ARTICLES

Technology for improvement and production of wheat in China

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ABSTRACT

Recent advances in wheat (Triticum aestivum L.) cultivation in the People's Republic of China have greatly increased production of this major food crop. Objectives of this report are to review some of the advances in wheat improvement and production in China and to discuss their implications for the future. Wheat is the second most important staple food in China, and the country is expected to rank first in world wheat production during 1984-1985. Noodles, steamed bread, and baked goods are important wheat products. The crop is grown in all provinces in the country; Henan Province in the northern winter wheat region leads the others in total production. Wheat is cropped intensively in most regions, usually in intercropping and multiple cropping systems with other species. Inputs of labor, fertilizer, and other requirements are high. Wheat breeding by conventional techniques, mutation, and anther culture has increased yield and pest and stress resistance of new cultivars. Recent spectacular advances in production stimulated by the rural responsibility system were possible because of availability of productive cultivars, fertilizers, and irrigation in most regions. Progress in wheat production has exploited much present technology. Future advances will require emphasis on grain quality, basic research, and extension of present practices to problem areas.

Additional index words: Crop breeding and research, International agriculture, Intensive crop management, Triticum aestivum L.

The struggle to feed citizens of the People's Republic of China depends heavily upon wheat (Triticum aestivum L.). Wheat is the most important crop after rice (Oryza sativa L.) in the world's most populous country, being the staple food for about one-third of the population. China is expected to rank first in world wheat production during 1984-1985 (Foreign Agriculture Service, 1984) and is first in total food grain production (China Reconstructs, 1984). Total food grain production for 1984 is estimated at 400 million t, or about 400 kg per capita, about one-fifth of which is wheat. Noodles, steamed bread, and baked goods are the major wheat products.

Table 1. Advances in wheat production in the People's Republic of China from 1949 to 1983.†

<table>
<thead>
<tr>
<th>Item</th>
<th>1949-1951</th>
<th>1978</th>
<th>1983</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat production (t)</td>
<td>15 200 000</td>
<td>53 800 000</td>
<td>81 400 000</td>
</tr>
<tr>
<td>Wheat area (ha)</td>
<td>22 400 000</td>
<td>29 200 000</td>
<td>28 000 000</td>
</tr>
<tr>
<td>Wheat yield (kg ha⁻¹)</td>
<td>650</td>
<td>1 850</td>
<td>2 900</td>
</tr>
<tr>
<td>Wheat: Total grain (%)</td>
<td>12.4</td>
<td>--</td>
<td>21.0</td>
</tr>
</tbody>
</table>

† Data for 1949-1951 from Johnson and Beemer (1977); for 1978 from Huang (1981); for 1983 from Beijing Review (1984); 1983 wheat area is estimate.

The history of wheat production in China dates to at least the Yin dynasty (1384-1112 B.C.) (Kuo, 1976). The modern era is much more recent, starting in 1949 and, in some respects, even later. Wheat production has increased rather spectacularly since 1949, both in real terms and as a proportion of total food grain production (Table 1).

Production of wheat in China has many implications for this important crop in the USA and other countries. It directly affects grain trade with China. Technology and germplasm developed during the long history of wheat cultivation in China are applicable to wheat improvement and production in other countries. The impressive success in increasing yields in China during recent years, in particular, contains many lessons for USA and international wheat scientists.

Delegations to China on plant studies in 1974 and wheat studies in 1976 were sponsored by the National Academy of Sciences (NAS). Reports by Wortman (1975) and Johnson and Beemer (1977) provide a comprehensive overview of wheat in the country. However, neither NAS study delegation visited the most important wheat province, Henan, which is the focus of this report. In addition, the demise of the Cultural Revolution and the introduction of the rural responsibility incentive system have altered many aspects of wheat production since the visits by the study delegations.

This report is based on published literature and a tour of wheat-producing regions of China in April 1984. The
tour covered regions where winter wheat, the more important type, is produced. Objectives of the report are to review the technology of wheat improvement and production in China, to explore reasons for the marked increases in wheat yields, and to discuss some implications for the future.

PRODUCTION RESOURCES

Wheat is produced in all the provinces of China from 18°N latitude to 50°N latitude and from below sea level to over 4000 m above sea level (Johnson and Beemer, 1977). The country is commonly divided into three major wheat regions encompassing 10 areas (Fig. 1). The northern winter wheat region, producing mostly hard white wheats, is most important; it includes the North China area around Beijing and the Huang-Huai Plain of Henan, Hebei, and Shandong Provinces. The southern winter wheat region of hard, semihard, or soft wheat production includes the Sichuan, Yangtze Valley, and Yunnan-Guizhou Plateau areas. Spring wheat, hard, semihard, or soft and red or white, is grown in the northeastern Mongolia Plateau, Xinjiang, and southern areas of China. Most of the wheat, 85% to 90%, is winter wheat. It is nearly all common wheat; little durum (T. turgidum L. var. durum) or triticale (X-Triticosecale Wittmack) is produced in the country. Henan, the leading wheat province, contains about 15% of the total wheat area and accounts for about 20% of the total wheat production.

Alluvial and loessial soils predominate in regions of greatest wheat production. Soils of lower productivity—sands, clays, etc.—are also common in most of the wheat regions. Nitrogen is the most limiting nutrient in these soils, followed by phosphorus and a few instances of micronutrient deficiencies. The fertilizer regime followed by wheat producers appeared to provide ample nutrients, and few deficiencies were noted.

The cropping season for winter wheat ranges from about 180 days for early ripening wheat in the Sichuan area to 280 days for late ripening wheat in northern China. The season for spring wheat ranges from about 90 days in northeastern China to 170 days in southern China, where it is usually planted during the fall.

Precipitation during the wheat season ranges from about 100 mm in Xinjiang to 700 mm in the Yangtze Valley (Nuttonson, 1947). In the Huang-Huai Plain, which includes Henan, it averages about 300 mm. Most of the precipitation in this region occurs during July, August, and September, i.e., after the wheat has been harvested. Average annual temperature ranges from about 0°C in the northeast to 24°C in the south.

TECHNOLOGY OF WHEAT PRODUCTION

Organization

The rural responsibility or household contract system started in 1978 soon after the end of the Cultural Revolution in 1976. Details of the system appear to vary widely. Land belonging to collectives is generally contracted to member households, and the quotas, taxes, and subsidies are specified. Households remit their quota of produce at a fixed price, and the balance is sold to the state or the local market at a higher price. The purchase and sale of wheat has been a monopoly of the state since 1953.
Wheat is intensively cropped in China, and its production is more akin to gardening than to field cropping as practiced in the West (Wortman, 1975). Labor requirements for wheat production, estimated as 375 man-days ha⁻¹ (Johnson and Beemer, 1977), are high.

All available land, including small areas, is utilized, but most wheat is grown in large fields. The households follow the collective plan, but decide how the wheat will be grown and the cropping system. Land preparation and planting are largely mechanized. Typically, equipment owned by the collective is contracted to a machine group, which performs the operations for a fee. Land preparation usually consists of plowing with a moldboard plow pulled by a large tractor, followed by harrowing with small tractor- or animal-pulled equipment. Wheat is usually planted with drills; in small fields and in inaccessible parts of large fields, however, hand planters or broadcasting are used. Planting practices vary among regions, but wheat is typically seeded in October at a rate of 100 kg ha⁻¹ in 15-cm rows in Henan.

Increasing private ownership of farm equipment is causing some changes in the above system of farming operations. Instead of contracting for the work, individual households or groups of several households do the operations with draft animals or small tractors pulling small plows, harrows, and 3-row planters. The proportions of wheat planted by the two systems is unclear, because private ownership of equipment is still limited. In Henan Province, for instance, 239,000 tractors are owned by individuals, the most in any province, and in the entire country, 2.12 million tractors are privately owned (Beijing Review, 1984). Most of these are small two-wheel tractors.

Irrigation is handled much the same as land preparation, with a collective irrigation group providing water to the fields for a fee. Irrigation in China is highly developed. Approximately 80% to 85% of the wheat area is irrigated, and the total irrigated crop area is exceeded only by India (Johnson and Beemer, 1977). The most common system for wheat is flood or furrow irrigation from canals using water from deep wells or reservoirs.

Harvesting of wheat is done manually in most regions except in the spring wheat region of northern China, where combines are used. Threshing is accomplished in a variety of ways, including large stationary threshers, small drum threshers, flail threshers, and trampling by animals or machines. Cylindrical threshing stones must have been used extensively in the past, judging from their profusion.

Intercropping and Multiple Cropping

Both intercropping and multiple cropping are practiced extensively in most major wheat regions. Intercropping is usually done by alternating three to nine rows of wheat with one to three rows of vegetables, rape (Brassica napus var. annua Koch), cotton (Gossypium hirsutum L.), or other crops. Multiple cropping involves planting of rice, cotton, soybean [Glycine max (L.) Merr.], sweet potato (Ipomoea batatas Lam.), corn (Zea mays L.), or millets (Panicum miliaceum (L.) and Setaria italica (L.) Beauv.) after the wheat is harvested. The goal appears to be two crops per unit area per year by the year 2000 (Wortman, 1975). Wheat followed by two crops of rice within 1 year is already used in southern China.

Fertilizer Use

The wheat crop in China is well fertilized, and signs of nutrient deficiencies are infrequent. Organic farming is still practiced extensively as it has been for centuries, but increasing emphasis is being placed on chemical fertilizers. Crop residue composts, organic matter (nightsoil, etc.), and chemical fertilizers seemed to contribute more or less equal shares. Crop residues are usually removed from fields immediately after harvest, mixed with soil, and then composted until the next season. The compost is spread on the soil, after which it is incorporated by plowing.

Chemical fertilizers are rapidly increasing in importance, and China is now the third largest producer of chemical fertilizers after the USA and the USSR. Average use of chemical fertilizers was estimated as 148.5 kg ha⁻¹ in 1983 (Beijing Review, 1984).

Foliar application of dilute KH₂PO₄ solution to wheat at about the boot growth stage is widely practiced (Johnson and Beemer, 1977). The treatment is said to increase leaf duration, kernel weight, and grain yield. The purpose of this practice is to counteract the hot, dry winds that frequently cause “green-dry” or early senescence of wheat. The physiological basis of the treatment is unclear; the luxuriant appearance of the wheat makes it unlikely that a nutrient deficiency is involved.

Other Agricultural Chemicals

Use of chemicals other than fertilizers on wheat appears to be strongly discouraged because of costs and concern about pollution. Only insecticides are manufactured in any quantity. Herbicides are rare because weeds are usually removed by hand and fed to livestock. Plant growth regulators are not considered necessary because breeding for lodging resistance accomplishes the same end.

TECHNOLOGY OF WHEAT IMPROVEMENT Organization

Wheat research is highly organized at the national, provincial (state), district (administrative area, or prefecture, consisting of several counties), and county levels. Institutes in the Chinese Academy of Agricultural Science, the provincial academies of agricultural science, and the provincial agricultural colleges conduct much of the new research and develop improved cultivars. Some district institutes of agricultural science also
conducted large wheat improvement programs, and district experimental farms and seed farms do mostly applied production and testing research and increase seed of new cultivars. County institutes of agricultural science and experiment farms test and demonstrate wheat cultivars and production practices for local conditions.

**Wheat Breeding**

Wheat improvement has evolved in stages since 1949. In Henan, local varieties and land races predominated until 1949-1953. During that period, the local types were evaluated, and farmers were encouraged to plant the best available. Many varieties were introduced from neighboring provinces and other countries, particularly Australia, Italy, and Mexico. Wheat breeding has been carried out since the 1950s, somewhat later than in many other countries. This delay was undoubtedly caused by the turmoil of wars before 1950 and the dominance of Michurin-Lysenko theories during the early years (Kuo, 1976). The Cultural Revolution disrupted many scientific activities, including plant breeding, during 1966 to 1976 (Fen, 1983).

Emphasis is on conventional breeding by the pedigree method. Most intense selection is at the F2 stage. Promising experimental lines at the F2 or F3 stages are tested in local performance tests for 3 or 4 years, in provincial or inter-provincial performance tests for 2 to 3 years, and in production and demonstration tests for 2 years. Candidates for release must pass approval of a provincial varietal examination committee. Even after this thorough testing, performance of new cultivars must sometimes be guaranteed before they will be accepted by many farmers.

Mutation breeding with gamma rays from 60Co, X-rays, and EMS (ethyl methanesulfonate) has been used with some success to develop new cultivars. These techniques are apparently used in conjunction with conventional breeding methods.

Anther culture is used extensively, but it has not been as successful with wheat as with rice. It is fitting that a wheat agronomist recently received the first Award for Promotion of Scientific and Technological Advances for developing the first winter wheat cultivar by anther culture (China Daily, 1984).

Hybrid development also has been less successful with wheat than with rice, and Chinese agronomists have encountered many of the same problems as breeders in other countries. These problems include poor fertility restoration, low seed germination, low tillering, and excessive height of hybrid wheats.

**Breeding Objectives**

High grain yield and the traits that are necessary to achieve it are predominate objectives. Improved wheats are characterized by high tillering capacity, large spikes, multiflorets, large kernels, and short stature. Early maturity is needed in most regions for avoidance of hot, dry winds and for early establishment of the succeeding crop. The most important diseases of wheat are stripe rust (*Puccinia striiformis*), leaf rust (*P. recondita* f. sp. *tritici*), stem rust (*P. graminis* f. sp. *tritici*), powdery mildew (*Erysiphe graminis* f. sp. *tritici*), and scab (*Fusarium* spp.). Relative severity of these diseases varies considerably among regions. Genetic resistance to most of them is available, and they receive much attention in breeding programs. Insects are usually less troublesome than diseases. In Henan, however, larva of two wheat midges, *Sitodiplosis mosellana* Gehin and *Contarinia tritici* Kirby, are important pests.

Environmental stresses are severe in most of the wheat-growing regions. Hot, dry winds, drought, and cold affect wheat in most regions. Salinity, excessive moisture, and preharvest sprouting are important in several regions. Resistance to these stresses also receives considerable attention in wheat improvement programs. Grain functional quality (milling and baking) and nutritional quality receive little attention because of the emphasis on yield. There is a marked preference for white wheats over red wheats, however, except in regions where preharvest sprouting occurs. Chinese wheat scientists are aware of the importance of wheat quality and will likely increase work in this area as yields are stabilized at higher levels.

**Germplasm Resources**

Wheat breeding nurseries in China frequently contain a wider array of germplasm than is present in most USA breeding programs. Extensive cultivation of improved cultivars, however, has caused many land races of wheat to disappear (Wortman, 1975). This is unfortunate, because China’s wheat germplasm has contributed greatly to improvement of wheat all over the world. The semidwarf genetic trait in the “miracle wheats” that started the Green Revolution, for instance, may have originated in China (Kihara, 1983).

The Germplasm Institute of the Academy of Agricultural Science in Beijing has overall responsibility for collecting and maintaining germplasm of wheat and other species.

**Production Research**

Wheat production research is conducted by many agencies that engage in wheat improvement. In addition, production research in specific areas such as fertilizer use is done by fertilizer institutes and other organizations. This research frequently involves large tracts of land instead of small plots and little use of statistical analysis of data. Some of it seemed highly innovative. One commune in Henan, for instance, covered wheat with plastic to accelerate early growth, a technique used extensively with vegetables. The commune’s objectives were to increase yields by avoiding hot, dry winds on wheat and to advance planting of rice after wheat.
Training of Scientists

The needs for advanced specialized training of scientists, basic research, and increased communication have been noted (Wortman, 1975; Johnson and Beemer, 1977). Deficiencies in these areas were difficult to assess, however. Senior wheat scientists in China are obviously highly competent and have enjoyed great success in improving wheat and its production. These scientists, like successful wheat scientists everywhere, tend to belong to the generalists, not specialists. The myriad of attributes that improved cultivars must have—high yield, pest resistance, stress resistance, and good quality—requires broad knowledge. Questions asked by young scientists during discussions and seminars also indicated a good knowledge of wheat science and its advances in other countries. The combination of academic training, on-the-job experience, and literature reading seems reasonably effective.

The status of the sciences that are basic to wheat production—genetics, biochemistry, physiology, entomology, and plant pathology—is mixed. The widespread use of rice hybrids, successful application of tissue culture, and good understanding of yield-limiting factors indicate considerable capabilities in these areas. Yet, these basic fields, which are neglected seriously compared with wheat breeding, are those from which future advances must come. It is not unlikely, then, that greater attention must be given to training, research, and equipment for the basic sciences.

Equipment

Laboratories for research in wheat science and allied fields such as soils are not well equipped by Western standards. In most cases, however, even the equipment that is available is underutilized. This situation is undoubtedly due to the emphasis on yield improvement. If increased emphasis is given to basic sciences, laboratories must be better equipped. Sophisticated items such as atomic absorption spectrophotometers, electron microscopes, and lasers exhibited at the Canton (Guangzhou) International Trade Fair suggested there is indigenous production of laboratory equipment.

OTHER FACTORS

Field Factors

Many primary problems such as lack of productive cultivars, fertilizer availability, and water supply have been mostly overcome. Substantial advances from these inputs will be increasingly difficult in the future. Wide-spread irrigation, for instance, has increased and stabilized wheat yields at a high level, and this practice cannot be exploited for future gains in most areas. The opposite, in fact, may occur: soil salinity and lowering of groundwater reserves in areas of heavy irrigation may cause yields to decline.

Wind and water erosion are historical problems. These are being countered by extensive reforestation, construction of windbreaks, reservoirs and dikes, and dredging. A "Great Green Wall" 7000 km long is being constructed across the north of China to slow erosion. In Henan, as in other areas, roads are lined by several rows of poplars (Populus spp.) and wheat fields are crossed by long rows of paulownia (Paulownia tomentosa Thumb.). These trees break the wind, raise the humidity, and provide fuel. Windbreaks should provide substantial benefits in the years ahead, but they may have some adverse effect on yields of wheat immediately adjacent to them.

Siltation of rivers and consequent flooding have been two of the great problems of the past. Flooding has been largely controlled by dikes, but siltation continues. The Yellow (Huanghe) River, which flows through Henan, carries 1.6 billion t of silt each year, the most of any river in the world (China Reconstructs, 1984). This has raised the riverbed 10 to 15 m above the level of the surrounding land in places. Reforestation, dikes, dredging, and widening of the river will help overcome the problem, but all remedies are expensive.

Arable land per capita, slightly over 0.1 ha, has diminished about 50% since 1949 because of the population growth. Reclamation probably will only offset the use of other land for nonagricultural purposes. Industrialization will free some of the 80% of the population from direct dependence on the land, but not from the need for food.

Seed Production

Distribution of seed of improved wheat cultivars seemed quite effective in Henan Province. Some mixing of plant types of wheat in the field was evident in other areas, however, and interest was expressed in the seed certification procedures in the USA. Most seed appeared to be produced on district farms, which would ensure control of the quality and purity of seeds. Production of seed by contract under the responsibility system might necessitate different isolation, inspection, and handling procedures.

Grain Storage and Transportation

Opportunities to observe grain handling were limited. Storage problems noted by other study tours (Johnson and Beemer, 1977) have been aggravated by 4 successive years of record grain production (Beijing Review, 1984). This is redirecting some use of grain from food for people to feed for livestock. It seems likely that this trend will continue if grain harvests remain high and that the diet of the population will be improved as a result.

Local grain transportation problems have been alleviated as grain-deficit areas become self-sufficient. On the whole, however, the increased volume of grain probably has affected grain transportation as it has storage.
IMPLICATIONS FOR THE FUTURE

Wheat production in China is a success story by nearly any measure. Achieving the present status has required a number of essential components, all of which seem to be present. Productive, well-adapted cultivars have been developed by wheat scientists. Fertilizer, water for irrigation, and other resources are present in seemingly ample quantities in most areas. The knowledge of production practices for high yields and the ability to apply them were evident in the countryside. Little information was obtained on the agricultural extension (propagation) system, but it appeared to be highly effective. The responsibility incentive system has undoubtedly stimulated wheat production, but it could do so only because the other essential components were present.

Technology for wheat production in China is less advanced in one sense, but is highly advanced in another sense. The high labor input and simple equipment used in most major wheat areas, while appropriate for present needs, are typical of a developing country. The scientific skill and production management techniques applied to wheat, on the other hand, are highly developed. Wheat scientists and growers in most areas of North America are only beginning to apply some of the intensive cereal management technology used commonly in China. Thus, there is much to learn from each other.

Additional near-term gains will be realized by increasing the application of present technology to areas where productivity is already high. The rate of gain must slow, however, as yields approach their potential. Some gains also will be obtained by applying present technology to areas where productivity is low because of one or more problems. The diminishing magnitude of these areas will eventually limit gains. These near-term gains will come from many sources: productive and stress-tolerant cultivars, rapid distribution of improved seeds, alleviation of soil problems such as alkalinity and salinity, and greater use of irrigation and fertilizer.

Intermediate-term changes probably will increase efficiency of wheat production more than wheat yields. Soil testing and calibration are necessary to remedy deficiencies where nutrients are needed. In many other areas, they are needed to prevent over-fertilization, which causes inefficient use of nutrients and pollution. Intercropping and multiple cropping of wheat are already widespread; expansion of these systems may increase total land productivity, but not wheat yields.

Wheat functional (milling and baking) and nutritional qualities will receive more emphasis as the food needs of the people are met. The people probably will demand it as their diets become more diversified. It is not inconceivable, too, that modest amounts of wheat will be available for export in the future. This grain must meet international grade standards.

Mechanization of wheat production will continue as farmers’ incomes increase and the countryside becomes more industrialized. This trend, already seen with small tractors, will occur with tillage and planting equipment, threshers, and other implements. Most of this equipment will be small, such as that used in much of Japan. In the northern spring wheat areas, where wheat production is already more mechanized, larger equipment is used.

Long-term future gains in wheat productivity will be increasingly difficult. Past gains have exploited much of the present knowledge of wheat science. Future gains will require accumulation of new knowledge from basic research. The need here seems especially critical for China, because intensive cultivation and heavy input of resources into wheat make it increasingly difficult to know the source of long-term gains. Balanced programs of basic research in wheat genetics, physiology, pest management, biotechnology, and other areas can provide knowledge for future advances. This will require an added emphasis, not a shift from present emphasis on wheat improvement and production.

REFERENCES