis shown by S13 is maintained over the entire lifespan of the aphid. Daily nymph production (Figure 2) is much reduced on S13 plants in comparison with S16. The antibiosis is not manifested as a reduction in aphid longevity nor as a delay in time to maturity. Aphids feeding on S13 simply produce fewer offspring than those feeding on S16.

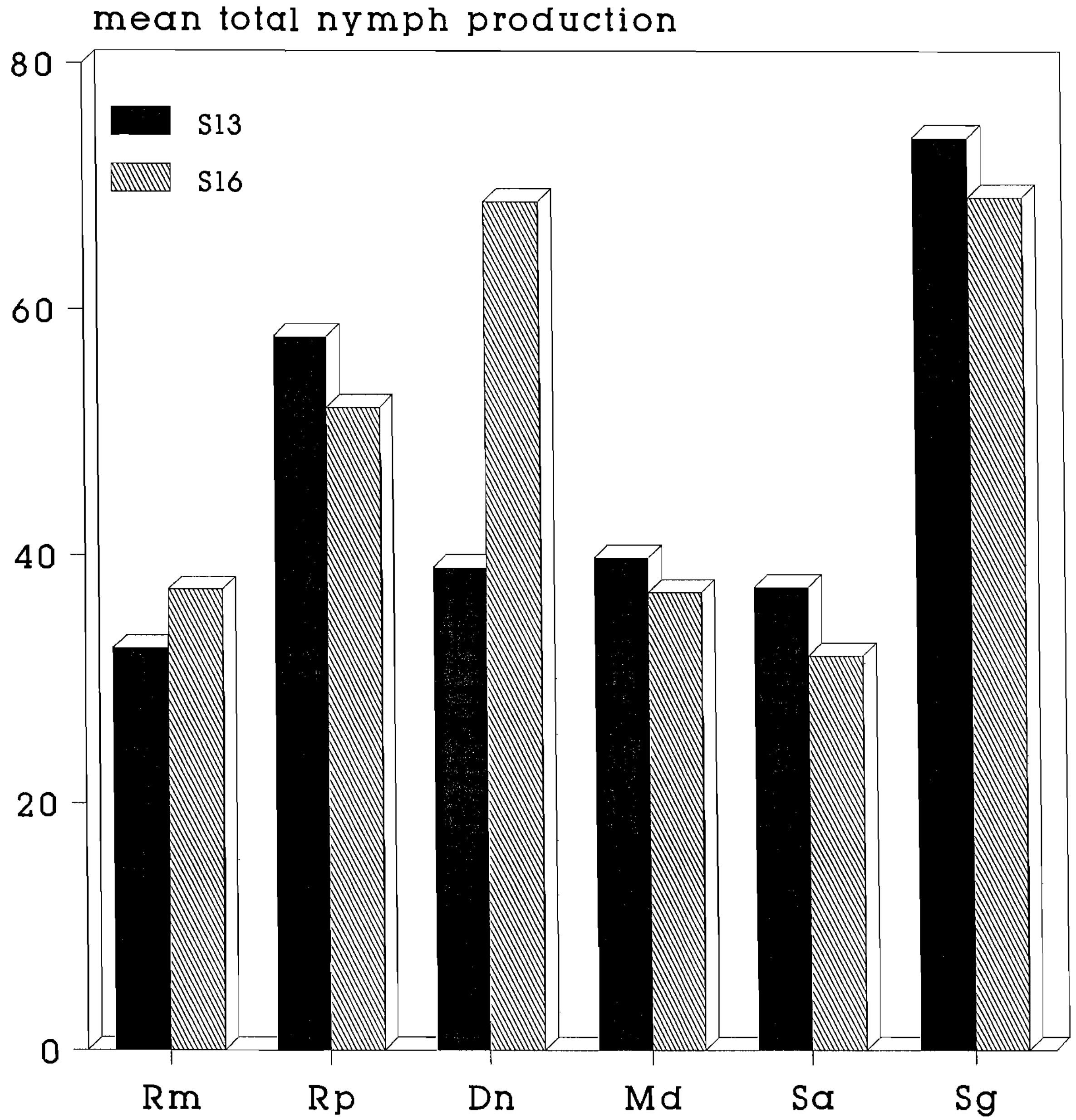

Figure 1. Mean RWA nymph production on individual plants of the barley genotypes S13 and S16.

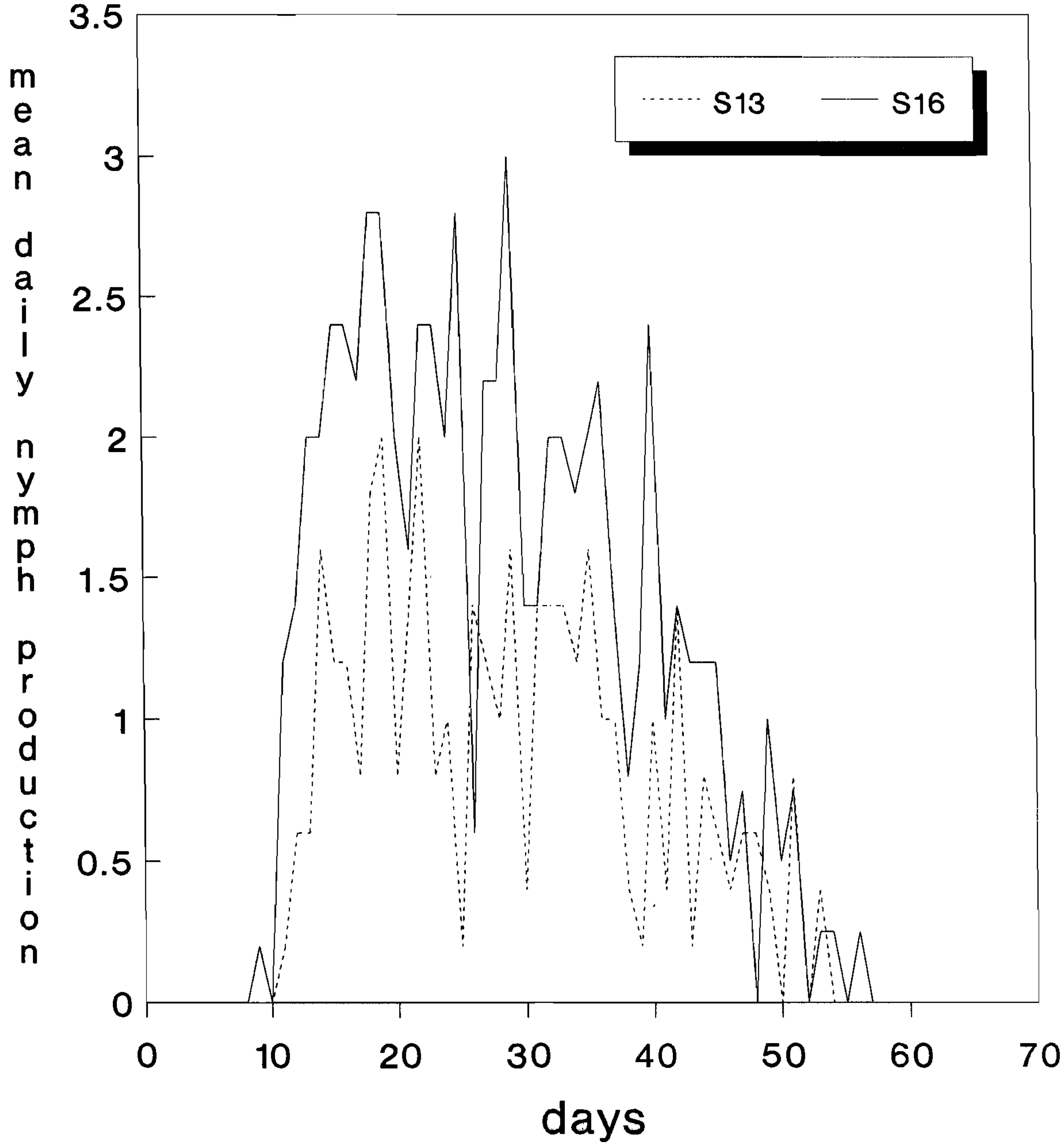

Figure 2. Daily nymph production on whole plants of barley genotypes S13 and S16.

Antibiosis can be measured in various ways in addition to nymph production.

- Measuring colony growth from a single aphid in terms of aphids produced after a known period.
- Weighing the colony in bulk.
- Counting embryos with pigmented eyes (in a recently mature aphid).

These above measurements confirm the antibiosis of S13 in comparison with S16 and represent alternative and more convenient ways of assessing antibiosis. Care has to be taken not to confound the effects of tolerance.

Antixenosis

Given a choice of five barleys, RWA chose to settle on S13 significantly less than on the others (Table 2). This effect may be due in part to the preconditioning regime the aphids were subjected to.

Table 2. Antixenosis to RWA in five barley genotypes.

	Total number of aphids		
Genotype	**Run 1**	**Run 2**	**Total**
S4	102a	102a	204a
S6	95a	72b	167b
S8	83a	68b	151b
S13	39b	50b	89c
S16	81a	69b	150b

Totals in a column follwed by the same letter are not significantly different ($P>0.05, \chi^2$)

Damage Scoring

- There is an indication that damage scores in the field and greenhouse can be correlated, but timing of scoring is crucial. Too early and the germplasm can't be differentiated; too late and everything appears susceptible.
- Damage scores are probably a reflection of all three resistance mechanisms operating simultaneously.
- Damage scores are the starting point for selecting resistant plants. Mechanisms of resistance can be assessed if necessary later (in the greenhouse).

- It is useful to score for RWA resistance in the field in artificially infested hill plots. Using triticale as an example (Table 3), results have been shown to be consistent over years.

Table 3. RWA damage scores for selected spring triticales.

Entry	Pedigree	Classification[a]	Score±SE[b]
813	Brumby 11-1	R	1.50±0.10
815	Brumby 12	R	1.54±0.10
814	Brumby 11-3	R	1.58±0.13
812	Brumby 7	R	1.67±0.13
811	Brumby 4	R	1.75±0.11
818	BGLT/LNC//DGO 4/3/TATU 4	R	1.79±0.13
848	LASKO//2*REH/HARE 212-11	R	1.88±0.11
816	BGLT/LNC//DGO 4/3/TATU 4	R	2.04±0.19
847	LASKO//2*REH/HARE 212-11	R	2.08±0.12
817	BGLT/LNC//dgo 4/3/TATU 4	R	2.08±0.16
839	GAUR 3	S	3.62±0.18
843	HARE 286/ELK 32//STIER 19-1	S	4.04±0.18
Least significant difference between scores at $P = 0.05$			0.94

[a] R = resistant, S = susceptible.
[b] Mean damage scores from our replicates, three times and 2 years.

- Ultimately, resistance has to be expressed in the field and, therefore, field testing is better than greenhouse/growth chamber because useful germplasm is less likely to be overlooked.

Integrated Pest Management (IPM)
The following IPM components fit together in an economic framework:

- Biology
- Ecology
- Host plant resistance
- Biological control
- Cultural control
- Insecticidal control

Regarding RWA, we are still at the "best guess" stage because the pest is relatively new and basic information on its biology/ecology is limited. Host plant resistance studies are progressing.

Biological control studies (and some releases of parasitoids/predators) are in motion using various predatory and parasitoid insects and entomophagous fungi. The basic problem is that the RWA successfully protects itself from predation/parasitization by living/feeding within tightly rolled leaves. It is difficult and expensive in view of the need to spray several times in a season and the low produce prices. Contact insecticides are generally not as effective as systemics, but Lorsban (a contact) is able to volatilize within rolled leaves.

Grassland management and crop rotation can go some way to reducing reservoirs of the aphid. However, host plant resistance is the most practical and environmentally friendly solution to this problem.

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Germplasm Bank Involvement in RWA Activities

Bent Skovmand, Head, Germplasm Bank

Need for Further Evaluation and Pre-breeding Strategies

Further evaluation

As indicated by J. Robinson, it appears that there are a number of available sources of RWA-resistance material. We have germplasm in the collection that has not been screened anywhere and which might be interesting to evaluate, such as additional *T. dicoccum* and *T. spelta* accessions. However, at this point in time, we do not perceive that there is a great need to evaluate more germplasm for resistance to this pest because resistance is available. It should be of a much greater urgency to introduce the resistances identified into the CIMMYT types of spring bread and durum wheats.

We have identified resistance in *T. aestivum* and in *T. dicoccum*, but neither can be easily used in our breeding programs. The accessions with resistance found in the bread wheat landraces from Turkey are highly susceptible to stem and leaf rust in Cd. Obregon when they were initially grown during the 1987-88 cycle. Most of the emmer wheats are not adapted to Mexico, although some of the RWA resistant accessions are resistant to the rusts. Most are too late in Cd. Obregon to even obtain seed. It appears that, for either source, it would be useful to transfer these resistances to improved wheats.

Pre-breeding strategies

Several strategies can be employed to transfer these resistances to improved wheats, but the screening for RWA resistance, which is necessary, limits the amount of material that can be handled. The strategies to be employed include 1) simple crosses, 2) back-crosses, and 3) population improvement.

Simple and back-crosses--These have been made between the Turkish bread wheats and CIMMYT lines. The F1s are being grown in the 1991 El Batan cycle and BC1 will be made. The parents, the F2s, and BC1 seed will be available to the breeding programs for the Yaqui 1991-92 cycle. The segregating populations could be subjected to the normal selection process and advanced lines (if any) could be screened again.

The BC1 generation should be screened against RWA in the winter cycle and resistant plants with improved agronomic type could be selected and advanced by single-seed descent to near-homogezygosity, when they could be re-tested. If necessary, additional back-crosses could be done after resistant plants have been identified. This method should work if the inheritance is simple.

Population improvement

Known sources could be crossed to the dominant male-sterile lines produced by R.P. Singh. Such a population could be subjected to infestation of RWA and as susceptible plants most likely would not produce seed, the resistance could be improved over a number of cycles. Selection for plant type could be performed at the same time.

Screening for RWA Resistance

J. Robinson, P. Burnett, and B. Skovmand

Screening for resistance to the Russian wheat aphid (RWA) was initiated in the winter of 1990 at El Batan. In that first cycle, the bread wheat spring crossing block, a number of barleys, triticales, ryes, and lines from the wide cross program were screened. All bread wheats, regardless of source, were found to be susceptible, while the barleys, triticales, and ryes ranged in reaction from resistant to susceptible.

Based on these observations, materials with different origins have been included for screening during the 1991 cycle as outlined below. Preliminary observations are indicated:

	Resistant	**Susceptible**
Collection from Eastern Turkey	Few	Most
Idaho crosses to South African sources of resistance	Many	Some
Spring bread wheats selected under natural infestation	None	All
Collection of *Triticum dicoccum*	1/3	2/3
Triticale	As in 1990	
Rye	As in 1990	
Barley	As in 1990	
Germplasm Development Program	None	All
South African sources of resistance	All	None

The experiment is planted in hill plots with 10 seeds/hill with four replicates. The inoculation was done with 100 live aphids applied per hill, at the two-leaf stage.

Wide Crosses Involvement in RWA Activities

A. Mujeeb-Kazi, Head, Wide Crosses

More emphasis will be devoted to studying the genetics of RWA resistance and simultaneously advancing germplasm for the applied breeding objectives of other programs.

Specific activities will involve:

T. turgidum x *T. dicoccum*

- Susceptible durums are to be crossed by five elite *T. dicoccum* accessions resistant to RWA. CIMMYT durums are assumed to be RWA susceptible.

- The F1s are to be screened for RWA resistance/susceptibility.

- F1 seed is to be separately planted and crossed by maize to produce haploids.

- The doubled inbreds are to be seed increased and screened for RWA resistance/susceptibility. The resistant inbreds will be transmitted to the Durum Wheat Section.

T. dicoccum x *T. tauschii*

Resistant *T. dicoccum* accessions will be crossed to *T. tauschii* accessions (preferably resistant to RWA) and synthetic hexaploids will be derived from the F1 hybrids. The synthetics shall be screened for RWA resistance and those found resistant will be transferred to the Bread Wheat Section.

Screening and use of synthetic hexaploids

- From the synthetic hexaploids currently available with adequate seed quantities, a field screen will be conducted to identify resistant types at El Batan during the 1991-92 cycle.

- The data obtained by March 1992 shall enable crosses to be made between the susceptible bread wheats and the resistant synthetics.

- The F1 seed will be planted at El Batan in 1992 and resulting plants crossed with maize to produce haploids leading to doubled inbreds (homozygous). The F1 progeny will also follow the breeding route through back- or topcrossing through group interaction.

Discussion Notes

G. Hettel

Burnett: There appears to be no BYDV transmission by RWA in North America.

Varughese: How closely related are the 32 winter wheats mentioned?
Robinson: Most not closely related, they are from all over.
Burnett: Some accessions are closely related. Work on genetics of resistance will be coming out in the next 18 months...Best to push the Turkish lines...Some of the winter wheats and triticales show better resistance than the barleys.

van Ginkel: Plants seem to grow out of RWA damage in Ethiopia.
Burnett: But economic damage has already been done, i.e., yield reduction.

van Ginkel: Wheats with Hessian fly resistance may have the same resistance mechanism for RWA.
Robinson: It might be possible.
Burnett: Hessian fly feeding is quite different from that of RWA.

Vivar: We must determine different sources of resistance to determine biotypes...Results under greenhouse conditions are always a question--same results are not manifest in the field.

Burnett: Aphid problems are just around the corner for us; maybe now is the time to think about resistance to other aphids as well.

Robinson: Don't know from current field work what resistance mechanism(s) is operating.
Burnett: We've just seen the tip of the iceberg on publications: in the next 2 years, there will be a rush of papers on the genetics of resistance...CIMMYT's advantage is field testing and its crossing to spring wheats...Don't think we are competing with the ongoing efforts in the USA, however, we need to ask the North Americans what they have been doing so we don't duplicate efforts--a lot of information is currently in unpublished papers in the USA.

Robinson: We can produce up to 500,000 aphids for screening purposes, but there are labor constraints.

Saari: Some of the good aphid experts in Turkey could provide some useful historical background.

Robinson: RWA is not like other aphids--it does not like to move all that much; I've never seen the RWA on the ground...I'd be surprised if a single gene is involved in tolerance.
Varughese: The more genes the better.

Burnett: It will be important to plant material from around the world and look at it in hot spots.

Varughese: From the map, it looks like it will be important to get resistance in the durum wheats.
Vivar: Resistance will be important in the durums, particularly in the dry areas.

Saari: Not much resistance found in the durum wheats to date; need to look at material from N. Yemen and Ethiopia.
Varughese: Suggest we screen the durums in our collection from those countries...For sources of resistance for both bread wheat and durum wheat, we currently have about 250 synthetics (*T. tauschii* x *T. durum*) to check. If we find tolerance in the resulting synthetic hexaploid, then we can identify the *T. tauschii* accession that has it because all of our durums are susceptible.

van Ginkel: Why not try to make an RWA-resistant Baconora by making 4 or 5 backcrosses?

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FOR IMMEDIATE RELEASE
June 19, 1991

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Russian Wheat Aphid: Number One Insect Threat to Wheat and Barley Farmers in the USA and Around the World

MEXICO CITY, MEXICO -- The Soviet Union and the United States may be getting along better than ever, but don't look for the American farmer to invite the Russian wheat aphid to dinner.

Unlike your average ambassador, this emissary is a small, pale green insect that is ravaging wheat fields in the United States and other countries around the world. Assessments of damage have been made only in the US, where the insect has hit particularly hard and is now considered the number one pest in wheat. Since 1986, when the aphid was first recorded in the western US, the aphid has cost American farmers more than $300 million in crop losses and chemical control measures. Control costs can easily exceed $10/acre.

Originally recorded in 1900 in the southern Soviet Union and in Spain in 1945, the Russian aphid wasn't considered a serious pest anywhere until 1978 when it was identified as the causal agent of a wheat leaf streak in South Africa. The insect has been recorded most of the countries bordering the Mediterranean, to Ethiopia, the Middle East, Pakistan, Afghanistan, and areas as remote as northeastern China. It has now spread to the US and other countries in the Americas.

The aphid feeds inside tightly rolled leaves of wheat, barley, rye, and other small grain crops. Nestled comfortably in the micro-environment of rolled leaves, the insect is protected from climatic extremes, insecticides, and predators. The most attractive (inexpensive and environmentally sound) method of control involves finding genetic resistance in the collections of wheat, barley, and other small grains stored in the world's "gene banks," and then transferring that resistance to commercial varieties.

- More -

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Add 1--Russian Wheat Aphid

Large collections of wheat, barley, rye, the wild relatives of these crops, and of triticale (a cross between wheat and rye) are maintained by the International Maize and Wheat Improvement Center (CIMMYT), located outside Mexico City, Mexico, and the International Center for Agricultural Research for the Dry Areas (ICARDA), near Aleppo, Syria. CIMMYT and ICARDA are members of the Consultative Group on International Agricultural Research (CGIAR), a union of donors and international research institutions whose mission is to help the poor in developing countries by making their agriculture more productive in ways that protect the environment and conserve natural resources.

CIMMYT and ICARDA develop improved plant types of wheat and barley for use by national agricultural research programs in the Third World. These two centers are involved in the search for resistance to the Russian wheat aphid and its incorporation into high yielding varieties. While the experimental materials produced by CIMMYT and ICARDA are aimed at developing country researchers and, eventually, poor farmers, they also make them available to research institutions in the USA and other developed countries.

As the search for resistance progresses, the value of the CIMMYT and ICARDA collections is becoming clear. So far, several thousand barleys, wheats, triticales, ryes, and wild relatives of wheat have been tested for resistance. Resistant plant types are most frequently encountered among the barleys, ryes, and triticales. Only a small number of resistant plants have been identified among the wheats, most of which are part of collections coming from the geographic origin of the aphid itself -- southern Russia, Iran, and Turkey. Even as the search for resistant plants continues, the sources of resistance already identified will be tapped by the breeding programs of the two centers.

The genetics of resistance found in the ICARDA/CIMMYT barleys is now being evaluated, and CIMMYT's Applied Molecular Genetics Laboratory is developing methods for identifying resistance using DNA markers. These activities will eventually help speed the breeding for resistance to this growing menace to the world's supply of small grains.

- End -

Appendix II. For CIMMYT Update

RUSSIAN WHEAT APHID: A GROWING PROBLEM FOR SMALL-GRAIN FARMERS

A small, pale green menace is ravaging the fields of wheat and barley farmers in both developing and developed countries. The Russian wheat aphid (RWA), *Diuraphis noxia*, is "chomping" its way into new areas at an incredible rate and finding genetic resistance in the accessions of germplasm banks at CIMMYT and other institutions may be the only practical way to stop the insect's onward march.

Originally recorded in 1900 in the southern Soviet Union and in Spain in 1945, RWA did not reach pest status anywhere until 1978 when it was identified as the causal agent of a wheat leaf streak in South Africa. Since then, the pest has spread to the Americas, most countries bordering the Mediterranean, Ethiopia, the Middle East, Pakistan, Afghanistan, and areas as far east as northeastern China. It has the uncanny ability to colonize environments very different from its center of origin.

Our Wheat Program and our sister institution, ICARDA, are concerned that improved wheat and barley germplasm may be vulnerable to the RWA. This is of particular significance to poor countries where farmers do not have access to the control measures required to combat the aphid successfully.

Assessment of costs as a direct result of the RWA has only been made for the USA, where the insect has hit particularly hard and is now considered the country's number one pest in wheat. Since 1986, when the aphid was first recorded in the USA, RWA has cost more than $300 million in terms of crop losses and chemical control. Control costs have been as high as $25/hectare.

Plant resistance represents the best practical control method. Since the RWA feeds deep within the leaf whorl inside tightly rolled leaves of wheat, barley, rye, triticale, and a range of grasses, the micro-environment of rolled leaves partially protects the pest from the ambient climate, contact insecticides, predators, and parasitoids.

With the search for RWA resistance underway, the value of the genetic resources in thousands of small grain accessions stored at CIMMYT and elsewhere becomes readily apparent. Our breeders are able to tap into the vast genetic variability in the CIMMYT Wheat Germplasm Bank. To date, several thousand spring wheats, triticales, ryes, barleys, and wild relatives of wheat have been screened for RWA resistance. The material is field-screened in the central Mexican highlands during the winter season. The plants are inoculated with greenhouse-reared aphids and scored for RWA damage several times during the plants' growth period.

It has been possible to identify triticale and rye genotypes in the CIMMYT collection and barleys from the ICARDA/CIMMYT program that possess useful levels of resistance to RWA under field conditions. In 1991, two wheat collections from the CIMMYT Germplasm Bank have been tested and some resistant accessions identified. These resistances and those from winter wheat genotypes selected elsewhere will be incorporated into the CIMMYT spring wheat germplasm. This transferred resistance will avert disasters in countries where the RWA has been identified as a pest and perhaps even prevent the aphid from ever reaching pest status in countries, such as Australia, where it has yet to be recorded.

A study on the genetics of resistance of the ICARDA/CIMMYT barleys is underway. Furthermore, staff from CIMMYT's Applied Molecular Genetics Laboratory are developing methods of discriminating between aphid species and their biotypes by looking at their DNA. Although, to date, no RWA biotypes have been identified, their existence would have obvious consequences for breeding programs and for countries where the aphid has not yet been recorded.

It appears that the RWA is becoming increasingly important as a pest of small-grain cereals in both the developing and developed world. Breeding resistant crop cultivars may be the only practical means of limiting the effects of the RWA and will certainly have advantages over chemical control in terms of costs and limiting damage to the environment.

- End -

Appendix III.

Will We Run Low On Food?

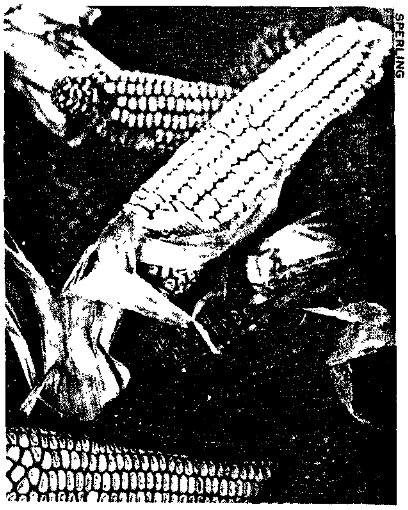
As the diversity of crops declines and the world's population explodes, grain supplies become more vulnerable

By EUGENE LINDEN

MANY CROPS ARE DISAPPEARING...

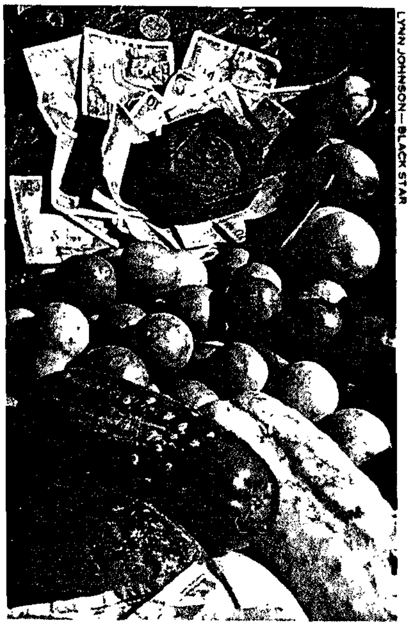
CALVIN R. SPERLING

Ecuadorian farmers still grow tree tomatoes



SPERLING

A sampling of rare corn varieties



LYNN JOHNSON—BLACK STAR

Local crops in a Sri Lankan market

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Bent Skovmand is not exactly a household name, but he has more to do with the welfare of the earth's 5 billion people than many heads of state. As a plant breeder at CIMMYT, the internationally funded agricultural research station in El Batán, Mexico, he spends his days in silent battle with threats to the world's wheat crop. Recently Skovmand discovered a rare strain of wheat from eastern Turkey that is resistant to the Russian aphid, an invader that has so far cost American farmers $300 million. By using the Turkish strain to develop hearty new hybrid wheats, CIMMYT breeders may help growers outwit the aphid.

Unfortunately the strains of crops that seem to have almost magical qualities are becoming ever harder to find. As farmers go for the highest possible yields these days, they all want to use the same kind of seeds. Individual crops share more genetic material, and local varieties are vanishing. Moreover, as the explosive growth of the world's population causes more farmers to turn more forest land into fields, wild species of plants are getting wiped out. Potentially valuable food sources are lost—forever—before they are even discovered. The world is losing a marvelous diversity of genetic material that has enabled the plant kingdom to overcome pests, blights and droughts throughout the ages.

Plant breeders have used this genetic diversity to help fuel the green revolution and keep agricultural production ahead of population growth. But as the raw material of the revolution disappears, the food supply becomes more vulnerable to catastrophe. Skovmand, for one, is not optimistic about the prospects for the coming decade. "The world has become complacent about food," he says. "In the 1970s the surprise was that India could feed itself. In the coming years the surprise may be that India can no longer feed itself."

Ever since Thomas Malthus' 1798 *Essay on the Principle of Population* proposed that human fertility would outstrip the ability to produce enough food, human ingenuity has consistently belied such predictions. Books such as Paul Ehrlich's *The Population Bomb* in 1968 and the Club of Rome's 1972 study *The Limits to Growth* raised fears that unchecked population growth might lead to mass starvation. Later in the '70s, Lester Brown of Washington's Worldwatch Institute argued that the world's farmers were already pushing the practical limits of what good land, high-yield crops, irrigation and artificial fertilizers and pesticides could deliver.

The Malthusians, however, have consistently underestimated how much the technological wonders of the green revolution—along with the ability of farmers to make good money growing crops—can spur food production. Ehrlich and Brown have long predicted that food prices would rise as agricultural production fell short of demand, and they have been wrong. India, where 1.5 million people died in a 1943 famine, became a grain exporter by 1977, even as it doubled its population. Farmers planting short, seed-laden wheats developed by Nobel laureate Norman Borlaug at CIMMYT had to post guards to protect the riches in their fields.

Beginning in the mid-'80s, however, the momentum of the green revolution slowed dramatically, especially in parts of India, China and Pakistan. In India's Punjab state, yields of rice and wheat have begun to flatten despite increasing reliance on fertilizers and better use of water. Elsewhere in Asia, rice researchers have failed to raise yields significantly for more than two decades. Hidden costs of the green

Appendix IV. Current Bibliography on Russian Wheat Aphid, compiled by J. Robinson

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