Oat improvement in China

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1. Introduction

Oat belongs to the genus Avena of the Gramineae family. Two types of oats are cultivated in China, namely naked oat (*Avena nuda* L.) and hulled oat (*A. sativa* L.). Naked or non-hulled oat is traditionally cultivated in China. Hulled oats were introduced from other countries only in recent decades, and have been successfully cultivated in northwestern China. Naked oats are mainly used as food, whereas hulled oats are used for feed and forage.

Oat has many names in China, for example, *youmai* in the north, *yumai* in the northwest, *lingdangmai* in the northeast, and *yanmai* in the southwest. Oat, recognized as a health food and an important forage and feed crop in China, has received considerable attention from researchers. In general, naked oat is characterized by large grains, more florets and seed set, early maturity, strong resistance to drought, and tolerance to poor soils. It plays a very important role in the dry areas of northern and northwestern China. Naked oats, which account for about 90% of the total oat area, are easier for local consumers to thresh and process into flour or food with simple tools and equipment (Yang, 1989; Tian, 2002).

1.1 Origin of naked oats

It is widely recognized that China is the center of origin of naked oats. Vavilov (1926), for one, wrote in *Centres of Origin of Cultivated Plants*, that naked oats originated in China. Stanton (1955) also indicated that naked oats originated in China or the eastern part of the former USSR. It was also accepted that naked oat was a special geographical form that arose by mutation in the region between China and Mongolia (Dong and Zheng, 2006). In China, oats are mostly grown in the north, particularly in Inner Mongolia, where wild species of oats are also found. Recent studies using molecular markers on Chinese oat landraces and wild species support the idea that naked oat originated in China (Xu et al., 2009).

1.2 Oat production in China

Oat has been cultivated in China for more than 2000 years. According to descriptions in historical records by Si Matsian (145-87 BC), it played an important role in food production. It was widely distributed throughout the country and grown for food in competition with other crops. However, oat cultivation area declined dramatically in recent decades. In 1939, oat covered 1.07 million ha with a production of 0.9 million tonnes. During the 1950s and 1960s, it was grown on about 1.5 million ha annually and distributed over 210 counties across the country. Since the 1970s, the oat area has decreased due to the adoption of high yielding varieties of rice, wheat, and corn. Today the average annual cultivated area is about 0.5 million ha, where about 0.6 million tonnes are produced. Although grown in many parts in the country, oats are mainly concentrated in northern and northwestern China. Inner Mongolia has the largest area of production, with about 37% of the total cultivated area, followed by Hebei with about 21%, Gansu with 18% and Shanxi with 15%. These four provinces thus account for more than 90% of China's total oat cultivated area and production.

Oats are usually grown in poor soils in dryland areas, and higher yielding crops such as wheat, rice, and corn always occupy the better land. In many oat producing areas, few resources are invested in oats, and annual precipitation, especially in the north and northwest, can be meager. Under such conditions, oats yields range from 500 to 2,200 kg/ha, but may reach 3,000-3,750 kg/ha, or even over 4,500 kg/ha, when the crop is grown under well-managed, irrigated conditions.

1.3 Uses of oats in China

Oat is used not only as staple food in some production areas, but also as a health food because of its high level of nutritional components. In northern and northwestern China, oats contribute to the livelihoods of many millions of people. Oats were recently recommended as a priority food for people suffering from high blood pressure, high blood fat levels, and diabetes. The protein and fat contents in oat grain are about 15.0% and 8.5%, respectively. The lysine, phosphorus, iron, and calcium contents are higher than that of any other cereal crops. Oat grain is also rich in vitamins B1 and E. Research carried out in hospitals showed that cholesterol, lipoprotein, and triglyceride levels, and the body weight of patients suffering from hyperlipoidemia diminished with a diet that included eating 100 g per day of oat flakes for three months; there were no side effects (Shi et al., 1988; Lu, 1990).

Oats are considered an important source of feed and forage. Oat stems are characterized by a soft, tender texture and good palatability, and have more juice and more digestible fiber than similar tissues of millet and barley. They are considered one of best forage crops for animals. It has been claimed that cows fed oat grain produce more milk, and that hens fed on oats lay more eggs. Dry oat stalks are also good industrial raw materials for making paper and instant food boxes.

1.4 General oat research in China

Oat improvement research in China focuses on germplasm resources, breeding, and biotechnology applications. Research on germplasm resources involves collection, characterization, evaluation, documentation, and conservation of genetic materials. This research activity is implemented by the national genebank at the Institute of Crop Science (CAAS) in cooperation with relevant research organizations throughout the country. Research on oat breeding aims to develop varieties with high yield potential, disease resistance, and drought tolerance, and to advance oat productivity and use in China.

The organizations engaged in breeding include Zhangjiakou Prefecture Agricultural Research Institute (Zhangjiakou PARI) in Hebei; Inner Mongolia Academy of Agricultural Sciences (Inner Mongolia AAS); Shanxi Academy of Agricultural Sciences (Shanxi AAS); Baicheng Academy of Agricultural Sciences (Baicheng AAS) in Jilin; as well as research teams at different universities. National multilocation testing of oat varieties is coordinated by the National Extension Center of Agricultural Science and Technology. Biotechnology approaches such as molecular markers are widely used for assessing genetic diversity (Wang et al., 2004; Xu et al., 2009) and gene mapping (He et al., 2007). These research activities have gained support from the Ministry of Agriculture, the Ministry of Science and Technology, as well as provincial governments. A new national oat research program involving oat research organizations in major oat producing areas will focus on germplasm enhancement, improved yield potential and quality, improved cultivation technologies, and various food processing aspects.

2. Oat-based production systems in China

2.1 Production zones

Oats are mainly planted in the northern, northwestern, and southwestern agricultural regions. Ecological conditions in oat growing regions vary widely, especially in terms of environmental stresses, cropping systems, variety ecotypes, and productivity levels. In the1970s, the natural ecological division for oat production was based on variety characteristics and their performance in regional tests. Oat production areas were divided into two major agro-ecological zones and four subzones:

Zone I: Northern China Spring Oats Region

- ***Subzone 1:*** Northern Early Spring Oats Region
- ***Subzone 2:*** Northern Mid-late Spring Oats Region

Zone II: Southern China Facultative Oats Region

- ***Subzone 1:*** Late Oats in the Southwestern Mountainous Region
- ***Subzone 2:*** Late Oats in the Southwestern Plains Region

2.2 Ecological conditions and variety types in different zones and sub-zones

2.2.1 Zone I: Northern China Spring Oats Region

Subzone 1: Northern Early Spring Oats Region. This subzone includes the Tumochuan Plain in Inner Mongolia, and the Datong and Xinding Basins in Shanxi. This subzone has an annual planting area of about 66,700 ha, comprising 5-7% of China's total oat area. The region possesses calcareous alluvial and chestnut soils with good fertility. Yearly precipitation is 300-500 mm, of which 50% falls in July and August. The annual average temperature is 4-6°C, and 15-25°C in the growing season from May to August. Oats are sown generally in early or mid-April, and harvested in late July or early August. This region mainly grows naked oat varieties with a strong spring growth habit, good tillering ability, and cold and drought tolerance. Generally, the 1000-grain weight is 20-22 g and the growth period is 90-95 days. Representative varieties include Yong 492 and Hebei 2.

Subzone 2: Northern Mid-late Spring Oats Region. This subzone consists of many areas, including the central and western parts of Xinjiang, Dingxi, and Linxia located in the southern foothills of Helanshan Mountain and Liupanshan Mountain in Gansu; mountainous areas of the Huangshui and Yellow River Valleys in Qinghai; the northern foothills of the Qinling Mountains and Yanan area in Shaanxi; the Guyuan area in Ningxia; the southern and northern parts of Yingshan Mountains in Inner Mongolia; Taihangshan and Lingshan Mountain areas in Shaanxi; Bashang area in Hebei; the Yanshan hilly areas in Beijing; and the southern foothills of the Large and Small Xinganling Mountains in Heilongjiang. The area sown to oats in this region represents about 80% of China's total oat area. The topography in this subzone is complicated, with altitudes ranging from 500 to 1,700 m. Soils vary from chernozem and meadow chestnut soils to light chestnut soils, with large differences in fertility. The climate is characterized by strong winds and drought, and is especially dry in spring. Total annual precipitation is 300-400 mm, of which about 70% falls from June to August. This coincides with the period of high water requirement in oats. The mean annual temperature is 2.5-6°C, and the annual effective accumulated temperature (equal to or higher than 10°C) is 1,500-2,000°C, which meets the needs of oats during the growing season. Three types of varieties are grown in this subzone:

- *Mid to late varieties on hilly dryland.* These varieties cover more than 80,040 ha, and are characterized by slow seedling development, early prostrate growth, strong tillering ability, and rapid elongation after the onset of warm weather in July, when rainfall is more likely. Usually tall, with weak stems, long, narrow leaves, and large grain (1000-grain weight: 22-25 g), they are sown in mid- to late May and harvested in late August or early September. The entire growing period is 95-110 days. Representative varieties are Sanfensan, Huabei 2, and some local large-grained naked genotypes.

- *Early varieties on hilly dryland.* Varieties of this type have shorter plant height, a longer creeping growth period, shorter grain-filling, 1000-grain weight of less than 20 g, and a growth period of 80-85 days. They can be grown as emergency crops following failures of other crops. Examples are local, small-grained, naked oat varieties such as Mengyan 1809 and Beihuang 1.

- *Mid-season varieties in arid sandy areas.* These varieties are planted on a relatively large area (233,300 ha). The Yellow River is used as a source of irrigation water in some areas. Seedlings of these varieties are upright or semi-upright, with short wide leaves, and tall plant height; they are tolerant to waterlogging and fertilizers, as well as resistant to lodging. Planting occurs in early or mid-May and harvesting in mid-August; the growing period is 90-95 days. Representative varieties are Sanfensan, "578" and Yan 1211.

2.2.2 Zone II: Southern China Facultative Oats Region

Subzone 1: Late Oats in the Southwestern Mountainous Region. This region, with altitudes above 2,000 m, and covering about 100,000 ha, is in Yunnan, Guizhou, and Sichuan Provinces, where there are wide temperature variations and inadequate sunlight during the growing period. Yearly rainfall is about 1,000 mm. Oats are planted in autumn and harvested in spring; the total growing period is 220-240 days. Varieties here have strong drought and cold tolerance, but poor lodging resistance, poor seed-holding capacity, and low 1000-grain weight. A representative variety is Tuotuoyanmai.

Subzone 2: Late Oats in the Southwestern Plains Region. The area sown to oat in this region is about 66,700 ha and includes the Large and Small Langshan Mountains of Sichuan, Guizhou, and Yunnan. The area is noted for its rich soil fertility, humid climate, good irrigation, and intensive cultivation practices with planting done with drills. The varieties in this high yielding area are characterized by tallness, strong stems, slow seedling development, large, wide, dark-green leaves, and a long grain-filling period. The 1000-grain weight is about 17 g. Planting occurs in mid-October and harvesting in late May and early June of the following year. The total growing period is 200-220 days. A representative variety is Yunnan Large Naked Oat.

2.3 Major pests and diseases of oats

World surveys of oat diseases have been conducted since the 1920s. All species of oats, including diploids, tetraploids and hexaploids, are attacked by fungi, bacteria, and viruses. The main oat diseases in China are smuts, rusts, red leaf disease (BYDV), and several physiological diseases.

2.3.1 Oat diseases

Oat smut. Two related fungal pathogens cause smut diseases on oats: *Ustilago avenae* (loose smut) and *U. kolleri* (also known as *U. hordei* and *U. levis*) (covered smut). The latter is more common in China. In the case of loose smut, the black chlamydospores blow or wash from the maturing spikes leaving denuded structures, whereas in the case of covered smut the spore mass is enclosed in a pale grayish membrane that remains intact until the plants are mature. Spores of both pathogens are either seed-borne or survive in the soil. Both *Ustilago avenae* and *U. kolleri* infect the coleoptiles of germinating seedlings, and the fungi grow with the growing points and sporulate in the florets of infected tillers. Spores can survive for long periods, especially under low temperatures and dry conditions. Both species occur as distinct races that can be distinguished on sets of differential host genotypes.

Oat smut can cause heavy yield losses. Generally, over 10%, but sometimes up to 46-90%, of spikes can be affected in northern and northwestern China. Control methods are: (1) seed treatment using 1% formalin (HCHO) to achieve 95-100% control; (2) disease resistant varieties to replace local varieties, more than 90% of which are susceptible; a few are resistant, e.g., Yong-492, 73-7, Baxuan 3, and Yong-75; and (3) integrated management, using, for example, resistant varieties, crop rotation to avoid soils with high spore loads, fungicide seed treatment, and soil sterilization.

Barley yellow dwarf virus (BYDV). The disease known as oat red leaf disease in China is commonly called barley yellow dwarf or cereal yellow dwarf in western countries. The disease appears in most oat growing regions of China. Symptoms include thick, hard, red leaves, reduced plant height, premature senescence, floret sterility (blasting), and reduced 1000-grain weight. The aphid vectors of the disease are *Schizaphis graminum* and *Macrosiphum avenae.*

The BYD virus can survive the winter in perennial grass weeds and autumn-sown cereal crops. The non-crop hosts may be symptomless or have varying degrees of the symptoms described above, depending on actual host species (often tending to yellow rather than red color) and genotype, time of infection, and environmental conditions. BYDV occurs as a number of serotypes; those reported in China include GPV, GAV, PAV, and RMV (Zhou et al., 1984). The major methods for combating the disease in China are to control the aphid vectors using SUMILEX (N-(3,5-Dichlorophenyl)-1,2-dimethyl-1,2-Cyclopropanedicarboximide); remove or reduce primary infection points to reduce the likelihood that pathogens will transfer to neighboring plants; and use resistant varieties such as Xiaoluoyanmai, Yong 492, and Jian 19.

Oat stem rust. The pathogen that causes oat stem rust is *Puccinia graminis* f. sp. *avenae*. Stem rust is important only in northern China, mainly in Inner Mongolia, where it attacks the crop in early or mid-July. Red urediniospores (summer spore stage) are produced on leaves and stems. Stem rust can cause yield losses of 25-50%. In 1980-1982, most oat fields in the Wumeng region of Inner Mongolia were infected with stem rust that caused losses exceeding 30%. The uredinial stage of the pathogen overwinters on grasses such as *Bromus* species in the warmer parts of southern China; urediospores migrate to the north with summer winds and infect oats. Stem rust is favored by high temperatures and high humidity. Control can be achieved with resistant varieties and chemical fungicides, provided they are applied sufficiently early. The pathogen occurs as a complex of races, and resistance may be short-lived due to increases in previously rare races or to new mutants with virulence.

2.3.2 Pests

Aphids. Aphids not only transmit BYDV but also cause significant damage by their feeding activities. Control measures were discussed under BYDV.

Armyworm. Armyworm (*Mythimna separate* Walker), one of 10 major pests of oats in China since the 1950s, can seriously damage oats, especially in the north and northwest. The larvae, characterized by a yellow-brown or black body, brown head with black-brown lines, half ring brown crochet, and six instars; they consume leaves and young spikes. Armyworms cannot survive the winter in northern China. They must migrate from the south, permitting 3-4 generations in the oat growing regions of the north and 2-3 generations in the northwest. First-generation larvae are particularly damaging to oats. Control includes trapping the adults with snare nets, and chemically controlling the larvae before the third instar.

Grasshoppers. Six species of grasshoppers can seriously attack oats. They are common in the oat growing areas of Inner Mongolia. They survive for one generation annually in northern China. Monitoring of eggs and nymphs, and using pesticides on the nymphs are the most effective means of control.

Wireworms. These pests undergo one generation in three years, and the larval stage lasts 2-3 years. Both larvae and adults overwinter in the soil and become active when soil temperatures at 10 cm depth are over 10°C (the critical time to control wireworm). Treating seed with 20% phorate and baiting and disinfecting the soil are effective ways to control wireworm.

3. Oat genetic improvement

3.1 History of oat improvement

Before the founding of the People's Republic of China in 1949, there were no special research units for oat improvement. In the 1950s, CAAS, in cooperation with agricultural research institutes in oat producing areas such as Inner Mongolia, Shanxi, and Hebei, initiated special efforts to collect, identify, and conserve oat germplasm from the main oat growing areas of the country. In the early 1980s, the wild oat genetic resources in China were initially investigated. In 1983, the first *Catalogue of Chinese Oat Germplasm Resources* was published by the Institute of Crop Germplasm Resources (ICGR, CAAS). It contains passport and characterization data on 1,492 oat accessions collected throughout the country. Efforts to collect and conserve oat germplasm resources continued in the 1990s, and a national project on oat germplasm resources was implemented by the ICGR (CAAS) in cooperation with relevant research organizations in the main oat producing provinces. In 1995, the second *Catalogue of Chinese Oat Germplasm Resources* was published, in which a further 1,484 accessions collected from China and abroad were documented. Currently, more than 3,200 accessions of oats are conserved in the national genebank. The work on germplasm collection and conservation established the basis for variety improvement of oats in China.

China initiated breeding activities in the 1960s, when regional yield trials of naked oats were conducted in the north, particularly Zhangjiakou in Hebei and Wumeng in Inner Mongolia. As a result of the tests, Huabei l and Huabei 2 were selected and released for production. These varieties produced oat yields that were 10-30% higher than those of local varieties such as Sanfensan. In the mid-1960s, naked varieties of the Yanhonghao series were bred through intervarietal crossing by the Yanbei Prefectual Agricultural Research Institute in Shanxi. Subsequently, hybridization became the main method used for breeding new naked oat varieties.

From the beginning of the 1970s, interspecific crosses between *Avena sativa* and *Avena nuda* were carried out. New strains of naked oats were selected that had shorter, thicker stems and better lodging resistance than older varieties. The improved varieties had a yield potential of over 4,500 kg/ha in rich soils and adequate water conditions. For example, variety Yong 492, with short stature and strong lodging resistance, had a yield increase of 10-20% compared with Huabei 2. Yong 492 was well-suited to irrigated areas. Later interspecific cross derivatives included Jingyan 2, Neiyan 4, Neiyan 5, Jingza 2, Wuyan 2, "578", and Jian 19. The yields of these varieties were over 10% higher than those of the main local varieties.

Of all the cross combinations that were made annually in the 1980s, 70-80% were interspecific crosses between *Avena sativa* and *Avena nuda*. Many varieties with good agronomic traits were developed, such as Tiegandali (7634-10-1) with a 1000-grain weight of 35 g, about 15 g higher than that of landraces. Variety 766-38-2-1 with more florets, more grains set, and BYDV resistance was developed by the Zhanjiakou PARI. Neiyou 1 (suitable for both irrigated and rainfed environments) and Neiyou 2 and early variety 758-38 (growth season: 65-70 days) were bred by the Wumeng Prefectural Agricultural Research Institute in Inner Mongolia. In addition, new breeding materials with special traits were developed, and these in turn contributed to oat improvement. Some progress was also achieved by pedigree selection following irradiation treatments, mainly with gamma rays.

In the last two decades, varieties Neicaoyou 1, Neiyan 3, and Neiqingyou 323, characterized by fast growth, tall plant height, and high forage productivity, contributed to the development of animal husbandry. With the development of oat markets, many breeders focused on developing good quality varieties with high protein content and large grain in order to meet the needs of oat-flake processing. A tetraploid oat (*A. magna*) from Morocco, with 32.4% protein content, 36.1 g 1000-grain weight, and stem rust resistance, was used in oat improvement. After overcoming the incompatibility of wide crossing and poor seed-holding capacity, strains with more than 18% protein content were selected. To meet the needs of oat flake processing, breeders developed a number of naked oat varieties with 1000-grain weights of more than 30 g. For example, Mengyan 7306 with a 1000-grain weight of 32 g was developed by the Inner Mongolia AAS. At the same time, varieties with green stems at maturity were developed for forage use. Green stems are more tender than yellow stems and contain more juice, which is preferred by animals. In recent years, increased grain β-glucan content has been a focus in oat breeding, and a number of varieties such as Bayou 1 and Baiyan 2 were released by the Zhangjiakou PARI and the Baicheng AAS, respectively.

3.2 Oat genetic resources

Since the 1950s, China has been collecting oat germplasm throughout the country. As a result, more than 3,200 accessions of oats have been collected and stored in the national genebank in Beijing. Of these, about 1,700 accessions are naked oats and 1,500 are hulled oats, in addition to 50 accessions of wild oat species. After the collection was characterized for major agronomic traits, many accessions with important traits such as drought tolerance and resistance to various diseases were made available to breeding programs. More than 60% of accessions are local varieties collected from farms. Some of these varieties have a short growing period (generally 60-75 days), 50-175 cm plant height, growth habits ranging from erect and semi-prostrate to prostrate, very different panicle types and fertilities, and 1000-grain weights ranging from 11 to 40 g. Protein content ranges from 11.9 to 20.5%, and β-glucan content is 2.5-7.5% (Zheng et al., 2006).

3.3 Naked oat breeding objectives

Breeding objectives for naked oats in the different agro-ecological zones vary depending on their use, major biotic and abiotic stresses, and production conditions. Oats are mostly grown in cool, high mountainous regions under a mixed crop/livestock system. New varieties are thus likely to be used for both grain and fodder.

In rainfed areas, breeding objectives should focus on developing varieties with good tillering ability, high grain and vegetative harvest indices, longer growing period, slow growth at the seedling stage, fast grain-filling rates, taller plant heights (100-124 cm), large spikes, well-developed root systems with stronger and deeper roots, and a good combination of yield components (3 million spikes per hectare, 30-35 kernels per spike, and 1000-grain weights of more than 25 g).

For irrigated conditions, varieties should have a shorter growing period (90 days), short stature (95-100 cm), compact plant type, lodging resistance, uniform tillering with more florets and kernels, tolerance to high water and fertility conditions, and a good combination of yield components (4.8-6.7 million spikes per hectare, 35-50 seeds per spike, and a 1000-grain weight of more than 20 g).

Covered smut, stem rust, and BYDV occur very frequently, and aphid damage can also limit oat production in most oat growing areas. Therefore, improving varieties with resistance to these diseases and aphids should be a priority for oat breeding programs.

Development of high quality oat varieties is a major objective in China. Breeding varieties with high protein content (more than 17%) began in 1990. Forage varieties should have green stems with high protein content at maturity and higher stature (over 120 cm). Today oat breeding programs focus on high quality, yield, drought tolerance, and diversified maturities. Improving the quality of oat varieties, particularly the β-glucan content, became a priority in order to meet processing requirements, particularly for oat flakes. Because oats are grown mostly in dry areas of Inner Mongolia, Gansu, Ningxia, it is important to have strong drought tolerance. Oats are planted as a second crop in a single season in areas such as Baicheng in Jilin Province. Improved varieties with short growing periods and photoperiod insensitivity are important in such areas.

3.4 Major breeding techniques used in oats

Landrace improvement. Initially, Chinese breeders mainly improved landraces. Varieties collected from local farms in the 1950s were very different in terms of agronomic traits. Breeders used population improvement to raise yields of landraces. They usually selected superior individual plants from large populations of particular varieties and formed new populations with improved traits. This resulted in varieties such as Sanfensan and Huabei 1.

Cross-breeding. Cross-breeding was popularly used to develop oat varieties after the 1960s. Varieties, particularly hulled types with useful traits such as high yield potential and lodging and disease resistance, were selected as parents and crossed with Chinese naked genotypes. Pedigree selection was then used to develop new varieties such as Jizhangyou 2, Neiyan 2, and Pin 6.

Irradiation treatment. Varieties Yanhong 3, Fuza 2, and naked oat "1809" were selected following gamma ray treatments of 15,000-25,000 Roentgen units at 100-150 units/min.

3.5 Descriptions of major oat cultivars

Yong 492 (Xiao 46-5) was released in Inner Mongolia under the name Yong 492 and in Shanxi as Xiao 46-5. It has spring habit, lodging resistance, strong tillering ability, and an intermediate response to BYDV. Seedlings are erect with short, erect, wide, dark-green leaves. Plant height is around 100 cm, and plant type is compact. The panicle spike is about 20 cm long, with 25-30 spikelets. Each spike generates 60-70 seeds with pale yellow color, spindle shape, and good quality. Its 1000-seed weight is about 19 g. Seed protein content is 14.4%, fat 4.6%, and lysine 0.57%. The growing period is about 85 days; yield potential is about 3,000 kg/ha under normal growing conditions and 4,500-6,000 kg/ha with irrigation and fertilizers.

***Huabei 2**, a* spring type naked variety, was widely distributed in Inner Mongolia, Hebei, and Shanxi Provinces in the 1960s. It has weak tillering ability and an intermediate response to BYDV. Plant height is about 120 cm, and panicle spike is 20-25 cm long with 21-23 spikelets. Each pale yellow spike contains 40-50 seeds. It has good quality and 1000-grain weight of about 20 g. It is prone to lodging under high fertility and irrigated conditions. Protein, fat, and lysine contents are 15.8, 6.7, and 0.56%, respectively. Its growth period is about 95 days; yield potential is 1,500 kg/ha under normal growing conditions and 3,750 kg/ha under high water and fertilizer levels. Huabei 2 is broadly adapted and well-suited for dryland or wetland soils with intermediate fertility levels.

Baxuan 3 was developed in 1961 by bulk selection from Hungarian variety 1-6-800 by the Zhangjiakou PARI in Hebei. It is characterized by good resistance to lodging and grain shattering. Plant height is about 100 cm. It has a panicle spike and 1000-grain weight of 21-22 g. Baxuan 3 is an intermediate to early naked oat, with a growing period of 85-90 days. It is suitable for irrigated plain conditions.

Jizhangyan 1 was developed in 1971 through intervarietal crossing by the Zhangjiakou PARI in Hebei Province. It is characterized by a semi-prostrate seedling habit, high tillering ability, and a panicle spike. Plant height is 110-130 cm, spike length 20-25 cm, and each spike contains 40-55 seeds. The 1000-seed weight is 26-28 g. The variety shows vigorous, uniform maturity with medium resistance to drought and lodging, but is susceptible to covered smut. The elongated grains contain 16.2% protein, 8.7% fat, and 0.513% lysine. It is intermediate maturing with a growing period of 85-95 days. Its yield potential is 1,800-2,400 kg/ha under normal growing conditions. The area sown to Jizhangyan 1 was 66,700 ha in the early 1980s. It is suitable for high fertility conditions in arid areas.

Pin 1 was bred from the cross Xiao46-5/Yong 118 by the Zhangjiakou PARI. It has a panicle spike and strong, thick stems. Plant height is 80-100 cm. Its 1000-seed weight is about 20 g. It is resistant to lodging and covered smut. Pin 1 is mid-early maturing with a growing period of 85 days. Its yield potential is 3,000-3,750 kg/ha under normal irrigated conditions.

Jinyan 1 was developed in 1973 from Huabei 2/Huabei 1 by the Crop Research Institute for Cool and High Land, Shanxi Academy of Agricultural Sciences (SAAS). Jinyan 1 has large spikes with many spikelets and strong, thick stems. Plant height is about 124 cm, and 1000-seed weight is about 24 g. Jinyan 1 is a late maturing variety with growing period of 104 days. Its yield potential is 2,737-3,247 kg/ha. It is suitable for wet, hilly areas.

Jinyan 3, selected in 1974 from Huabei 1/Sanfensan by the Crop Research Institute for Cool and High Land, SAAS, is characterized by semi-prostrate seedlings and strong stems. Plant height is about 124 cm, and 1000-seed weight about 23 g. It has medium tillering ability with high spiking rate, lodging resistance, drought tolerance, and wide adaptability. Jinyan 3 is a mid maturing variety with a growing period of 95 days. Its yield potential is 1,507-4,000 kg/ha. It is suitable for growing under both irrigated and arid conditions in Inner Mongolia, Ningxia, Shanxi, and Hebei.

Jinyan 4 was developed in 1980 from Huabei 2/Sanfensan by the Crop Research Institute for Cool and High Land, SAAS. It is characterized by semi-prostrate seedlings, relatively low numbers of short leaves, and a gray, waxy stem. It has a 1000-kernel weight of about 22 g and good tillering ability with high spiking rate, strong drought tolerance, and wide adaptability. Jinyan 4 is a mid maturing variety with a growing period of 88 days and yield potential of 3,900 kg/ha. It is suitable for growing in arid areas of northern China, but does not respond to high fertilizer and water conditions.

Neiyou 2 was developed in 1975 from Hebol/Jianzhuang by the Wumeng Agricultural Research Institute in Inner Mongolia. Neiyou 2 is characterized by medium tillering and 100-110 cm in height. The 1000-seed weight is 24-25 g. It has strong resistance to lodging, mid-early maturity, and a growing period of 85-87 days. Its yield potential is 4,185 kg/ha. It is suitable for intermediate to high fertility soils.

Neiyou 1 was developed from Huabei 2/Milfotd in 1974. It has strong stems and is 115 cm high. Its 1000-seed weight is 21-23 g. It has good tillering ability and lodging resistance, but is susceptible to stem rust. Neiyou 1 is a mid maturing variety with a growing period of 88-92 days. Its yield potential is about 4,176 kg/ha. It should be grown under high fertility conditions.

Neiyan 4. Derived from Jianzhuang/Yong 492 by the Inner Mongolia Academy of Agricultural Sciences, Neiyan 4 is characterized by spring habit, panicle spikes, and resistance to lodging and BYDV. Plant height is 100-110 cm, and l000-seed weight is 22-24 g. It is an early maturing variety with a growing period of 85-90 days. Its yield potential is 5,115-5,655 kg/ha, and it is mainly suitable for irrigated conditions.

Neiyan 5 developed from Yong492/Huabei 2 by the Inner Mongolia Academy of Agricultural Sciences, is characterized by spring habit, compact plant type, and panicled spikes. Its height is 115-120 cm, and its spindle-shaped panicles are yellow in color. The 1000-seed weight is about 20 g. It is tolerant to high fertility and irrigation, and resistant to lodging and diseases. This mid to early maturing variety has a growing period of 90 days. It has high yield potential (6,075 kg/ha) under optimal water and fertilizer conditions.

Mengyan 7312. Developed by the Inner Mongolian Academy of Agricultural Sciences, this variety is about 115 cm in height, with a 1000-grain weight about 20 g. It is early to intermediate in maturity with a growing period of 90 days.

Bayou 1 was bred by the Zhangjiakou Bashang Agricultural Research Institute in Hebei. Its plant height is 100-110 cm, and 1000-grain weight about 25 g. Its grain has a distinct elliptical shape and light-yellow color, about 15.6% protein and 5.5% fat. Bayou 1, a medium-term variety (90 days), shows strong resistance to lodging and is suitable for growing in a wide range of environments.

8309-6 was developed by the Dingxi Dry Area Agricultural Research and Extension Centre in Dingxi, Gansu Province. Its plants are 90-120 cm high and are characterized by a one-sided loose spike and yellow glumes. Its 1000-grain weight is 21-22 g, and its grain contains 12.1% protein and 6.7% fat. It has strong tolerance to drought and lodging. It is a medium-term variety, with a growing period of 93-110 days.

4. Applications of biotechnology in oat improvement

Molecular markers such as AFLP, RAPD, RFLP, and SSR have been used to characterize oat genetic resources. Chen et al. (2001) constructed a linkage map with 112 RFLP loci, and three horizontal resistance QTLs (namely, PRQ1, PRQ2, and PRQ3) were identified on oats. Wang et al. (2004) detected genetic diversity in 21 oat genotypes from 8 oat species using RAPD markers and confirmed a classification of these species similar to that achieved using the traditional method. Xu et al. (2009) analyzed the genetic diversity of Chinese naked oats using AFLP markers and found that accessions from Inner Mongolia and Shanxi were the most diverse, which made them potential parent materials for the oat breeding program. Molecular markers are also being used to map useful traits and genes. Research on identifying key genes controlling β-glucan content in oat grain is being conducted at the Institute of Crop Science (CAAS). Using in vitro culture, Zhang et al. (2000) selected calli and oat variants for resistance to high saline conditions and obtained a variant of salt resistant callus. Yang and Wang (2005) developed Huazhong 21, the first oat variety bred using issue culture.

5. Future prospects

In China, oat is not only a traditional food, but also a health food based on its functional components. Its grains and stems also make good feed and fodder. Due to the multiple uses of oats, there is a bright future for research on oat nutritional value, breeding methods, agronomic practices, and processing techniques.

5.1 Improving oats as a health food

Research has shown that the digestible fiber, particularly the β-glucan component, in oats can prevent and cure diabetes by reducing the levels of blood cholesterol, fat, and sugar. The β-glucan content in oat grain may vary from 2 to 7%, but higher levels are desirable. Therefore, breeding varieties with improved grain β-glucan content is a major objective of oat breeding programs.

In China, various traditional oat products are made by hand, including steamed dough roll, steamed dough drop, and several types of noodles. These foods are popular in rural households, and are being introduced to restaurants in the cities. However, manual processing of oat products cannot meet the increased need for oat-based foods in the cities. Thus oat processing has attracted researchers' attention and gained government support. Products such as oat flakes, oat porridge, oat instant noodles, and oat ice cream have become popular and provide more options for people to increase the amounts of oats in their diets.

5.2 Promoting oats for multiple uses

In addition to food, oats can be used for feed and forage, and as a crop for preventing desertification. In western China, particularly Xinjiang, Qinghai, and Tibet, oats are widely cultivated for animal feed. They will continue to play an important role in the development of animal husbandry in those regions. Also, research in western China has shown that oats can grow in very dry soils and thus have a potential use in preventing desertification.

5.3 Developing and adopting new technologies for oat improvement

Currently, many modern technologies such as molecular tools and in vitro culture are playing important roles in improving crops in China, and oats are no exception. Molecular markers will be widely used to identify and map desirable traits and genes in oat germplasm. They also will be useful for MAS in breeding programs. Such applications will be extremely important for selecting genes required to improve quality. Since oats are beneficial to health, research aimed at identifying the causes of those benefits will be a priority. But whether the breeding objectives are food- or feed-related, it is essential to breed varieties with high nutritional content, high yield potential, drought tolerance, and disease and pest resistance. Given the advances in gene cloning and transformation, there will be even greater opportunities to improve oats as a cultivated crop in the future.

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