GROWTH AND PRODUCTION OF WHEAT

Vinod Tiwari and **Jag Shoran**
Crop Improvement Division, Directorate of Wheat Research (ICAR), Karnal, India.

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Contents

Summary

Wheat is the most important cereal crop, and a staple food of the vast majority of the human population. It is a cool-season crop, widely cultivated under varied agro-ecologic conditions and cropping systems throughout the world. On a global basis, wheat provides more nourishment than any other food crop. The popularity of wheat lies in the wide variety of food products prepared from it, which partially explains its expansion even to non-traditional wheat cultivated areas.

The incorporation of reduced height genes in wheat created new varieties that changed the extent of wheat cultivation all over the world. The semi-dwarf and high-yielding cultivars ushered in the ‘green revolution’ by bringing about a phenomenal jump in yield and production. Efforts to raise the yield level of wheat and finding ways to tackle the impeding factors affecting yield have attracted attention from all quarters. Plant breeding efforts for enhancing yield make use of the wide variability available in germplasm resources like elite germplasm, winter wheats, synthetics and wild species to recombine them in developing new high yielding cultivars. Biotechnology has come to the aid of plant breeding as a novel method to accomplish genetic manipulations. Hybrid wheat cultivars hold some promise for increasing yield and deserve further studies and refinements in application**.**

Nutrient availability directly determines wheat yield, as do water supply and plant protection measures. Crop management techniques have been crafted taking into account the nutrient and water use efficiencies of new cultivars for obtaining high yields.

Raising the production of wheat is a challenge for the future. Abiotic factors appear to be more prominent than biotic ones for limiting yield in the existing scenario of climate changes. Conventional techniques and biotechnology are believed to increase wheat production as a means to feed the growing world population.

1. Introduction

Cereals are generally regarded as the “staff of life”. Wheat, rice and maize are the major cereals constituting the staple diet of the majority of the world population. Cereal crops serve as the major source of calories, carbohydrates, and some proteins for the human population in developing countries.

During the year 2007, among the cereals, maize recorded the maximum production (786.79 million tons) followed by rice (651.74mt), wheat (607.05mt) and barley (136.21mt). However, the majority of maize produced is utilized as feed and for biofuel production. Similarly, barley is being utilized as feed and for malt extraction. Wheat is, however, the most important cereal crop as well as the most diversified in relation to food preparations. It constitutes the staple diet of a vast chunk of the human population, providing over 20% of the required calories. It is consumed daily, in some form or other by almost every person.

Wheat has incorporated the whole gamut of crop improvement technology, and it has become the standard for being replicated in other crops. A rich store of knowledge is available on the changes that have occurred in the architecture of the wheat plant. This calls for providing a clear understanding of the different stages of development and growth in wheat.

The growth and trends in wheat production are discussed below, so as to understand the crop and the factors that render it valuable for both consumption and trade.

2. Origin and Distribution

Evidences from archeological excavations reveal that the domestication of wheat took place over a very long period, stretching from 12 000 BC to 6 500 BC. Wheat cultivation is reported about 6 000 years ago in the Mesopotamian Fertile Crescent, and from there it apparently spread to the Middle East, North Africa, Asia and ultimately Europe (Harlan, 1981). Wheat spread to the Americas and Southern Africa around 1500 AD, and it was introduced into Australia in 1790. Today, wheat is the most widely and diversely grown food crop in the world. It is grown under varied agro-ecologic conditions and at different altitudes, from sea level to 4500m, which reflects its cultivability and adaptability.

A quantum jump in wheat production has been recorded from the 1970s onwards (Table 1). This phenomenal growth in production was largely due to the introduction of semi-dwarf cultivars, developed by Nobel Laureate Norman E. Borlaug, during the 1960s and their spread thereafter, along with improved irrigation and management techniques. From 1961 to 2007, the total area under wheat cultivation was around 210 to 220 million hectares, except for a nominal increase observed during the 1970s and the 1980s (Table 2).

Continent/ Country	**Production (million tons)**				
	1961-1970	1971-1980	1981-1990	1991-2000	2001-2007
World	278.28	388.35	509.25	571.23	598.33
Africa	6.95	9.03	11.18	15.79	20.62
Asia	60.99	108.52	175.98	243.39	260.86
Europe	136.82	174.51	195.48	182.83	196.83
North America	52.06	70.10	90.04	89.96	76.51
South America	9.68	11.64	16.68	17.49	21.42
Australia-New Zealand	9.77	12.0	15.63	18.18	19.08
China	23.34	45.32	83.35	106.25	96.34
India	13.30	27.78	44.76	63.91	70.46
United States of America	36.02	52.44	64.68	63.10	54.21
USSR (up to 1991)	72.57	88.67	80.01	71.99	-
Russian Federation	-	-	-	35.95	45.60
France	13.01	18.30	28.37	34.15	35.16
Pakistan	4.93	8.31	12.51	16.98	20.33
Canada	16.04	17.65	25.35	26.86	22.30

Germany	6.81	10.29	13.70	18.24	22.26
Turkey	9.30	14.60	18.00	19.35	19.67
Australia	9.46	11.68	15.35	17.91	18.77
Ukraine	-	-	-	15.79	15.64
Argentina	6.89	7.64	10.65	12.61	14.20
United Kingdom	3.60	5.75	12.25	14.71	14.33
Egypt	1.44	1.84	2.46	5.47	7.24

Table 1. Decadal growth in production of wheat from 1961 to 2007.
(Source: Faostat.fao.org).

Continent/ Country	**Area (million ha)**				
	1961-1970	1971-1980	1981-1990	1991-2000	2001-2007
World	213.75	225.41	229.34	220.22	214.96
Africa	8.16	8.86	8.18	8.73	9.51
Asia	63.50	75.49	82.19	99.51	97.21
Europe	95.08	87.45	77.67	57.22	56.68
North America	30.67	34.57	39.81	35.97	29.48
South America	7.61	8.97	9.66	8.07	9.09
Australia-New Zealand	7.89	9.30	10.79	9.88	12.37
USSR (up to 1991)	66.78	61.09	50.79	45.87	-
India	14.0	20.11	23.30	25.55	26.39
Russian Federation	-	-	-	22.24	23.20
China	24.79	27.71	29.18	29.45	23.03
United States of America	19.97	24.75	26.41	24.18	19.96
Australia	7.79	9.21	10.73	9.83	12.33
Canada	10.70	9.82	13.40	11.78	9.52
Turkey	8.16	9.03	9.25	9.48	9.06
Pakistan	5.38	6.21	7.42	8.18	8.25
Argentina	5.03	4.86	5.73	5.50	5.82
Ukraine	-	-	-	5.69	5.74
France	4.11	4.11	4.90	4.98	5.14
Germany	1.91	2.31	2.39	2.62	3.04
United Kingdom	0.90	1.20	1.87	1.95	1.85
Egypt	0.55	0.56	0.59	0.98	1.12

Table 2. Decadal growth in area under wheat from 1961 to 2007.
(Source: Faostat.fao.org).

The semi-dwarf cultivars were responsible for growth in yield by giving higher productivity per unit area (Table 3). A significant growth in yield has been recorded over the years by China, India, the United Kingdom, Germany, France, Egypt, Argentina and Pakistan, while it has not been very prominent in the case of USSR, the

United States of America, Australia and Canada. There was a rapid and phenomenal growth in production from the 1960s to the 1980s, and from the 1990s onward the growth has been at a slower rate (Table 1).

A review of the production data from 1961 to 2007 (Table 1) shows that the countries in Asia and Europe produce the bulk of wheat grown every year. The high production in European countries is mostly due to winter wheat which gives higher yields than spring wheat (Table 3).

Continent/ Country	**Yield (tons/ha)**				
	1961-1970	1971-1980	1981-1990	1991-2000	2001-2007
World	1.30	1.72	2.22	2.59	2.78
Africa	0.85	1.02	1.37	1.80	2.16
Asia	0.96	1.43	2.14	2.45	2.68
Europe	1.44	1.99	2.53	3.21	3.47
North America	1.71	2.03	2.26	2.51	2.59
South America	1.27	1.29	1.73	2.16	2.36
Australia- New Zealand	1.24	1.28	1.45	1.80	1.53
China	0.94	1.62	2.85	3.61	4.19
India	0.94	1.37	1.92	2.50	2.67
United States of America	1.81	2.13	2.45	2.61	2.71
USSR (up to 1991)	1.09	1.45	1.59	1.57	-
Russian Federation	-	-	-	1.60	1.96
United Kingdom	3.99	4.74	6.53	7.56	7.71
Germany	3.54	4.44	5.71	6.95	7.32
France	3.17	4.44	5.78	6.84	6.84
Egypt	2.60	3.28	4.12	5.57	6.46
Ukraine	-	-	-	2.77	2.61
Pakistan	0.90	1.33	1.68	2.07	2.46
Argentina	1.37	1.56	1.85	2.28	2.45
Canada	1.51	1.79	1.88	2.28	2.34
Turkey	1.14	1.61	1.94	2.04	2.17
Australia	1.21	1.26	1.44	1.80	1.51

Table 3. Decadal growth in wheat yield per hectare from 1961 to 2007.
(Source: Faostat.fao.org).

During the period 1961-2007, India, Australia and Pakistan recorded an increasing trend in area under wheat, while in most other countries the cultivated area increased only slightly, or even decreased. An increase in acreage also reflects changes in comparative advantage and profitability for farmers. The USA, China and Canada recorded a decline in area under wheat cultivation during the period 2000-2007.

China and India are now the major producers of wheat in the world (Table 1). The development of high yielding cultivars, showing better adaptation to cultural conditions, responsiveness to higher doses of fertilizers, disease resistance together with better quality features meeting the requirements of producers, processors and consumers, have helped in the overall growth of wheat production.

3. Botany

Morphologically, the wheat plant is rhizomatous (showing relationship with the grass family) with the shoot bearing several leafy culms (tillers). The number of culms per plant varies with the seeding depth, density of stand, genetic features and environmental factors. The culms are cylindrical, generally hollow with solid nodes; the diameter reduces gradually towards the top internode (peduncle) which bears the spike. The plant length is attributed to variation in length of the internodes and it is mostly genetically determined. Each culm has five to seven elongated nodes, while the basal nodes are closely packed together. A leaf develops at each node; the basal leaves die early, and at maturity about four or five of the upper nodes of the culm bear leaves. The leaf consists of a tubular sheath and a blade. The leaf sheath encases the culm and extends from the node to which it is attached to the next higher node. The leaf-blade is long, narrow and flat with parallel veins.

The inflorescence, commonly called ‘ear’ or ‘head’, is a spike having florets (spikelets) arranged on opposite sides of the flat rachis. Each spikelet in turn is a condensed reproductive shoot consisting of two sterile bracts (glumes) that enclose 3-5 florets. The florets consist of two bract-like structures, the lemma and the palea, which encase the reproductive organs. The lemma extends to form the awns that may be short, long or absent (awnless) (Fig. 1). The spikes in durum wheat are dense having long awns (Fig. 2). There are three stamens and the pistil bears two styles with a feathery stigma. Pollination is predominantly by self-pollination.

Figure 1. Spikes of *T. aestivum* : awnless (a) and awned (b) types; awnlessness is a dominant trait.

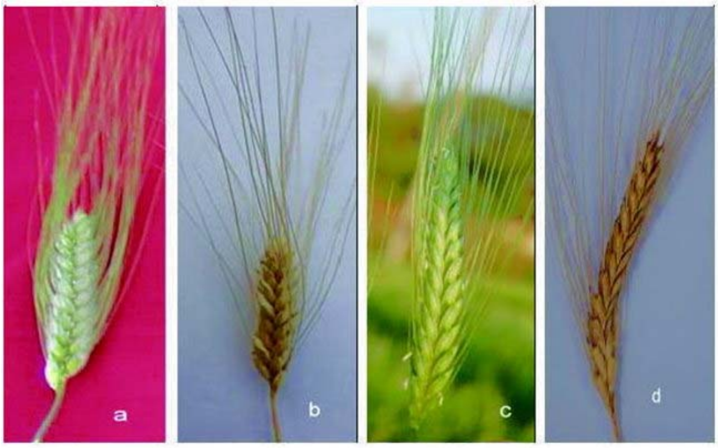

Figure 2. Spikes of *T. durum* (a, green; b, mature) and *T. dicoccum* (c, green; d, mature)

The rachis of cultivated einkorn (*T. monococcum*), emmer (*T. dicoccum*) and spelt wheat (*T. spelta*) is less fragile and remains intact until threshed. Dehulling is needed in these species before the grains can be processed for food preparation. Bread wheat (*T. aestivum*) and durum wheat (*T. durum*) are free-threshing (genetically governed by a dominant gene *Q* that also makes the rachis tough).

The wheat grain, botanically a fruit (caryopsis), is ovoid in shape with the embryo at the base of the dorsal side, while a crease runs from end to end on the ventral side. A tuft of hair (brush) is present at the apex of the grain. The grains on maturity are variously classified on the basis of color into white, amber and red, the texture being hard or soft. The grains of *T. durum* are the hardest of all species of wheat. In the USA and Europe, classes of wheat are recognized on the basis of grain color, texture and growth habit, such as, hard red spring, hard red winter, soft red winter, hard white and soft white.

The coleoptile, an embryonic structure that encloses the first leaf, is very important in facilitating germination and emergence of the seedling after sowing of the grain. The length of the coleoptile, being genetically controlled, is important in the case of semi-dwarf cultivars for obtaining a good crop stand in sowings that may be done below 30mm depth.

Wheat is categorized into spring, winter and facultative types. The growth habit reflects the need to survive in different climates and affects productivity by timing crop stages to more favorable conditions. Spring wheat has a continuous growth cycle with no required inactive period, but it will not survive if exposed to temperatures below -10°C for more than 12 hours. The plant is semi-erect or erect and is more or less insensitive to photoperiod.

Winter wheat needs exposure to cold (5°C – 10°C) for three to six weeks after germination in order to form flowering stems and to produce grain. Vernalization, a genetically governed temperature response mechanism, ensures that winter wheat does not enter its reproductive growth stages too early. It has a prostrate habit, appears grassy and weed-like during early growth stages and starts to grow before winter sets in and remains inactive as long as low temperatures persist. As temperatures rise during spring, the plant again resumes its growth.

Facultative type wheat tolerates cold more than spring wheat but less than winter wheat, and does not require extended exposure to cold temperatures to reproduce.

4. Taxonomy and Cytogenetics

4.1. Taxonomy

Wheat (genus *Triticum*) belongs to the grass family of Poaceae, tribe Triticeae. Many changes in the taxonomic description of *Triticum* and its related genera have occurred since the first nomenclature by Linnaeus in 1753. There is now general agreement that the genus *Aegilops*, which is closely related to wheat, gets merged with *Triticum* as done by Bowden (1959). The genus *Triticum* comprises species that are diploid, tetraploid and hexaploid. Thus, polyploidy has played an important role in the evolution of wheat.

The diploid species (commonly called 'einkorn wheats') like *T. monococcum* and *T. urartu* are generally found in the wild and their grains are hulled. *T. monococcum* is also cultivated in some areas in small quantities for consumption. The tetraploid species include both hulled and hulless or free-threshing forms. The wild species *T. turgidum* subsp. *dicoccoides* and domesticated *T. turgidum* subsp. *dicoccum* (now designated as *T. dicoccum* or *T. dicoccon*) are hulled and commonly called 'emmer wheats', while *T. turgidum* subsp. *durum* (now designated as *T. durum*) is hulless and commonly called 'macaroni wheat'. The hulled hexaploid wheat species are *T. aestivum* subsp. *spelta* and *T. aestivum* subsp. *macha*. *Triticum aestivum* subsp. *aestivum* (now referred as *T. aestivum* or commonly as 'bread wheat'), *T. aestivum* subsp. *compactum* (*T. compactum* or 'club wheat') and *T. aestivum* subsp. *sphaerococcum* (*T. sphaerococcum* or 'Indian dwarf' or 'shot wheat') are free-threshing.

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Bibliography

Blum, A. (1988). *Plant Breeding for Stress Environments*. CRC Press, Boca Raton, Florida, USA. [Book detailing the process of developing cultivars resistant to abiotic stresses].

Borlaug, N. E. (1965). *Wheat, Rust and People*. Phytopathology, 55:1088-1098. [An article detailing the need to keep rusts under control].

Bowden, W. M. (1959). *The Taxonomy and Nomenclature of the Wheats, Barleys and Ryes and their Wild Relatives*. Canadian Journal of Botany, 37: 657-84. [A review paper on the systematics of wheat, barley and rye].

Curtis, B. C., Rajaram, S. and Gómez Macpherson, H., eds. (2002). *Bread Wheat: Improvement and Production*. FAO, Rome. [A compendium detailing various aspects of wheat improvement and production].

FAO. (2008). FAO Land and Plant Nutrition Management Service, FAO, Rome. http://www.fao.org/ag/agl/agll/spush [Global network on integrated soil management for sustainable use of salt-affected soils].

Flor, H. H. (1942). *Inheritance of Pathogenicity in a Cross Between Physiologic Races 22 and 24 of Melampsora lini*. Phytopathology, 32: 5. [First paper on gene-for-gene concept for disease resistance mechanism].

Flor, H. H. (1971). *Current Status of the Gene-for-Gene Concept*. Annual Review of Phytopathology, 9: 275-296. [Status paper on gene-for-gene concept].

Harlan, J. R. (1981). *The Early History of Wheat: Earliest Trace to the Sack of Rome*. *In*: L.T. Evans and W.J. Peacock, eds.: *Wheat Science – Today and Tomorrow?* Cambridge University Press, Cambridge, UK. pp 1-19. [A review paper on the origin of wheat].

Heyne, E. G., ed. (1987) *Wheat and Wheat Improvement*, 2nd edition. American Society of Agronomy, Inc., Crop Science Society of America, Inc., Soil Science Society of America, Inc. Publishers, Madison, Wisconsin, USA. [A monograph on wheat].

Horsfall, J. G. and Cowling, E. W. (1978). *Some Epidemics Man has Known*. *In:* J.G. Horsfall and E.W. Cowling, eds.: *Plant Diseases: An Advanced Treatise*. Vol. II, p.17-32, Academic Press, New York. [A book dealing with various aspects of disease resistance].

Lupton, F. G. H. (ed.) (1987) *Wheat Breeding: Its Scientific Basis*. Chapman and Hall Ltd, London, New York [A monograph on wheat].

Osborne, T. B. (1907). *The Proteins of the Wheat Kernel*. Carnegie Inst., Washington, Publ. 84. Judd and Detweiler, Washington, USA. [A treatise on wheat proteins].

Osborne, T. B. (1924). *The Vegetable Proteins*. Longmans, Green & Co., London [A treatise on proteins].

Shellenberger, J. A. (1982). *Processing and Utilization: Wheat*. *In*: J.A. Wolff, ed.: *Handbook of Processing and Utilization in Agriculture*. Vol. II, part I, pp. 91-121, CRC Press Inc., Boca Raton, FL. [A handbook on wheat processing and utilization].

Wiese, M. V. **(**1987). *Compendium of Wheat Diseases* (2nd ed.), APS Press. St Paul, Minnesota, USA. [A compendium of wheat diseases].

Biographical Sketches

Vinod Tiwari is engaged in wheat research for the past 31 years. After obtaining his PhD degree in Genetics and Plant Breeding from the Banaras Hindu University, Varanasi (India) in 1981, he worked as a teacher and researcher for 18 years in two Agricultural Universities and became professor in 1998. His contribution relates to developing varieties, supervising thesis work of students, resource person for human resource development, and a subject expert on the research degree committees of some universities. His forte is breeding for stress resistance and devising breeding methodologies for crop improvement. Dr Tiwari joined ICAR service as Principal Scientist in 2000. At the Directorate of Wheat Research, Karnal, he is associated with the program coordination activities and developing breeding material incorporating variability from winter wheat into spring wheat.

Jag Shoran obtained a MSc. in Genetics from PG School, IARI, New Delhi and a PhD in Plant Breeding from GBPUA&T, Pantnagar, India. He joined the Agricultural Research Service of ICAR in 1976 and has been engaged in wheat research since then. He has developed many wheat varieties and registered genetic stocks for disease resistance. He joined the Directorate of Wheat Research, Karnal in 1994 as leader of the durum breeding program and became Principal Investigator of Crop Improvement in 1996 to coordinate crop improvement work at the national level. Dr Jag Shoran was also acting Project Director during 2003-2005 and 2008-09. He has been leader of many externally funded projects. He has evaluated dissertations and delivered lectures in seminars and training courses. He has been abroad to attend conferences and has received numerous awards for his excellent contributions.