GROWTH AND PRODUCTION OF BARLEY

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

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Contents

1. Introduction
2. Origin and Distribution
3. Botany
4. Chemical Composition
5. Uses
6. Taxonomy
7. Genetics and Cytogenetics
7.1. Genetics and Genomics
7.2. Cytogenetics
8. Crop Husbandry and Improvement
8.1. Agronomy
8.2. Yield Enhancement Methods
8.2.1. Germplasm Lines, Pre-Breeding and Wide Hybridization
8.2.2. Conventional Breeding
8.2.3. Novel Methods of Breeding
8.3. Breeding for Malt
8.4. Quality Considerations for Improvement
9. Growth and Biotic Stress Conditions
9.1. Fungal Diseases
9.2. Viral Diseases
9.3. Nematodes
9.4. Insect Pests
10. Growth and Abiotic Stress Conditions
10.1. Drought, Pre-Harvest Sprouting and Water Logging
10.2. Extreme Temperatures
10.3. Salinity and Alkalinity
11. Trade
12. Conclusions
Glossary
Bibliography
Biographical Sketch

Summary

Barley has been under cultivation since antiquity. It is the most widely adapted crop among the cereals, and it suitably withstands the vagaries of nature, like scarcity of water and extremes of temperature stress. Barley was the staple food for people in many countries till wheat supplanted it. A change in food preference by people in favor of

wheat has resulted in a drop in demand for barley, thereby causing a great reduction in the area under barley cultivation during the last few decades.

Barley is mostly used for feed and fodder besides being a significant crop industrially, particularly in the manufacture of beer. Quality wise barley is multifaceted. It is a rich source of B vitamins and essential minerals. It is also rich in fiber content, particularly beta-glucan, which has many health benefits, like keeping the blood sugar levels low for benefit of diabetics and checking cholesterol deposition for safety against heart ailments. Although beta-glucan content may be high for food, it should be low for beer production.

The basic morphological, biochemical and genetical features of barley have been described. The enhancement of yield, a major requirement for increasing barley production, can be brought about by incorporating new techniques like marker assisted selection and doubled haploids along with the conventional approaches for crop improvement. The major diseases afflicting barley along with their control measures have been detailed in the biotic stresses that affect growth of barley. Similarly, the important abiotic tolerance features of barley have been enumerated for better utilization in increasing production. The availability of barley via growth in production and trade opportunities has been discussed.

1. Introduction

Barley (*Hordeum vulgare*) is one of the cereals which tolerate rather well abiotic stress conditions. Growers driven by the market demands tend to cultivate wheat even in areas which are more suited for barley; such areas can, however, easily be brought again under barley. **A**lthough the area under barley and wheat can be interchanged, on an overall basis, the area under barley cultivation is governed by a wide range of other factors like demand from consumers or market price.

Barley was the staple food of people in many countries for ages, but it drew away from favor due to changes in food preferences. Barley is now again returning to favor as it is considered the best food for health by nutritionists.

It also possesses many nutritional benefits. Its consumption leads to lowering of low density lipoprotein (LDL) cholesterol (hypo-cholesterolemic effect) that reduces the risk of heart diseases and regulates blood sugar level in diabetics. Barley is a rich source of fibers, which makes it a comfortable diet crop for the heart patients. Barley is also an important industrial crop and is increasingly used in the brewing industry.

The increasing awareness about health-related benefits and industrial uses of barley may lead to a rise in its production, and this has been supported by the availability of a range of suitable cultivars to growers. Concerted efforts in barley breeding have resulted in enhanced yield and quality to meet the needs of consumers and industry. Knowledge about a better understanding of the barley genome, breeding methods and cultivation technologies is also of vital importance. These trends and the factors that make barley valuable for consumption and trade are discussed below.

2. Origin and Distribution

Barley (*Hordeum vulgare*) was one of the earliest crops to be domesticated and it has been under cultivation since the beginning of civilization. Barley played an important role in ancient Greek and Roman cultures as a staple bread-making grain as well as an important food for athletes. Gladiators were known as *Hordearii*, meaning 'eaters of barley'. The use of barley grains in social and religious ceremonies by Hindus, Greeks and Romans illustrates its antiquity. Carbonized grains discovered from archeological excavations at various sites in the Near- and Middle-East prove that barley was cultivated around 7000 to 5000 BC (Harlan, 1976), and that the crop was domesticated about 8 000 BC (Zohary and Hopf, 1993).

During the sixth and fifth millennium BC, barley spread from its center of diversity in the Near- and Middle-East to eastern parts of the Mediterranean basin, highlands of Ethiopia and the Indian subcontinent, and the Caucasus and Trans-Caucasus regions. Barley reached China during the second half of the second millennium BC from where it spread further to the Korean peninsula and Japan. The six-rowed types of barley (see below, Botany) reached Central and Northern Europe during the fourth and third millenniums BC, while two-rowed ear types are believed to have been introduced with seeds brought along by the crusaders from the Near-East only during the twelfth and thirteenth centuries. Barley remained the main cereal food crop of northern Europe until the 16th century when it was gradually supplanted, mainly due to culinary preference for wheat which showed a better processing ability into numerous types of food products. Barley was first introduced into North America probably by Columbus in 1492, and later by immigrants and settlers from Europe.

There is no consensus on the area in which domesticated barley was grown historically. The crop is believed to have a multi-centric origin and it could have been domesticated along a broad area from Morocco to Tibet. However, the evidences from archaeology, genetics and distribution patterns of wild and cultivated barley species available in the Near-East (the Fertile Crescent) point towards a monocentric origin and domestication of barley in this particular area.

Harlan and Zohary (1966) were of the view that "domestication may not have taken place where wild cereals were most abundant". Thus, cereals like wheat and barley originated in areas adjacent to, rather than in, the regions of greatest abundance of wild cereals. This view was endorsed by the studies of Badr *et al*. (2000) who, through molecular analysis, located the probable area of domestication in Israel and Jordan. Similarly, Jones *et al.* (2008), guided by the principle that photoperiod (day length or duration of daily exposure to light) response plays a role in allowing crops to be grown in new environments, based their observations on molecular studies of the photoperiod regulating gene in barley, *Ppd-H1*. They concluded that another area of domestication was situated in Iran, east of the Fertile Crescent. These areas also contributed to the diversity of barley cultivars in Europe besides the regions in Central Asia and the Far East.

Barley is the most widely adapted crop in the world. Very few other crops show such wide altitudinal adaptation as does barley – from sea level to 4500m altitude (in both the

Andes and the Himalayas). A moderately cool and dry climate is most suited to barley. Although barley is able to withstand heat in a dry climate or high humidity in a cool climate, it performs poorly in a hot and humid climate.

Barley is regarded as a drought-tolerant crop which accounts for its popularity in areas receiving scanty rainfall. It is commonly grown in the semi-arid regions of North Africa, the Near- and Middle-East, South Asia, the Russian Federation, Eastern Asia, Europe, Australia and the Andean countries of South America. Spring barley is cultivated in larger areas than winter barley because it is less risky. Winter barley is prone to damage from winter kill which affects the harvested yield. Furthermore, spring barley is preferred as a rotation crop with winter wheat as its short duration helps in fitting in the crop rotation very well. The production of barley between the decades 1970 to 2000 (Table 1) fluctuated around 150 million tons with a little increase during the 1980s. Production has further decreased to around 140 million tons during 2000-2007. European countries produce the bulk of barley. The USSR, now the Russian Federation, has produced the highest quantity of barley among all nations over the last fifty years (Table 1).

Continent/ Country	**Barley Production (million tons)**				
	1961-1970	**1971-1980**	**1981-1990**	**1991-2000**	**2001-2007**
World	99.38	150.51	167.03	151.65	141.56
Africa	3.27	3.97	4.80	4.48	4.99
Asia	16.37	15.37	17.95	24.23	21.89
Europe	62.65	107.29	115.40	94.09	88.44
North America	14.31	19.23	23.19	21.03	15.96
Central America	0.20	0.40	0.51	0.51	0.86
South America	1.16	1.12	0.85	1.32	1.87
Australia-New Zealand	1.42	3.12	4.33	5.98	7.34
USSR (up to 1991)	23.35	45.31	44.35	41.51	-
Russian Federation	-	-	-	18.65	17.58
Germany	5.68	10.55	13.52	12.39	11.78
Canada	5.54	10.55	12.45	12.86	10.87
France	7.70	10.28	10.21	9.48	10.26
Australia	1.28	2.85	3.90	5.63	7.19
Turkey	3.54	4.36	6.39	7.76	8.48
Spain	2.48	6.09	8.63	8.62	8.37
United Kingdom	7.58	9.24	9.59	6.91	5.84
USA	8.77	8.69	10.74	8.18	5.09
Denmark	4.12	5.75	5.29	3.78	3.66
Poland	1.52	3.37	3.88	3.34	3.42
China	3.66	3.01	2.96	3.96	3.29
Iran	0.95	1.18	2.55	2.74	2.87
Kazakhstan	-	-	-	3.74	1.98
Morocco	1.60	2.09	2.22	1.87	1.80
India	2.63	2.49	1.79	1.51	1.33

Table 1. Barley production from 1961 to 2007.
(Source: faostat.fao.org)

The world acreage under barley has shown a declining trend during the last forty years or so from 1970 onwards (Table 2). The current cultivated area in Europe is almost half of what it used to be during the 1970s and 1980s. The USSR, and the Russian Federation in particular, has the maximum area sown with barley (Table 2). The area under barley has over the years, nevertheless, witnessed a decline in all countries.

The decline in area under barley has mainly been due to a transfer of barley cultivation into wheat, particularly after new higher yielding and fertilizer responsive semi-dwarf wheat cultivars were developed. The availability of more wheat, contributed by advances made during the green revolution, also led to a change in food preference by the people. An increasing trend in area under barley cultivation occurred nevertheless in Australia during the period 1961 to 2007 as major part of the production was utilized for export purposes.

Continent/ Country	**Cultivated Area (million ha)**				
	1961-1970	**1971-1980**	**1981-1990**	**1991-2000**	**2001-2007**
World	61.14	77.81	77.65	65.83	56.52
Africa	4.31	4.58	5.08	4.70	4.70
Asia	13.91	11.27	12.05	15.86	12.01
Europe	33.58	50.06	48.26	34.25	28.92
North America	7.14	8.25	8.64	6.90	5.36
Central America	0.23	0.26	0.27	0.25	0.32
South America	1.09	0.94	0.60	0.73	0.86
Australia-New Zealand	1.17	2.44	2.76	3.14	4.35
USSR (up to 1991)	19.31	31.19	29.51	28.59	-
Russian Federation	-	-	-	11.97	9.41
Canada	2.93	4.66	4.75	4.30	3.80
Australia	1.13	2.36	2.66	3.07	4.29
Turkey	2.73	2.60	3.28	3.57	3.59
Spain	1.62	3.11	4.08	3.63	3.15
Morocco	1.84	2.12	2.30	2.21	2.15
Germany	1.77	2.62	2.82	2.23	2.01
France	2.58	2.76	2.10	1.58	1.67
Iran	1.34	1.37	2.23	1.78	1.62
USA	4.22	3.59	3.88	2.59	1.55
Poland	0.71	1.20	1.21	1.14	1.10
United Kingdom	2.13	2.30	1.94	1.23	1.02
Denmark	1.07	1.49	1.17	0.76	0.71
Kazakhstan	-	-	-	3.69	1.74
China	3.13	1.80	1.11	1.50	0.84
India	2.93	2.36	1.35	0.85	0.67

Table 2. Cultivated area under barley from 1961 to 2007. (Source: faostat.fao.org)

The worldwide decline in area under barley has been compensated by an increasing trend recorded in the yield per hectare from 1961 to 2007. There has been a significant increase in productivity in European countries (France, Germany, United Kingdom) as compared to Asia. China as well has achieved a significant increase in yield (Table 3).

Continent/ Country	**Barley Yield (tons/ha)**				
	1961-1970	**1971-1980**	**1981-1990**	**1991-2000**	**2001-2007**
World	1.61	1.93	2.15	2.31	2.50
Africa	0.78	0.86	0.94	0.93	1.05
Asia	1.18	1.37	1.49	1.53	1.82
Europe	1.85	2.14	2.40	2.78	3.06
North America	2.00	2.33	2.68	3.05	2.98
South America	1.06	1.19	1.41	1.79	2.17
Australia- New Zealand	1.21	1.28	1.56	1.89	1.72
France	2.97	3.73	4.92	5.97	6.14
Germany	3.19	4.01	4.80	5.56	5.87
United Kingdom	3.55	4.01	4.95	5.59	5.74
Denmark	3.83	3.86	4.60	5.00	5.13
China	1.18	1.77	2.67	2.63	3.92
USA	2.10	2.43	2.75	3.16	3.29
Poland	2.12	2.81	3.19	2.92	3.10
Canada	1.85	2.67	2.62	2.99	2.85
Spain	1.51	1.94	2.09	2.40	2.65
Turkey	1.29	1.67	1.98	2.17	2.36
India	0.89	1.05	1.35	1.79	1.98
USSR (upto 1991)	1.19	1.45	1.51	1.45	-
Russian Federation	-	-	-	1.54	1.87
Iran	0.71	0.87	1.14	1.55	1.78
Australia	1.13	1.21	1.46	1.81	1.67
Kazakhstan	-	-	-	0.98	1.13
Morocco	0.87	0.99	0.95	0.81	0.82

Table 3. Barley yield from 1961 to 2007. (Source: faostat.fao.org)

3. Botany

The barley plant has several cylindrical culms (tillers) with hollow internodes separated by solid nodes. Typically there are 5-7 internodes in a culm which increase in length and are progressively smaller in diameter towards the tip. The number of tillers per plant is influenced by plant density of crop stand, genetic and environmental factors. Though the height of culms is affected by genetic and environmental factors, the height of individual culms in the same plant may vary. Single leaves, consisting of a tubular sheath and blade, are borne alternately on opposite sides at each internode. The leaf sheath encases the culm and extends from the node to which it is attached to almost the whole length of the next internode. At the junction of the sheath and the blade, two colorless or pigmented lateral projections called auricles or ‘claws’ are also formed. The leaf-blade is long, flat and narrow with parallel veins.

Barley’s flower (inflorescence), commonly called ‘ear’ (spike of spikelets), is distinguishable into two morphological types – six-rowed and two-rowed. In the six-rowed spike, a triplet of spikelets is placed on alternating sides, in a zigzag manner, at each node of the flat rachis (Fig. 1a and 1b), while in the two-rowed spike, the lateral spikelets of the triplet are either sterile (Fig. 1c) or are more or less rudimentary (Fig. 1d). Analysis of carbonized grain samples have suggested that the six-rowed barley is of later origin than the two-rowed forms (Zohary, 1973).

The florets consist of a lemma, which terminates in a long or short awn, and a palea. The awns may vary in length from 0.5cm (awnless or awnleted) to 25cm in different species. The awns in some varieties, called ‘hooded barley’, get modified to develop hoods (wing-like appendages) which may be of different shapes and sizes. The sexual parts of the plant are enclosed by the lemma and palea. The anthers are three in number, while the ovary’s stigma is bifid and hairy. Pollination is mainly by self-pollination. The fertilized ovary grows to form the grain which may be hulled (lemma and palea remain attached to the seed at maturity) or hulless (naked barley, threshing free of the lemma and palea). Except in cultivated species of barley, the rachis is fragile at maturity causing shattering of grains. The grain color of hulless varieties may be pale yellow, blue, red-purple or various shades of grey to black. On the other hand, hulled grains may be pale yellow or may show a greenish tinge due to blue aleurone color and yellow husks. The husk may have shades of yellow, orange, brown or even grey or black.

Figure 1. Barley spikes: a: matured 6-rowed ear; b: green 6-rowed ear; c: 2-rowed ear with sterile lateral spikelets; d: 2-rowed ear with rudimentary lateral spikelets.

The barley plants can either be of winter or spring habit. Winter barley requires a period of exposure to cold (vernalization or chilling exposure) in order to produce spikes and set seeds and is, thus, planted in autumn. Vernalization in barley is controlled by genes *Vrn-H1*, *Vrn-H2* and *Vrn-H3*. Like *Vrn-H1*, *Vrn-H3* is dominant for spring-growth habit and has similar epistatic interactions with *Vrn-H2*. After germination, winter barleys form a rosette type of growth and remain inactive during the winter months; in early summer they develop tillers and spikes. If seeded in the spring, winter barleys fail to produce spikes. The winter varieties of barley are hardier than winter oats, but somewhat less hardy than winter wheat or rye. Spring barley varieties, on the other hand, do not require exposure to cold in order to develop spikes, do not produce a typical rosette stage and so they develop fewer tillers than winter varieties.

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Biographical Sketch

Dr Vinod Tiwari has been engaged in wheat research for the past 32 years. After obtaining a PhD degree in Genetics and Plant Breeding from the Banaras Hindu University, Varanasi (India) in 1981, he worked as a lecturer 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 the year 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 varieties into spring wheat.