GROWTH AND PRODUCTION OF OAT AND RYE

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

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Contents

Summary

The oat is primarily grown for feed and forage, but its food use is now more focused on mining its benefits as a health food. Oats match barley in features that are beneficial for good health, sometimes even better in a few respects. Oat cereals are a constituent of breakfast foods in most developed countries. The importance of oat in the biomedical and cosmetics industry is also on the rise.

Rye is essentially a crop of Northern and Eastern Europe. It has its own compulsions for cultivation and consumption as a preferred food item in many parts of Eurasia. With the feed and forage uses apart, rye is increasingly used in producing whiskies and as a component of beer in some countries.

In this paper the basic morphological and biochemical features of oat and rye are described, together with the methods to achieve higher production and commercial availability via enhanced trade. The impeding biotic and abiotic factors have also been enumerated.

1. Introduction

Oat and rye are able to tolerate abiotic and biotic stresses to a great extent and are most suited among the basket of crops for many countries to mitigate the current regime of climate change. Oat (also called oats), the staple food of people for ages in some countries, drew away from favor due to changes in food preferences. The oat is now being preferred as a ‘functional food’ (food for good health) as it is a rich source of fibers and also has antioxidant properties. It is consumed primarily as a breakfast cereal. The consumption of oat leads to lowering of low density lipoprotein (LDL) cholesterol which assures safety against heart diseases, regulates blood sugar level in diabetics, and also manages gastro-intestinal health and obesity.

Rye is essentially a European crop. Its features of winter hardiness and resistance to diseases and pests along with its adaptability to grow better on poor soils have established it as the preferred cereal crop in northern Europe.

Oat and rye are also used for feed and fodder besides having great industrial significance. Rye is increasingly used in the brewing and distillery industries. On the other hand, oat has found greater use in the biomedical and cosmetics industry. The increasing awareness about health-related benefits and varied industrial uses of these crops have also raised hopes for a boost in their production. The advances in scientific knowledge and technology have led to enhancement in yield and quality of oat and rye cultivars suited to the requirements of consumers and the industry.

The growth and trends in production of the two cereal crops have been discussed below with a view to understand the crop and the factors that make them valuable for consumption and trade.

2. Oat

2.1. Origin and Distribution

The oat (*Avena sativa*) was domesticated around 2000 BC. The hexaploid oats originated in the Hindu Kush region (Malzew, 1930). Loskutov (2005) however considers the western part of the Mediterranean region (Morocco, Spain) as the primary center of origin of oats. The oats expanded from Asia Minor to the north into Europe as an admixture in cultivated emmer and einkorn wheat. The oats, being more adapted to cold conditions, thrived in the new environment of the northern latitudes, while wheat perished. Oats in mixed populations comprised many types of *Avena* species. Subsequently, *A. sativa* types, due to better adaptation to cooler climates, were favored by natural selection which resulted in their prominence and becoming the most widely cultivated oat species in northern Europe. Naked (hulless) oats are grown in Northern China and Mongolia from ancient times.

Oats were first planted in the United States in 1602 by Scottish settlers on an island off the Massachusetts coast. Today oat is grown mainly in North-West and Eastern Europe, North America, Canada and China. Oat of high quality is produced in Australia and New Zealand. Although oat is not a cereal for making bread, it has been the staple food for a long time in Northern Europe. It is a most valuable cereal crop in the eyes of a nutritionist.

The world oat production has declined over the years from around 48 million tons in the 1960s to current level of 25 million tons, a marked reduction of around 50 per cent (Table 1). The European countries account for the bulk of oat production. The USSR, later the Russian Federation, followed by Canada, the USA, Germany, Poland and Australia are the major oat producing countries.

Continent/ Country	**Production (million tons)**				
	1961-1970	**1971-1980**	**1981-1990**	**1991-2000**	**2001-2008**
World	48.66	47.41	42.46	30.72	25.36
Africa	0.18	0.20	0.23	0.18	0.19
Asia	1.74	1.41	1.27	1.76	1.10
Europe	25.48	30.40	29.05	20.02	16.25
North America	19.07	13.41	9.22	6.14	5.16
South America	0.78	0.73	0.91	0.97	1.29
Australia-New Zealand	1.35	1.20	1.65	1.58	1.27
USSR (up to 1991)	8.09	14.37	15.70	12.86	-
Russian Federation	-	-	-	8.32	5.49
Canada	5.72	4.22	3.01	3.35	3.51
USA	13.35	9.18	6.21	2.78	1.65
Poland	2.77	2.80	2.44	1.45	1.32
Germany	3.24	3.68	2.89	1.49	1.02
Australia	1.31	1.15	1.58	1.53	1.24
Finland	0.95	1.26	1.21	1.15	1.21
Sweden	1.35	1.49	1.56	1.13	0.91
Ukraine	-	-	-	1.05	0.87
United Kingdom	1.40	0.88	0.53	0.56	0.68
China	1.02	0.87	0.86	1.07	0.65
Belarus	-	-	-	0.65	0.60

Ireland	0.31	0.14	0.12	0.13	0.14

Table 1. Decadal growth in production of oats from 1961 to 2008

The world acreage under oat has also decreased significantly from 31 million hectares in the 1960s to the present level of 12 million hectares (Table 2). All oat producing countries have recorded a fall in acreage. Nevertheless, gradual increments were observed in the per unit yield over the decades from 1961-1970 to 2000-2008. Ireland and the United Kingdom harvest the maximum yields of oat, around 7 tons/ha and 6 tons/ha, respectively (Table 3).

Continent/ Country	**Area (million ha)**				
	1961-1970	**1971-1980**	**1981-1990**	**1991-2000**	**2001-2008**
World	31.31	28.06	24.01	16.61	12.02
Africa	0.20	0.24	0.28	0.20	0.18
Asia	1.67	1.14	0.79	1.02	0.58
Europe	16.08	17.74	16.42	11.04	7.46
North America	11.16	7.20	4.50	2.70	2.16
South America	0.67	0.57	0.65	0.65	0.66
Australia-New Zealand	1.46	1.11	1.26	0.95	0.93
USSR (up to 1991)	7.99	11.69	11.90	10.63	-
Russian Federation	-	-	-	6.42	3.51
Canada	3.31	2.21	1.38	1.36	1.42
USA	7.86	4.99	3.12	1.34	0.74
Australia	1.45	1.09	1.24	0.94	0.92
Poland	1.48	1.78	0.94	0.62	0.55
Ukraine	-	-	-	0.53	0.48
Finland	0.47	0.50	0.42	0.36	0.38
China	1.13	0.76	0.54	0.51	0.26
Germany	1.07	1.00	0.70	0.31	0.22
Sweden	0.48	0.47	0.43	0.31	0.24
Belarus	-	-	-	0.32	0.25
United Kingdom	0.46	0.23	0.12	0.10	0.12
Ireland	0.11	0.04	0.02	0.02	0.02

Table 2. Decadal growth in area under oats from 1961 to 2008

Continent/ Country	**Yield (tons/ha)**				
	1961-1970	**1971-1980**	**1981-1990**	**1991-2000**	**2001-2008**
World	1.56	1.69	1.77	1.87	2.11
Africa	0.91	0.83	0.80	0.90	1.06
Asia	1.05	1.29	1.61	1.73	1.92
Europe	1.59	1.72	1.77	1.83	2.18
North America	1.72	1.86	2.05	2.28	2.38
South America	1.17	1.26	1.38	1.49	1.97
Australia- New Zealand	0.91	1.07	1.32	1.67	1.38
Ireland	2.91	3.55	5.11	6.65	7.21

United Kingdom	3.06	3.80	4.63	5.59	5.87
Germany	3.01	3.68	4.15	4.71	4.66
Sweden	2.81	3.20	3.65	3.63	3.80
Finland	2.00	2.53	2.84	3.20	3.17
Canada	1.73	1.92	2.18	2.45	2.48
Poland	1.88	2.37	2.62	2.36	2.40
China	0.82	1.22	1.59	2.16	2.48
USA	1.71	1.84	1.97	2.09	2.21
Belarus	-	-	-	2.03	2.42
USSR (up to 1991)	0.99	1.23	1.32	1.21	-
Russian Federation	-	-	-	1.30	1.55
Ukraine	-	-	-	1.98	1.79
Australia	0.89	1.04	1.28	1.64	1.36

Table 3. Decadal growth in yield of oats from 1961 to 2008

2.2. Botany

The oat plant, in its early growth phase, may be erect, semi-erect, or prostrate, generally forming a rosette. The shoot comprises several hollow culms (tillers) bearing foliage leaves. The number of tillers depends on the density of seeding (crop stand), genetic features of the cultivar and growing conditions (e.g. dose of fertilizers applied). The tiller terminates in a large inflorescence called the panicle (Fig. 1a and 1b).

Figure 1. (a) Oat plant; (b) Portion of oat's panicle

The panicle consists of a central stem (rachis) and branches which arise in whorls at the nodes. Each main and lateral rachis ends in a spikelet (flower); spikelets are also borne at the nodes of the rachis. The spikelets, often drooping but upright in some cases, are subtended by two loose membranous glumes, which are generally longer than the spikelet. In hulled varieties, the spikelets usually contain three florets, one of which is rudimentary and nonfunctional. In naked (hulless) oats, 3 to 7 florets may be produced per spikelet. The florets consist of a lemma and palea, which enclose the reproductive organs – stamens and ovary. The lemma (which is awned or awnless) and the palea adhere to the developing seed in the hulled oats. The hulless oats thresh free from lemma and palea.

Generally, two kernels (seeds) are produced per spikelet, but sometimes only one develops. The oat kernel (also called groat), a caryopsis, is spindle in shape, and generally thinly covered with fine hairs (trichomes). The kernel comprises seed coat layers, starchy endosperm, and the embryo.

The oat is also broadly classified into spring and winter types depending upon the season of planting.

2.3. Taxonomy

Oat (*Avena* spp.) has a taxonomic pattern similar to that of wheat, consisting of a polyploid series of species with seven basic ($x = 7$) chromosomes, i.e., diploid, tetraploid and hexaploid. Besides the wild species, there are cultivated forms at each ploidy level: the diploid ($2n = 2x = 14$) grey oat A. *strigosa*, the tetraploid ($2n = 4x = 28$) Ethiopian oat *A. abyssinica*, and the hexaploid ($2n = 6x = 42$) red oat *A. byzantina*, and common oat or white or yellow oat *A. sativa*.

Jellen and Leggett (2006) have reported 16 diploid, 8 tetraploid and 8 hexaploid species of oat, all of them being autogamous (self-pollinated) annuals with the sole exception of *A. macrostachya*, which is perennial and allogamous (cross-pollinated) autotetraploid (having 4 haploid sets of the same genome, which is yet to be established).

Many aspects pertaining to the taxonomy of *Avena* species are still under dispute. Loskutov (2005), based on morphological traits, has divided the *Avena* genus into two subgenera and two sections, while Baum (1977), based on eco-geographic considerations, has described seven sections. On the other hand, Jellen and Leggett (2006) stress on the biological species concept, inter-fertility and cytogenetic relationships to describe the *Avena* species.

The genomic constitution of common oat, *A. sativa* is AACCDD. The species *A. strigosa*, *A. longiglumis* and *A. canariensis* have been suggested as sources of the A genome of tetraploid and hexaploid oats. In this regard, the morphological evidences point to *A. canariensis*, while cytological evidences are in favor of *A. longiglumis* as donor of the A genome. The species *A. ventricosa* is suggested as donor of the C genome. The C genome is, however, represented by incompatible variants C_p (*A. pilosa* syn. *A. eriantha*, *A. clauda*) and C_v (*A. bruhnsiana*, *A. ventricosa*). The tetraploid species *A. insularis* is suggested as the most likely donor of the CD genome, although in a recent review (Jellen and Leggett, 2006), it is attributed an AACC genome, which is still debated.

Based on morphologic similarity, meiotic (cell division during gamete formation) evidences and reciprocal crosses (exchanging male and female parents), *A. magna* is suggested as progenitor of the AC genome in cultivated oats, with *A. canariensis* and *A. ventricosa* as its diploid ancestors. Baum (1972) considered *A. septentrionalis* syn. *A.*

hybrida as the closest ancestor to the cultivated oat. On the other hand, Loskutov (2005) considers *A. sterilis* as the progenitor of the hexaploid cultivated species of *Avena*. The FAO (1996) has indicated the South and East Mediterranean sub-region, the East Asian sub-region (for hulless oats) and Europe as regions of diversity for *Avena* species.

2.4. Crop Husbandry and Improvement

2.4.1. Agronomy

Oat is planted for grain, straw or pasture, as a companion crop with legumes, and as a cover crop to prevent soil erosion. Oat grows well on sandy loam to heavy clay soils with good drainage. On acid soils, oat performs better than other small-grain cereals. Saline soils are not suitable.

The rates of seeding in oat vary depending on the location and purpose for which the crop is cultivated. Seed rates of about 125 to 175 kg/hectare are normal for sowing, which is either broadcast or drilled. Excessive seeding rates lead to lodging which causes reduction in yield; although somewhat higher rates are used to check the problem of weeds. Lower seed rates are used when oat is grown as an intercrop with legumes.

The fertilizer application rates usually depend upon the desired yield level, fertility of the soil, and the previous crop cultivated on the field. In general, oat requires lower doses of fertilizers than wheat. Fertilizer doses of nitrogen vary from 50 to 100 kg/ha, while 30 to 40 kg/ha phosphate, and 15 to 30 kg/ha potash are generally applied to get good yields. The rates of nitrogen are suitably reduced when legume is the preceding crop, or when ample manure has been applied in the field. Soils deficient in minor nutrients, particularly manganese, retard the growth of oat plants.

Oat, due to its vigorous growth habit, can beat competition from most weeds, although some broad leaved weeds need to be controlled with suitable herbicides.

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Bibliography

Altpeter, F. and Korzun, V. (2007). *Rye*. In: E.C. Pua and M. R. Davey, eds.: Biotechnology in Agriculture and Forestry, vol 59, Transgenic Crops, IV: 107-117. Springer Verlag, Berlin/ Heidelberg. [An update on applications of biotechnology in rye].

Baum, B. R. (1972). *Avena sepentrionalis and the Semi-species Concept*. Canadian Journal of Botany, 49: 647-649. [A paper expressing likely ancestors of hexaploid oat].

Baum, B. R. (1977). *Oats: Wild and Cultivated. A Monograph on the Genus Avena L. (Poaceae).*

Monograph No. 14, Supply and Services Canada, Ottawa, Canada. [Taxonomic description of oats on the basis of eco-geography].

FAO (1996). *The State of the World's Plant Genetic Resources for Food and Agriculture*. Background documentation prepared for the International Technical Conference on Plant Genetic Resources Leipzig, Germany 17-23 June, 1996. [Status paper on genetic diversity in oats].

Geiger, H.H. and Miedaner, T. (2009). *Rye Breeding*. In: M. J. Carena, ed.: Cereals. Handbook of Plant Breeding. pp. 157-181, Springer Science + Business Media LLC [An update on breeding techniques in rye].

Jellen, E. N. and Leggett, J. M. (2006). *Cytogenetic Manipulation in Oat Improvement*. In: R. J. Singh and P. P. Jauhar, eds.: Genetic Resources, Chromosome Engineering, and Crop Improvement. pp.199-231, CRC Press, Taylor and Francis Group, Boca Raton, FL 33487-2742. [Paper detailing taxonomy of oats based on cytogenetic considerations].

Khush, G. S. (1962). *Cytogenetic and Evolutionary Studies in Secale. II. Interrelationships of the Wild Species.* Evolution, 16:484-496. [Paper on phylogenetic relationship among *Secale* species].

Lorenz, K. (2000). *Rye*. In: K. Kulp and J. G. Ponte, eds.: Handbook of Cereal Science and Technology. Marcel Dekker Inc., 270 Madison Avenue, New York, NY 100166. [A paper illustrating chemical perspectives of rye grains].

Loskutov, I. (2005). *Classification and Diversity of the Genus Avena L*. In: Cereal Genetic Resources in Europe. Report of a Cereals Network, First Meeting, 3-5 July 2003, Yerevan, Armenia / Report of a Working Group on Wheat, Second Meeting, 22-24 September 2005, La Rochelle, France (E. Lipman, L. Maggioni, H. Knüpffer, R. Ellis, J.M. Leggett, G. Kleijer, I. Faberova and (compilers) Le Blanc A., eds.), 84-90. International Plant Genetic Resources Institute, Rome, Italy. [Paper dealing with taxonomy of oats].

Malzew, A. I. (1930). *Wild and Cultivated Oats*. Bulletin of Appl. Botan. Genet. Plant Breeding, Suppl. 38. [Paper on origin of oats].

McMullen, M. S. (2000). *Oats*. In: K. Kulp and J. G. Ponte, eds.: *Handbook of Cereal Science and Technology*. Marcel Dekker Inc., 270 Madison Avenue, New York, NY 100166. [A paper illustrating chemical perspectives of oat grains] .

Schlegel, R. (2006). *Rye (Secale cereale* L.*): A Younger Crop Plant with a Bright Future*. In: R. J. Singh and P. P. Jauhar, eds.: Genetic Resources, Chromosome Engineering and Crop Improvement. CRC Press, Taylor and Francis Group, Boca Raton, USA, pp.365-394 [A description of rye cytogenetics, breeding and cultivation practices].

Shang, H. Y., Wei, Y. M., Wang, X. R. and Zheng, Y. L. (2006). *Genetic Diversity and Phylogenetic Relationships in the Rye Genus Secale L. (rye) based on Secale cereale Microsatellite Markers.* Genetics and Molecular Biology, 29(4): 685-691. [Paper on phylogenetic relationship among *Secale* species based on studies with molecular markers].

Webster, F. H. (1996). *Oats*. In: R. J. Henry and P. S. Kettlewell, eds.: Cereal Grain Quality. Chapman and Hall, London, UK, pp. 179-203 [Paper dealing with quality and utilization of oats].

Weipert, D. (1996). *Rye and Triticale*. In: R. J. Henry and P. S Kettlewell, eds.: Cereal Grain Quality. Chapman and Hall, London, UK, pp. 205-224. [Paper on quality and utilization of rye and triticale]

Biographical Sketch

Dr Vinod Tiwari has been engaged in wheat research for the past 32 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 major tasks related 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 (Indian Council of Agricultural Research) 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 into spring wheat.