Breeding wheat for high yield, wide adaptation, and disease resistance

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Greater food production can be achieved through the coordination of the total efforts of the agricultural researchers, government policymakers, and farmers. The improved crop varieties and the package of new technological practices can only be meaningful if the governmental economic policy encourages farmers to use them. Farmers, especially the small ones, must have access to credit; inputs must be made available at prices they can afford; and they must be convinced that the new varieties are good for them. Development of improved wheat varieties in Mexico was done through a program involving a broad range of genetic material and disease testing at many geographic locations. In the beginning, scientists worked in 67 locations to produce the desired varieties in a short time. The researchers soon observed that by moving the breeding materials from one region to the other, wide adaptability could be built in. Cooperation not only among researchers in the country but also in other countries has helped tremendously in the development of wheat varieties with wide adaptability and stable yield. On-farm testing was an essential feature. The one-variety system—whether it be wheat, rice, or cotton—is dangerous because of the possibility of epidemics. Only a dynamic national breeding program where researchers keep producing and releasing varieties with different sources of resistance can cope with the problem. Insects and disease organisms are capable of genetic changes, too, so that scientists must continually search for and incorporate more sources of resistance.

AGRICULTURAL CHANGE

As we look at the overall picture of food production in the world, I think we are all convinced that varietal improvement in itself is no cure for stagnant agricultural production. If we are to push things ahead from this standpoint—as we must—we fully realize that we must manipulate and handle simultaneously, in a harmonious way, three groups of production factors. This is especially true in a developing country where the land has been cultivated for a long time, where the production levels are stagnant, where the essential plant nutrients are exhausted and production is limited—irrespective of crop variety or losses from diseases and insects. I am convinced that in all programs, whether in developing countries or affluent countries, the key to changing food production is a coordinated national effort. I am against fragmentation and local efforts.

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They fail to mobilize the experience and technological know-how that bear on the overall aspects of food production.

On the question of production, we must consider three groups of factors that are to be manipulated simultaneously and harmoniously, if programs are to be successful. These include a new package of technological practices which, in turn, comprise improved varieties, fertilizer practices, control of pests and weeds, and moisture management. Moisture management has to do with irrigation, or how you conserve moisture, especially in areas where moisture is likely to be limiting in certain parts of the crop season.

But even with this vital package—one that produces a big change in yields per hectare—change in food production does not come automatically. The governmental economic policy of the country must be hitched to the wagon. Unless this is accomplished, there is no possibility of provoking change—especially in those lower economic currents of the society, made up of the very large numbers of small farmers who have lived on the outside of the economy under subsistence agriculture.

This calls for a whole series of devices put together in a certain way by the government of the host country. It has to do with pricing of the grain, it has to do with the price and availability of such inputs as fertilizers, weed killers and pesticides, and especially credit for the small farmer so that he can begin to participate. Remember that the farmer has never had this opportunity before and, unless all these factors are combined in the national production campaign, there will be no change. I repeat, irrespective of how good the variety, the fertilizer recommendation and the pest control, no change will be forthcoming. Then, of course, one can have both of these factors under control but, unless these changes are spectacularly demonstrated by showing what is possible, one cannot put the change across to the farmers. Demonstration must be done in the farmer's field. In too many parts of the world in which I have worked, too much of the research, especially demonstration work, is being done on government experiment stations where they then try to bring the farmers to see the results. We are deceiving ourselves if we think we are going to promote a change in crop production practices with this kind of approach. Remember that the small farmer, in particular, is suspicious of all the things he sees being done on a government experiment station. He will always say that the government has all sorts of money; "They have my taxes and they can do things that I cannot do," and besides he is not so sure of how much is science and how much is "hokus-pokus." But if he sees the demonstration installed on his own farm or on a neighbor's farm, in his own village, he or his neighbor becomes the most effective extension agent in the whole countryside. It is up to us then, as extension workers and research scientists, to hitch these people together and spread the word. It is amazing, however, that even without this effort, the word spreads rapidly if the research is viable and the economic ingredients are brought together in the right way.

Now, having all of these, there is one more item which to me is the most important in making a national program work. This is the team spirit which can surmount problems in the midst of a whirlwind. The defeatist spirit is the greatest enemy of progress and it persists and is too widespread among scientists. If constructive change is to be provoked, there is no place for defeatism in the ranks of leadership or among the scientists charged with the responsibility.

WHEAT BREEDING IN MEXICO

I would like to turn now to consider the history of the wheat breeding program in Mexico as it is related to what has happened in wheat production in this last 4 to 5 years in many other parts of the world. In the early years, there were no government stations and it has only been in recent years that such stations were established and adequately equipped. From the outset, the development of high yielding varieties was our primary concern; the second most important consideration was the efficient use of irrigation water since this was limiting and most of the wheat was grown during the winter or non-rainy season. We were interested also in speeding up the plant breeding process from the time the cross was made to the emergence of a new variety.

Essentially all of the varieties being grown when our program started were mixed types, some of them probably dating back to early colonial times. It was not uncommon to see 15 or 20 types of wheat growing as mixtures in the field. This was not as common in the state of Sonora which had been influenced by the wheat breeding program in the state of California, but for the rest of the country, I am certain many of these mixtures date back perhaps 100 years. We were concerned also that the new varieties should carry a broad spectrum of disease resistance and that they should have broad adaptability.

To produce a variety in a short time to meet the needs, we decided we should grow two generations per year and, to accomplish this, we worked at 67 locations. After a short period of testing, we found that the same result could be obtained by growing our main breeding nursery in the winter in the state of Sonora, at about 28°N and at only a few meters elevation above sea level, and in the summer at a high elevation where diseases could be fostered and the wheat would grow adequately, because of cool temperatures. The first location represented, and still does, the main wheat growing region of Mexico. The second generation, summer season location was found near Mexico City, in the Valley of Mexico at an elevation of about 2200 meters and also in Toluca Valley nearby, at about 2600 meters. Here the heavy rainfall during the summer season provided good conditions for the development of epidemics to screen the materials. Different diseases were found to be important in these two locations. On the coast, for example, stem rust was the greatest enemy while in the high Valley of Toluca, stripe rust was important. Leaf rust and stem rust occurred in both places. By moving the breeding materials from one region to the other it soon became apparent that wide adaptability could be built in. We wanted this adaptability because Mexico is a mountainous country and varieties should be able to fit both the slopes and plains. This would simplify seed production problems. As these new varieties were moved from the coastal plains to the high valleys—from low elevation to high elevation—we began to find varieties that were well adapted to both conditions.

We also found why the Canadian varieties and the northern U.S. spring wheat varieties were so poorly adapted under Mexican conditions. This observation later proved to be the same throughout Asia, South Asia and the Near and Middle East. They were not adapted to the short days of the lower latitudes. But it was not only the total hours of daylight that was involved. Tremendous differences in plant response occurred depending on whether the days changed from long to short or short to long as the season advanced, even with the same number of hours of light. This was vividly illustrated at Chapingo, in the early years of our work. Normally, we planted our yield nurseries there in the last week of November, about 1 month before the shortest day of the year. Thus, the days were getting shorter in the early period of growth and becoming longer as the plant moved toward maturity. This added a new scientific dimension to the work. The next generation was sown just across the road, about the last week of May—again about a month before the longest day of the year—when the days were becoming longer. There was about 35 percent difference in yield, without any disease factors or soil fertility factors involved. It was evident that the total number of hours of light was not the principal factor but that, in this kind of variety, the conditions at Chapingo in the summer are similar to the life pattern for which they were selected in the northern U.S. and Canada.

YIELD STABILITY

I would like now to consider yield stability or broad adaptability, which now is one of the most important factors affecting whether we wish to use a new line as a commercial variety.

What is yield stability?

No one can define this fully because we do not know how many factors, other than hours of light and temperatures, are involved. There are obviously many others, but we have found these to be among the principal contributors to broad adaptability of a variety under commercial conditions. In addition, our method of selection under widely different environments—as mentioned previously—provided an opportunity to select types suitable to both.

I would like to say a few words about what has happened in the use of some of these varieties developed in Mexico. I am not going to refer to a particular variety, but to the group of varieties. Many of these were introduced based on initial experimental testing dating back to 1963 and 1964 in India and Pakistan and a number of other Middle East countries. It would seem on the surface that this was taking a long chance to move varieties so far from Mexico. But, after 2 years of widespread testing, it became evident that these varieties were very much at home and that the disease pattern was more or less similar to that present in Mexico. It was possible, therefore, to sort out which varieties were adapted and then develop a set of agronomic practices which would fit best in cultivation. This was done in India by a well organized national coordinated program. Based on Mexican experience, modifications were made in soil fertility manipulation, fertilizer, and cultural practices to fit local needs.

I am not going into details, but essentially the same was done in West Pakistan. Similar adaptive changes were made in certain low elevation agricultural areas of Turkey, in certain valleys of Afghanistan and Iraq and, more recently, in the rainfed areas of North Africa.

The important thing is that breadth of genetic adaptation was incorporated into these semi-dwarf varieties through earlier work that was done in Mexico, even though we did not recognize at that time that this characteristic had been incorporated to the degree that permitted this flexibility. We did have some earlier indication through our cooperative testing in Latin America. We also knew that we could breed for adaptability to high and low elevations for the latitudes involved in Mexico, but the number of locations for yield testing had been quite limited.

The first move made to increase the scope of yield testing was made at the Latin American Plant Breeders Meeting in Chile, in 1958, where a committee decided that it would be interesting to set up an Inter-American Yield Test. We agreed to coordinate this and it was decided that we would grow the seeds and select representative commercial varieties from all American countries, for inclusion in the test. The materials were then grown in all of the countries under a wide range of conditions. Immediately the varieties separated themselves. Some were specific in adaptation. The Canadian varieties were unable to function economically below 39°N latitude. This prevents them from being used in the tropics and subtropics and even in Argentina, where the main commercial area is in the region between 35°S to 36°S. We learned much in this test.

About a year or so later, when we began working in a training program in the Middle East with the Food and Agriculture Organization, there was interest among the students to set up a Middle East-Mexican-Colombian varietal program including daylength-insensitive varieties. This was set up and again we got some interesting data in about 3 or 4 years. Now, we make up 90 sets and these are sent around the world to many scientific collaborators. From this, data come in, and reports are made up which go back to the collaborators. There is an opportunity for any plant breeder who has a selection that is in the advanced stages of testing to submit it for test. We ask for 200 grams of seed, which we multiply. Those selected are incorporated into this yield test. By following this practice, a man can obtain more data in one year than he would get in 20 years on the breadth of adaptability and stability of yield. I refer to stability of yield in the broad sense, as it relates to adaptability when diseases are not limiting. But you can see also in which locations diseases limit a variety or new line that is under test.

The magnitude of change in total wheat production in a country such as India has been fantastic. Production rose from the high of 12.3 million metric tons before the green revolution to that of the present year, 23.2 million. Most of this gain has been achieved through increasing yield per unit of cultivated area and much less through expansion of cultivated area. This has changed the whole technology of wheat production as it relates to fertilizer and improved cultural practices.

There are many people who failed to comprehend some of the implications. Time and again economists write that we are making the rich richer and the poor poorer. That just is not so. Recent studies made both by India and Pakistan have shown that the little farmer, the one with 1 or 2 hectares, is participating and benefiting greatly. You will also hear many people say that these varieties require much more irrigation water and are very demanding. This is not true either, for you will find that they may require one extra irrigation, but if you calculate the water requirement per kilo of grain produced, you will find they are much more efficient producers than any of the previous varieties. After all, producing grain is the name of the game. You will find the same critics saying that they have to be babied and they have to have heavy fertilization. Of course they do, if we are to capitalize on their maximum potential. But, on the other hand, even at low fertility and on dryland, they do surprisingly well, displaying their efficiency even though they were developed under irrigation.

Again you always hear of their poor quality. This criticism is given not only by laymen but by scientists. Generally this can be considered scientific bias. Some of the people who have been most vocal about this, have been blindfolded and given the Chapati test. Often they put the Mexican varieties in the first place, so you see how bias voiced loudly in high places can tangle up the truth. All of these things you must contend with. The grain merchant all along the line wants to feature this difference so he can make more money. He has been found to buy grain of large-seeded dwarf varieties or screen out large seeds of other Mexican varieties which he can buy at a lower price, and mix them with indigenous grain to be sold at the higher price which these have traditionally commanded. This is market manipulation at its worst. Thus, you see one has to be a little careful when provoking change to avoid these types of confusion.

It is said repeatedly that the high yielding wheat and rice varieties are less resistant to diseases than the old land-race indigenous varieties. I think this depends on what basis you are using for comparison. If you define this on the basis of the microclimate it is true given both varieties being susceptible. Under unfertilized condition with plants widely spaced in order for them to extract from this depleted soil enough nutrients to produce some grains, there is little opportunity for the disease organism to produce an epidemic. But, under unusually favorable climatic conditions a rust epidemic can become established as I have seen happen in Mexico with these kinds of varieties, resulting in devastation of the crop. But once you start fertilizing the old varieties, even at intermediate level, epidemics are the rule and you have a true picture of its susceptibility. On the other hand, the new varieties are actually highly resistant, covering most of the races of the disease and certainly in all cases they are superior to the old land-races.

This does not mean that they are going to remain resistant very long and this change in the ecological balance because of the improved cultural practices, calls for a higher degree of resistance in the variety unless you are prepared to take chances on loss. We must, therefore, maintain a dynamic national breeding program to back up any initial effort that may have come out of the international scenery, like CIMMYT in this case, or IRRI in the case of rice.

My fundamental belief is that the backbone of continued progress in whatever you want to call this change in cereal production, let us say the green revolution, hinges on the dynamic national program. It is this program that will produce the diversification and make the multiplication of the varieties needed to cover up changing situations such as resistance to the principal diseases and I dare say insects. For wheat, not many insect problems exist. There is, however, one great danger and it is a built-in danger of success that comes with one variety. I'm glad to say that in India, at least, we have passed the vulnerable position created by the widespread use of varieties re-selected from cross 8156. Dr. D. S. Athwal made one of the selections, Kalyansona, and sister selections were made in Pakistan and in Turkey. These probably covered 10 million hectares a year ago. Fortunately, it is very well adapted and is high yielding and has many things going for it, but it is fortunate also that now large areas of three other dwarf varieties selected in India have been distributed and multiplied, so they are beginning to get diversification.

I am opposed to the one-variety system, whether it be in cotton, wheat, or rice. They are all the same. It is dangerous because of the epidemics that can start. It is only with a dynamic national breeding program where you keep producing and releasing varieties with different kinds of resistance, that you can cope with this problem.

Unfortunately, if the new varieties do not yield as well as former ones, they will not be grown long because it has been my experience that the farmers in 2 or 3 years' time will distinguish yield differences of 10 percent. Even though a new variety is the most disease resistant of all of the group, if it yields 10 percent below the present varieties, it will be out of operation in about 4 years. The farmer can spot this difference. He has paid the same price for his grain; he has not experienced losses to diseases as yet and he is going to take a chance on the higher yielding one. The only way to beat this is to keep turning out new ones that are at least better than the commercial varieties for several characteristics.

I would like to have been born a maize breeder, because people in rice and in wheat are among the most vulnerable in the world to changes in races of disease organisms. We are dealing with self-pollinated crops, so we develop inbred lines. We select for resistance to diseases and insects in the area in which we work at a given time. One of these is successful and suddenly the variety is out, like Kalyansona and Mexipak on thousands or millions of hectares. We have an explosive situation. If a race of rust changes, an epidemic can sweep all the gains away. Our only recourse is to diversify varieties. For maize, however, we are dealing with a cross-pollinated crop. In its native home it has been in harmony and balance with the organisms parasitic on it, except when some poor scientist messes it up. From the beginning of time, two species of rust, *Puccinia sorghi* and *P. polysora*, have been present, but they never caused appreciable damage. They were always there, but every plant in that open-pollinated variety is distinctly different and epidemics could not build up. An equilibrium was established. The only way to build up an epidemic is to take one of the high altitude populations to a low elevation or vice versa, where races favored by low or high temperature are present.

The maize variety in its new location is faced with a race that could not survive in its native place. There was no selection pressure and the variety is now susceptible and an epidemic can develop. The equilibrium has swung in favor of the parasite. However, hybrids involving resistance at both locations offer a tremendous advantage provided the inbred lines entering the cross have been properly screened. This brings up one other point which we tend to forget: In the tropics with tropical crops, the organisms live throughout the year and are not eliminated by cold as they are in the higher latitudes. Whether it is corn rust or wheat rust, the inoculum arrives late, giving the plant a definite advantage.

To fully appreciate how resistance can persist over long periods of time, in spite of the absence of the disease organism capable of attacking the population one has but to look at corn and corn rust in West Africa since the early fifties.

Apparently when maize was taken from the Americas to West Africa in the early colonial period, the rust that went with it (based on the early herbaria collections—which of course do not go back 400 years, but nevertheless were collected early in the period) was *Puccinia sorghi* which does not thrive at high temperatures, but only at low temperatures. It just did not find a happy home in that part of Africa. It managed to survive, but caused no damage. It was only after maize began to be grown in the highlands of East Africa that temperatures were favorable. The disease flared up and caused havoc in corn production. As a sequel about 1948 or 1949 the high temperature organism *Puccinia polysora* was introduced to West Africa. It immediately spread to the entire population of corn in that part of the continent and yields fell drastically. Scientists were called in and worked vigorously to produce resistant varieties, but before they were released, the epidemics subsided. Apparently the peasant farmers had selected resistant plants for seed stocks, which contained genes for resistance that had persisted in the population over the 400 or so years since it was introduced as a crop from the Americas. While this can also occur in close-pollinated crops, its likelihood is much greater in open-pollinated species, where the genes for resistance are passed around at random within the population in each generation.

Even more amazing is the case of the white pine blister rust in western white pines, which was introduced about 1900 into America. It was found that one in 20,000 trees was resistant. This disease, which was endemic in the Orient, had developed a high level of resistance in pines of Siberia, Japan, China, and extending into the Himalayas. The naturally resistant trees in America had apparently received these genes across the land bridge from Siberia thousands, or possibly hundreds of thousands, of years ago, when the ancestors of present species could still interbreed. They had persisted in the population and were only exposed when the organism was introduced and became epidemic. Recent fossil finds in Siberia indicate that types similar to the American species did exist in that area in the past.

I want to say one thing concerning my fears on the advisability of continuous cropping of the same crop species. I feel there is a moral obligation to say that if we continue this practice without breaking the cycle of the disease organism, the longevity of resistance can be expected to be short in dealing with one such as

Piricularia sp. in rice, where variability is well established. The question I pose is how long will resistance remain functional with two or more crops of the same species grown each year. There is bound to be more inoculum and, therefore, greater opportunity for the fungus to mutate to new forms which will attack the resistance.

In a similar vein we speak of resistance to insects. This also is transitory. Insects are capable of mutation too and we must continually search for and incorporate more sources of resistance. It is my advice that you keep the germplasm pool broad and make use of double crosses, top crosses, and other forms of multiple crosses with a continuous inflow of new variation.

We have found in wheat that single crosses made between tall varieties and dwarfs produce few dwarf plants and there is insufficient variation within this type to sample the variation present from the cross. Using multiple crosses of F_1 by F_1 and including three dwarf parents, the yield of dwarfs is high and our chances of selecting superior genotypes in the framework of the dwarf type are infinitely enhanced.

CONCLUSION

Before I close, I would like to say that we have to fight on another front, in this part of the world: The environmentalists are developing a real chaos in the United States. They think we are all going to die from poison. These fat-bellied philosophers who have never been hungry and who have tremendous power in the legislatures, would like to be called ecologists. I will never give them that satisfaction. They are environmentalists who are off balance. You have seen what they have done to DDT. There is little evidence that any single human has been harmed by DDT and plenty of evidence that control of malaria has saved millions. I happen to have worked in wild life in my early professional career and know about some of the other factors that are involved in the reduction in population of wild life. They have pointed their finger to three or four species that have been reduced by DDT and it isn't so. These species were on their way out for a long time before DDT had come into the picture. The excellent analyses that we have now in gas chromatography are involved in confusing the issue.

Before World War II we had difficulty in measuring one part per million in most chemicals; now one part per billion or several parts per trillion are easily identified by means of gas chromatography. This can be compared to the accuracy of putting astronauts on the moon and bringing them back after 800,000 miles or more to within a mile of the ship dispatched to pick them up.

If we throw common sense out of the window in this kind of thing and let these fat-bellied philosophers dictate our future, we are going to be in real trouble, particularly in the case of compounds like DDT, which has brought control of malaria to the world. There is no comparable substitute, according to the World Health Organization, so we better not throw it away until we have it.

Now they are speaking against chemical fertilizers. If they pass legislation to deny us the use of these, our efforts in agricultural research will have very little significance.

Discussion: Breeding wheat for high yield, wide adaptation, and disease resistance

V. A. JOHNSON: You mentioned the genetic isolation associated with self-pollination or inbreeding in crops like rice and wheat. In wheat we now have one or more chemical gametocides to induce male sterility. Is it time to put such a chemical to work in an organized manner?

N. E. Borlaug: I am for any means that would put more variability into the population that we can grow well commercially. I don't know how to reverse evolution and change the pollination system in wheat and rice, but perhaps we can manipulate it chemically. I continue to have an interest in the multilineal variety. In cooperation with national programs, we are building a series of phenotypically similar lines at two levels of plant height to have both wide adaptation and broad disease resistance. The multilineal complex will hold back a disease epidemic and they will provide a certain degree of protection. But it takes time to develop multilineal lines.

R. F. CHANDLER: How intense is your crossing program and how much effort should be put in the selection program in relation to the number of crosses being made?

N. E. Borlaug: We make a large number of crosses. We look through all of the international nurseries and early screening nurseries, which are made up of early generation lines sent around the world, and watch the large number of lines carefully as new parental lines. Then through the literature and the USDA-coordinated international rust nurseries, we search for those new types and cross them widely in our programs. Many of the crosses were discarded because of their tallness and photoperiod sensitivity. We threw away the single crosses but we use their pollen for backcrossing. More commonly, we make double crosses of these F_1 plants. By growing a reasonably large number of such populations, we expect to find combinations carrying the particular disease resistance. Meanwhile, our pathologists convert the unusually good lines to dwarfness and insensitivity and try to retain the disease resistance. So we work from several different sides. We probably make about 2,000 to 2,500 crosses and grow two generations in a year. But we do not grow all of the crosses. For the F_2 populations, we plant a minimum of 2,000 seeds each for about 600 crosses at our central stations. In addition, we send collaborating national programs about 50 sets of F_2 seeds each. We would like to grow more of these but we have to stop at about 250,000 plants. To get epidemics of rust, we inoculate the plants with mixtures of races to spread the rusts.

R. F. CHANDLER: With such large numbers, once in a while you may miss some promising plants.

N. E. Borlaug: Yes, but somebody else will catch the progeny. Our whole philosophy in plant breeding is to look everywhere for sources of resistance, to make many crosses, and to subject them to epidemic conditions in a wide range of environments to take care of the physiologic specialization of the pathogens in different parts of the world. This calls for international cooperation and growing large populations.

R. F. CHANDLER: Have you done any mutation breeding?

N. E. Borlaug: Not to any appreciable extent yet. We are considering using this technique to improve the shrivelled grains in one *Triticale* line. This line has disease resistance, insensitivity, semi-dwarfism, and high nutritive value.

H. L. CARNAHAN: What is the effect of photoperiod sensitivity on wheat performance other than adaptability?

N. E. Borlaug: I am not sure. But at high latitudes, the insensitive Mexican wheats can suffer badly from drought in the early spring. For northern areas, sensitivity may be advantageous.

L. M. ROBERTS: Do disease problems become more serious in the semidwarf wheats?

N. E. Borlaug: I don't think so, but when you make such a big jump, you may not have all of the disease resistance built into the varieties.

L. M. ROBERTS: How about insect problems?

N. E. Borlaug: We have not worked long enough in areas which have insect problems. In heavily infested areas such as Morocco and Tunisia, there is evidence of great diversity in an insect species. That would complicate and lengthen the breeding work.

H. E. KAUFFMAN: Please comment on the need for rice workers to move rapidly into a broad international testing program for diseases and insects like you have in wheat.

N. E. Borlaug: I think it is of tremendous importance to develop such international programs. For instance, we can obtain information quickly on a certain disease from a cooperating country, such as Tunisia, on *Septoria*, incorporate resistance into our new lines, and send the material to Tunisia and other countries for broad screening a few generations later. These steps can add long-time protection to a breeding program. I am particularly concerned about continuous cropping in rice because of the tremendous build-up and turn-over of inoculum.

R. F. CHANDLER: Could you or Dr. Johnson tell us about the Russian variety which yielded well at high latitudes in Turkey in the international winter wheat trials?

V. A. JOHNSON: This winter wheat, Bezostaia, has been the highest yielding variety in the international winter wheat performance nurseries since the project was established in 1969. It is in a performance class by itself and it has wide adaptability. Morphologically, it is similar to the CIMMYT wheats.

N. E. Borlaug: Although this variety was developed in a local program, it has tremendous yield stability built into it. The Russians also have an impressive spring wheat, 8156. There was an element of luck in breeding the 8156 complex which resulted in resistance to powdery mildew and immunity to loose smut.

T. T. CHANG: What are your views on genetic conservation?

N. E. Borlaug: I am concerned about it. Although the USDA world wheat collection has 17,000 accessions, it is still questionable if it is representative of all types. I understand a Rockefeller Foundation meeting will soon review the situation in wheat, rice, maize, sorghum, and millets and discuss ways to broaden the base for collection.

D. S. ATHWAL: I agree that a new variety may have to be replaced every 3 to 5 years because of the dynamic disease and insect situations. It will be a continuous struggle between plant breeding and the pests. We have to keep ahead of the diseases and insects by developing varieties with new sources of resistance before the disease or insect changes and causes serious damage. But I am concerned about the limited sources of resistance available to us. Shall we one day run out of resistant genes for one disease or one insect? What is the situation in wheat? Can you build up a higher level of resistance from lower levels by breeding? Or, are other means available?

N. E. Borlaug: I have to be optimistic. I think there are more resistant genes around. Some genes probably have a low level of protection individually, but we can bring them together and part of this is related to field resistance. With corn rust in West Africa or with rust on western white pines, these genes have long ago dispersed in a few varieties or trees and when they are brought together, they still function. I think that in rice you are in a better position because you can multiply rice seeds faster than wheat. We need a more efficient seed multiplication system so that we can have enough seeds of several promising selections before making a final decision on what to release and thus, to save a year or so. If we can move fast on seed multiplication, we may stay ahead of the disease or insect.

T. T. CHANG: I would like to point out a genetic mechanism that could provide sources of resistance in addition to mutation or cumulative action of weaker genes. Some varieties probably are phenotypically susceptible or moderately resistant because the resistant gene is masked by inhibitors. When you cross such a variety with the right parent, which may be a susceptible variety, the inhibiting effect is removed and resistant progeny may appear. As we learn more about inhibitors, it is clear that their presence in existing germ plasm is more widespread than we used to think.

G. SATARI: In Indonesia, we have several tungro-resistant rice varieties that are still resistant and high yielding 20 years after their release though we grow rice twice a year. What is your idea on this long-term resistance?

N. E. Borlaug: I do not pretend to understand it. I have mentioned cases of persistent functional resistance. But, more often than not, it does not last too long. Be thankful if you can make it last. But, I am worried, especially as we provide a more favorable environment for the insects and diseases by thick planting and fertilization that the whole ecology is changing. The plants become more palatable.

H. I. OKA: In rice, insensitivity to photoperiod is important to wide adaptability. I understand that you have the winter habit in wheat. Has the degree of winter habit been a limiting factor in the adaptation of the Mexican wheats?

N. E. Borlaug: No, most or all of the Mexican wheats are spring wheats. But in a cooperative program, one CIMMYT researcher is inter-crossing the winter and spring wheats to provide genetic material for the high plateaus in the Middle East and the Near East.

W. H. FREEMAN: You mentioned *Triticale*, a man-made species. Are there other possibilities?

N. E. Borlaug: It is incredible, looking back at the history of agriculture, that scientific man has not come up with a major cereal. All we are doing is putting the polish on what was done very well by Neolithic men. I think we can do better with all of the new techniques at our disposal. Despite the crossing or sterility barriers between the tetraploid wheats and rye, we are intercrossing *Triticales* made from different species of wheat to obtain new variability. We should go to all other sources. The original crosses were made from a handful of plants. When we work with wide crosses, we need to work with large populations.

L. M. ROBERTS: Broad crosses could be facilitated by using cell and tissue cultures. Protoplast fusion between cells of different species has been obtained. The problem is to have the regeneration of the cell wall. I believe that new hybrids can be made by such techniques.