New Wheats and Social Progress

Improved varieties of wheat have helped make possible unprecedentedly high levels of food production.

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Man's quest for food is everlasting. The supply of food can never be very far ahead of the need, because all food is perishable. Nor can man long survive when food is in short supply, because his body reserves are soon exhausted. We know this from very recent experience. In 1966, grounds for pessimism were easy to find: Our supplies of wheat were gone; India had had two droughts in succession; the U.S.S.R. had had two crop failures in 3 years; and Australia's wheat crop was poor (*1*). But the years since, while not entirely favorable, have brought supplies back to substantial amounts, worldwide, and reserve supplies have accumulated again in some places. Part of this turnaround is due to the new varieties of wheat, to slight expansion of acreage, and to the higher priority given wheat production in the assignment of resources, especially fertilizer, in the developing nations.

Jonathan Swift wrote approvingly of making "two blades of grass to grow where one grew before." This is about what the new wheats do when grown in association with good soil and crop management practices. Agricultural progress of this magnitude is having an impact on food supplies, markets, government farm programs, production practices, agribusiness, and population. Improved capability of producing the major cereal grains—wheat, rice, and corn, in particular—has given new hope of feeding the world's burgeoning population. If that hope could be realized without insurmountable side effects, this would surely lead to social progress. However, too much reliance on such agricultural development, good though it may be, will boomerang if other measures are not taken to balance the social pressures in every country, and may only alleviate the difficulties temporarily.

Wheat has been man's companion and food in Eurasia and North Africa for thousands of years. Prehistorians, in developing their time scale, have set wide limits for the first appearance of wheat on earth, and rightly so, because this event has repeatedly been set earlier and earlier.

Good archeological evidence shows that wheat was known in Neolithic times (*2*) and probably was a plant of great antiquity even then. Cereal pollen (not necessarily wheat) dating back to 10,000 B.C. is known (*3*). Principally, emmer was the species found associated with wheat husbandry of the 7th millennium (*4*).

What Is New?

Can there be anything new about a crop so old? We sometimes hear a similar question asked about man. The answer to both questions is "yes," in the long view. Both man and his food plants are subjected to stresses, and adjustments are made. In the press to obtain more food, wheat is grown now in selected sites in all continents, from latitude 60°N to 60°S, and from just below sea level to elevations of more than 3000 meters (10,000 feet). It exists in several thousand forms or varieties; nearly all of these may be broadly grouped into two species (*Triticum aestivum* L. and *T. durum* Desf.) having 21 and 14 pairs of chromosomes, respectively. Some varieties of recent origin have proved so highly productive and widely useful that they are being grown to the exclusion of other varieties over large areas.

What is really new about wheat boils down to one thing—higher grain yield per unit of land, popularly referred to as the "green revolution" (*4a*). To achieve this higher yield, modern breeders have manipulated several hundred known genes into desired combinations governing plant morphology, physiology, and resistance to disease, and uncounted other essential attributes, to create the varieties now associated with the green revolution (*5*).

Yields per unit of land have been increased dramatically in many countries in the last decade or two; they have been trebled in Mexico and doubled in the United States and in parts of India, Pakistan, Turkey, and many other countries. This is a consequence of (i) increased fertilization or plant food management, (ii) irrigation or better moisture management, (iii) control of pests, (iv) economic incentives, and (v) selection of responsive genotypes of wheat. New varieties undoubtedly provide a basis for obtaining higher yields, and they are a catalyst, making the other factors more interactive (*6*). These high-yielding wheats are not a single variety or genotype, as is erroneously implied in many reports. At least 50 varieties contribute to the worldwide green revolution.

The new wheats have been improved in three major ways. (i) They have shorter, stiffer straw than standard wheats; (ii) they have greater adaptability, hence are better suited to the environments where they are grown; and (iii) they are more resistant to diseases and insects. Most often talked about are the dwarf types, sometimes called semidwarfs to distinguish them from the extremely short (and worthless) freaks or dwarfs of purely genetic interest. The semidwarfs (Fig. 1) grow from half to two-thirds the height of standard varieties (*7*). Of all the new wheats, the semidwarfs are the most spectacular. The Gaines variety, developed in the state of Washington, has established a new world record of 209 bushels per acre (*7*). The new Mexican varieties have brought hope for hunger-stricken people in a score of countries where it had seemed that population growth must inevitably bring famine (*6–9*). The availability of these varieties has made it possible for nations to plan and carry out practical programs for increasing their food supply without resorting to territorial expansion. These nations have increased the productivity of their own resources through adaptive research, efficiency, education, capital

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investment, and expanded trade (*10*). This has been a stimulating, new experience that can help to alleviate other problems. Unquestionably, such experience is giving man a new opportunity to improve the quality of his living and forestall famine (*11*). Whether he does so, or only increases the numbers who will die of starvation at a later date, is the decision he faces (*9, 12–16*). Some say it is already too late. Malthus' dire predictions have had to be reassessed several times. New technology, which led to development of the new wheats, has caused another revision in estimates of the timing of the disaster. But unless other parts of the equation are changed, the general concepts of Malthus surely will be proved right in the end.

Genes from Japan

The details about the semidwarf wheats and how they were bred have been given in several accounts (see, for example, *6–8, 17–19*). New varieties of this type are being released each year. The main genes for dwarfism trace to the Orient (*8*), especially to the Japanese variety Norin 10. Dwarf wheats appear to have a long history in Japan. They were first observed there by Americans as early as 1873 (*20*). No use of this information was made in the United States, and Japan's short wheats had to be rediscovered in 1946 (*8*). However, short types from Korea, China, and elsewhere were used earlier in the United States, in some cases with gratifying results. Short-stemmed mutants are readily induced, and a chemical spray (CCC), which must be applied to each crop, has been used to reduce the height of otherwise tall varieties (*19*). Italian breeders were among the first to use Japanese varieties in their wheat improvement program. Records of their crosses from 1911 onward reveal Japanese varieties in the pedigrees; from this work they derived early-maturing, short-stemmed varieties (*8*).

The semidwarfs first attracted attention in the United States soon after S. C. Salmon, a U.S. Department of Agriculture (USDA) agronomist, brought back to the United States seed of Norin 10 and of 15 other varieties of this type in 1946 (*8*). These materials were distributed to U.S. breeders in the next 2 years. Beginning in 1949, a corps of workers at Washington State University, led by O. A. Vogel, USDA agronomist, utilized Norin 10 in a series of crosses with locally adapted varieties. From these crosses Vogel selected Gaines and Nugaines. Both varieties are short, have stiff straw, and, under good management conditions, give enormously high grain yields in the Pacific Northwest. They have winter habit of growth (that is, they require a period of cold to mature), hence they cannot be utilized where their requirements for cold during early growth are not met. They are not sufficiently resistant to the cereal rusts to avoid damage during epidemics. Early generation selections from crosses, and Norin 10, were made available in 1953 to N. E. Borlaug, a Rockefeller Foundation scientist in Mexico, and the crosses he obtained the next year mark the beginning of the now famous Mexican wheat varieties. Borlaug and his associates bred into these varieties dwarfing, spring habit, nonsensitivity to day length, early maturity, and a high degree of resistance to rust (*6–8, 17*). The most widely known and cultivated are the varieties Pitic 62, Lerma Rojo 64, Mexipak 65, Sonora 64, Indus 66, Penjamo 62, and Inia 66. But the pattern changes yearly as new and improved varieties appear. These varieties are now being used in at least 25 countries.

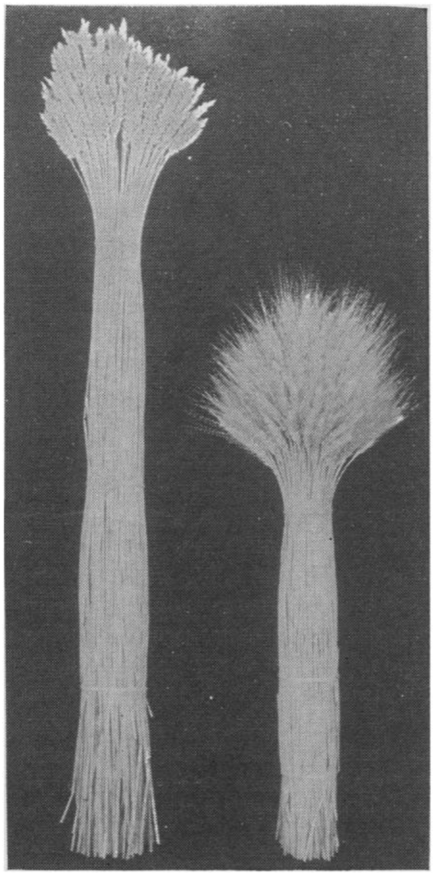

Fig. 1. Semidwarf wheats, such as Gaines (right), are half to two-thirds the height of standard varieties. The sheaves pictured (about one-tenth actual size) show the full height minus a 5-centimeter stubble.

Essential Help

Other significant, yet little known, research developments took place at about the time of the semidwarf episode. These events are little known because they were diffuse, of varied character, slowly cumulative, and not widely publicized. Many people were involved, but there were no heroes. (I have no objection to heroes, but some events do not fit the pattern.) I refer to work done through people serving several agencies not yet mentioned here, especially the U.N. Food and Agriculture Organization (FAO), the Agency for International Development, many universities, the Ford Foundation, ministries of agriculture, and the numerous research people who published their findings in professional journals and research reports which disseminated valuable information. Three direct activities, among a score or more of importance in bringing the new wheats to the attention of many countries, are here singled out: (i) the work of the International Maize and Wheat Improvement Center (CIMMYT), through its research, testing, and training program (*6, 21*); (ii) the International Rust Nursery Program, with 40 countries cooperating (*22*); and (iii) the FAO Near-East Barley and Wheat Improvement Program, which has regularly (since 1952) introduced new germ plasm into its regional tests in a dozen countries. Finally, of most importance, are the farmers in all of these countries, who, at considerable risk, accepted the new varieties and the new technology (mainly higher rates of fertilization) needed to make them spectacularly productive.

Each country has its own success story (*6, 17–19, 23*), and many of them will never be told. Each is a little different from the others. Although the explanation given is usually simple (the use of new, high-yielding varieties), an interaction of many complex factors had to occur in order for grain yields to exceed, as they did last year, anything ever before recorded. Not the least of these factors were plentiful supplies of good seed and increased amounts of nitrogenous and phosphate fertilizers. The reduced cost of nitrogenous fertilizer has been significant in obtaining greater use of this fertilizer on wheat. Timely and proper sowing of seed, increased irrigation and water management (including drainage), weed and pest control, and prompt harvesting and handling of the crop were also required for success. A breakdown in any of these interlocking events reduced efficiency of production or nullified the benefits of the other practices. Where adapted to the environment, the new varieties have a yield potential from 30 to 100 percent higher than that of traditional local varieties. Therefore, they give increases in yield far beyond fertility levels formerly considered excessive for wheat. It was demonstrated that farmers will readily accept new practices when resources are available and new returns are substantial (*1*).

Government Policy and Payoff

The effect of government policy has been amply demonstrated in this experience. The constant support of the Mexican Ministry of Agriculture was crucial in the success of the Mexican cooperative program whereby Mexico increased its wheat production sixfold in 20 years. CIMMYT sprang from this program and formed the base of operations for helping other countries (*17*). There can be no doubt that the boldness and commitment of the Minister of Agriculture in Turkey to a wheat revolution was decisive. He shocked his own advisers in calling for, and obtaining, seed and fertilizer for 170,000 hectares the first year and 650,000 hectares (1,605,500 acres) the second in their accelerated program. In the affected areas, a threefold increase over the amounts grown with native varieties of seeds and with native agricultural practices was achieved (*23*).

The Indian Agricultural Research Institute, after 2 years of wide-scale testing of Mexican dwarf varieties of wheat, enlisted the help of the government of India in importing large quantities of two Mexican varieties. The government imported 250 tons of seed in 1965 and 18,000 tons in 1966, with the result that about 2 million hectares of dwarf wheats were harvested in 1968. "There is no parallel [up to 1968] for such rapid spread of new varieties in the world," commented M. S. Swaminathan, a member of the Institute (*18*). This program is credited with having broken a yield barrier in India that for 30 years had seemed impenetrable.

These and other importations and increases in the use of high yielding varieties of wheat have recently been summarized (*24*). Thirteen countries imported massive quantities of Mexican seed. West Pakistan imported 42,000 metric tons of seed for its 1968 crop, Turkey imported 22,100 tons for 1968, and India imported 18,000 tons for 1967. The combined area seeded to Mexican varieties in 1966 in these three countries was less than 8000 hectares; for 1969, in distinct contrast, it was estimated that 7 million hectares had been sown. Afghanistan, Nepal, Iran, Lebanon, Morocco, and Tunisia also produced sizable acreages of this type of wheat, bringing the total for Asia and North Africa to just under 8 million hectares (*6, 24*). In Europe and the Americas, at least another 2 million hectares of wheats derived from Norin 10 are grown. The result is that one or two genes for dwarfness and closely linked blocks of genes are present over large areas of the world. Since a relatively small number of varieties make up the major part of the seedings, a large portion of the genetic makeup is nearly the same wherever the dwarf wheats are grown.

In 1967 and 1968 India produced 17 million tons of wheat, in contrast to a previous high of 12 million tons (*18*), and did so without an appreciable increase in total growing area. The estimate for 1969 is still higher (*6*). In West Pakistan almost half of the growing area was sown to the new wheats by 1969, and, with the total growing area increased by about 20 percent, production was almost double that of earlier years (*6*). In Turkey the new wheats contributed substantially to the 1968 and 1969 wheat crops, and projections indicate self-sufficiency by 1975 (*23*). Similar results on lesser acreages are evident in Iran, Afghanistan, Nepal, East Pakistan, Tunisia, and Morocco (*1, 6*).

In all of these estimates the contributions of many factors—the wheat genotype, the land selected, the fertilizer used, the amount of irrigation, and so on—are combined, and it is virtually impossible to separate them. In one study (*1*), the new varieties were roughly estimated to have added from 9.6 to 32 percent to normal wheat production in the Asian countries, the average being about 20 percent. Extending these known responses to larger acreages is hazardous, as yields will depend additionally upon factors such as future expansion and improvement of irrigation systems; future prices of grain; cost of fertilizer and other inputs; damage from pests; and government policies.

What Next?

Never before have so few genes been responsible for filling so many mouths with food. The genetic base of the new Mexican-type wheats is, unavoidably, relatively narrow. Breeders urgently need to broaden that base as a safeguard against catastrophic events that might follow the appearance of a new pathogenic culture of rust or some other disease. All cereal-growing regions where rust is a constant threat have seen resistance in their crops overcome by new, virulent organisms. There is no assurance that this will not happen again, and it could occur more often than it has in the past, requiring replacement varieties every few years.

When new varieties are grown on large acreages, the old varieties may quickly become extinct. This diminishes the diversity of germ plasm in nature. The U.S. Department of Agriculture has been aware of this process and has built a living herbarium of world germ plasm comprising over 20,000 accessions of wheat. The collection dates back to 1897, when the U.S. government organized the Seed and Plant Introduction Office. In harmony with activities of FAO, the International Biological Program, and other programs, a new effort is being made to obtain seed of indigenous wheats in those areas where introduction of new varieties threatens to make them extinct.

Conventional Varieties Improved

I have emphasized the semidwarf wheats of the Mexican and Gaines type because they give the most dramatic results. This does an injustice to breeders of improved conventional varieties. These varieties, while not semidwarf, have greater straw strength, are somewhat shorter, and yield more grain than older varieties. They are disease-resistant and, in some cases, notably insectresistant. Salmon *et al.* (*25*) assessed a half century of wheat improvement in the United States and estimated that the better varieties available in 1950 yielded 40 percent more grain than the varieties in use in 1900. The advances occurred mostly in the last decade of the 50-year period and were evident in all regions of the country. More recent but similar evidence has been presented for various regions (*26*). Many of the improved conventional varieties are of value primarily because of their resistance to disease or insects and show little merit over other varieties when these hazards are not present, or when the resistance has been overcome by the pathogen or pest. Prior to 1944 the United States had not harvested a single crop of wheat that exceeded 1 billion bushels, whereas since 1944 all but seven crops have exceeded this amount. The latest three averaged 1.5 billion bushels. The acreage has declined slightly, and the average yield has about doubled (*27*). For a long time, yields in northern Europe have been the highest in the world (*27*). As in other examples presented here, use of improved varieties was only part of the reason for the increased yields. Of great importance were soil management, the use of fertilizer, the more timely tillage made possible by improvements in power machinery, and the use of supplemental chemicals for controlling diseases, insects, and weeds.

Summary

Will the upward trend in all food production, so dramatically exemplified by the new wheats, be adequate to meet the needs of the growing population? Yes, for a while. No one knows for how long (*14*). The prophets of doom will undeniably be proved right in the long run unless their basic assumptions are nullified by concrete acts, and soon. At some point in time, either a zero population growth must be achieved or vast new sources of food must be developed, and purchasing power increased. There is nothing on the research horizon to reject "a prodigious need for mankind to practice human husbandry" (*12*). Our waste products have reached levels that cause major concern, and it may well be that both agricultural and social advancement will be halted by the demands dictated by population growth and the by-products of what now passes for progress but also brings environmental unbalance (*15*). At least, life will be different, and it may be catastrophic (*16*, *28*). The "Three Ancients" (*29*) who helped plan and then, after a quarter of a century, reviewed the agricultural research and development work of the Rockefeller Foundation in developing nations concluded:

> We have discovered no magic formula for success in aid programs. We visualize no miracles and few easy solutions. But we do think that persistent use of science and common sense is the best guarantee of progress. . . . The fight against ignorance and hunger is a tremendous undertaking and it will take tremendous efforts to win it.

The accumulation and use of research information for growing better and more nutritious crops needs to proceed in both the "have" and the "have not" countries. Among land-grown food crops, the cereal grains and large-seeded legumes are our greatest hope. Wheat is one of these, and it should be exploited to the limit. While wheat *production* is important, it is even more important to find ways to make wheat and other food crops available to remote, often very poor, people. Challenges remain; they are biological, environmental, economic, social, and international.

References

1. J. W. Willett, "The Impact of New Grain Varieties in Asia," *U.S. Dep. Agr. Publ. ERS-Foreign 175* (1969).
2. N. Jasny, "The Wheats of Classical Antiquity," *Johns Hopkins Univ. Stud. Hist. Polit. Sci. Ser. No. 62* (1944), p. 35.
3. K. V. Flannery, *Science* **147**, 1247 (1965).
4. H. Helbaek, "Plant collecting, dry-farming, and irrigation agriculture in prehistoric Deh Luran," in "Prehistory and Human Ecology: Deh Luran Plain," *Mem. Museum Anthropol. Univ. Mich. No. 1* (1969); *Science* **130**, 365 (1959).

4a. L. R. Brown, *Seeds of Change: The Green Revolution and Development in the 1970's* (Praeger, New York, 1970).

5. E. R. Ausemus, F. H. McNeal, J. W. Schmidt, in *Wheat and Wheat Improvement* (American Society of Agronomy, Madison, Wis., 1967), pp. 225–267.
6. *CIMMYT Rep.* (1968–69), pp. 57–101.
7. L. P. Reitz, in *U.S. Dep. Agr. Yearb.* (1968), pp. 236–239.
8. ——— and S. C. Salmon, *Crop. Sci.* **8**, 686 (1968).
9. W. Paddock and P. Paddock, *Famine—1975?* (Little, Brown, Boston, 1967).
10. W. Weaver, "The President's Review" (Rockefeller Foundation, New York, 1958).
11. Q. M. West, "The revolution in agriculture: new hope for many nations," in *U.S. Dep. Agr. Yearb.* (1969), pp. 81–86.
12. W. E. Howard, *Bioscience* **19**, 779 (1969).
13. C. R. Wharton, *Foreign Affairs* **47**, 464 (1969).
14. "World Population and Food Supplies, 1980," *Amer. Soc. Agron. Spec. Publ. No. 6* (1965).
15. J. J. Spengler, *Science* **166**, 1234 (1969); P. R. Ehrlich and J. P. Holdren, *Bioscience* **19**, 1065 (1969).
16. F. S. L. Williamson, *Bioscience* **19**, 979 (1969).
17. N. E. Borlaug, *Phytopathology* **55**, 1088 (1965); ———, in *Proc. 3rd Int. Wheat Genet. Symp. Canberra* (1968), pp. 1–36.
18. M. S. Swaminathan, "Five Years of Research on Dwarf Wheats," *Publ. Indian Agr. Res. Inst. New Delhi* (1968).
19. "Cereal Improvement—Hybrid Varieties and Aspects of Culm Shortening," *Euphytica* **17**, Suppl. 1 (1968).
20. H. Capron, "Agriculture in Japan," *Rep. Commissioner Agr. for the Year 1873* (1874) [as cited by D. G. Dalrymple, *Bull. U.S. Dep. Agr. Foreign Agr. Serv.* (1969)].
21. "Preliminary Reports of the First Three Inter-American and the First Two Near East-American Spring Wheat Yield Nurseries," *CIMMYT Misc. Reps. 1–5* (ed. 2, 1966).
22. W. Q. Loegering and N. E. Borlaug, "Contribution of the International Spring Wheat Rust Nursery to Human Progress and International Good Will," *U.S. Dep. Agr. Publ. ARS 34-46* (1963).
23. L. M. Humphrey, "Mexican Wheat Comes to Turkey," *Publ. Food Agr. Div. USAID/Turkey, Ankara* (1969).
24. D. G. Dalrymple, "Imports and Plantings of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations," *Bull. U.S. Dep. Agr. Foreign Agr. Serv.* (1969).
25. S. C. Salmon, O. R. Mathews, R. W. Leukel, *Advan. Agron.* **5**, 1 (1953).
26. L. P. Reitz, *Econ. Bot.* **8**, 251 (1954); ——— and S. C. Salmon, "Hard Red Winter Wheat Improvement in the Plains," *U.S. Dep. Agr. Tech. Bull 1192* (1959); V. A. Johnson, S. L. Shafer, J. W. Schmidt, *Crop Sci.* **8**, 187 (1968); F. H. McNeal and E. J. Koch, "Thirty Years of Testing Winter Wheats, *Triticum aestivum* L. em Thell., in the Western Wheat Region," *U.S. Dep. Agr. Publ. ARS 34-97* (1968); D. E. Anderson, *Farm Res. (N. Dak.)* **24**, 21 (1967).
27. "Agricultural Statistics" (*U.S. Dep. Agr. Publ.*) for 1969 and earlier years.
28. J. Platt, *Science* **166**, 1115 (1969).
29. E. C. Stakman, R. Bradfield, P. C. Mangelsdorf, *Campaigns against Hunger* (Belknap, Cambridge, Mass., 1967).