

Breeding, production, and supply chain of confection sunflower in China[☆]

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Abstract – Over the past 40 years, confection sunflower in China has achieved significant improvements from old landraces to open-pollinated varieties (OPV) through conventional breeding. Starting in 2010, after a short period of growing U.S. hybrids, superior Chinese proprietary hybrids were developed through contributions from both the private and public sectors utilizing old landraces, OPV and limited foreign germplasms as genetic resources which eventually enabled China to become a leading producer worldwide. The average yields have steadily increased from 1730 kg/ha (OPV) to over 2700 kg/ha (hybrid) largely due to genetic improvements and advanced cultivation practices. The planted area is expected to remain at around 0.60 M ha, with over 95% confection sunflower, and the remaining 5% oilseed type. Sunflower production in China is mainly concentrated in 10 provinces of the northwest region with around three-fourth of the production in Inner Mongolia, followed by Xinjiang. The potential for increased sunflower cultivation remains optimistic in those regions due to the benefit of an established industrial supply chain of producing, processing, and marketing near the production areas. More than half of all products is domestically consumed (~2.0 MT/year), but overseas exports have gradually increased in recent years. Future directions for confection sunflower breeding should continue emphasizing high quality, multi-disease resistance, and product versatility to meet the diverse market demands. Further enhancement of variety registration and the implementation of DNA fingerprinting for variety identification will help the sustainable development of the Chinese sunflower industry.

Keywords: confection sunflower / China / breeding / production / consumer market

Résumé – Sélection, production et chaîne d’approvisionnement du tournesol de confiserie en Chine.

Au cours des 40 dernières années, le tournesol de confiserie a connu en Chine des améliorations significatives, passant d’anciennes variétés locales à des variétés issues de pollinisation libre (OPV), grâce à la sélection conventionnelle. À partir de 2010, après une courte période de culture d’hybrides américains, des hybrides chinois de qualité supérieure ont été développés grâce à des contributions des secteurs privé et public, en utilisant d’anciennes variétés locales, des variétés à pollinisation libre et un nombre limité de germoplasmes étrangers comme ressources génétiques, ce qui a permis à la Chine de devenir un producteur de premier plan au niveau mondial. Les rendements moyens ont régulièrement augmenté, passant de 1 730 kg/ha (OPV) à plus de 2 700 kg/ha (hybride), en grande partie grâce aux améliorations génétiques et aux pratiques culturales avancées. La superficie plantée devrait se maintenir à environ 0,60 million d’hectares, avec plus de 95 % de tournesol de confiserie et les 5 % restants de type oléagineux. La production de tournesol en Chine est principalement concentrée dans 10 provinces de la région Nord-Ouest, avec environ trois quarts de la production en Mongolie intérieure, suivie par le Xinjiang (à l’extrême ouest de la Chine). Le potentiel d’augmentation de la culture du tournesol reste important dans ces régions en raison de l’avantage d’une filière bien établie de production, de transformation et de commercialisation à proximité des zones de production. Plus de la moitié des produits sont consommés sur le marché intérieur (~2.0 MT/an), mais les exportations à l’étranger ont progressivement augmenté ces dernières années.

[☆] Contribution to the Topical Issue “Construire de nouvelles filières oléoprotéagineuses / Creating new oil & protein crop value chains”

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Les orientations futures de la sélection du tournesol de confiserie devraient continuer à mettre l'accent sur la haute qualité, la résistance à plusieurs maladies et la polyvalence des produits pour répondre aux diverses demandes du marché. L'amélioration de l'enregistrement des variétés et la mise en œuvre de l'empreinte génétique pour l'identification des variétés contribueront au développement durable de la filière chinoise du tournesol.

Mots clés : tournesol de confiserie / Chine / sélection / production / marché de consommation

1 Introduction

Sunflower is the third largest oilseed crop in the world after soybean and rapeseed (Pilorgé, 2020). The popularity of sunflowers is driven by its versatility as an oil, seed and livestock feed, and the growing awareness about health and as a leisure snack making it one of the fastest growing crops in the world. According to its oil content, sunflower can be divided into oil type and non-oil type. The oilseed sunflower has an oil content of 50–55%, and relatively low protein content at 16–19%. The non-oil type has an oil content of 35% or less and protein content of 25–30% (Škorić *et al.*, 2012). Sunflower oil is regarded as a premium edible oil due to its high polyunsaturated linoleic fatty acid concentration, low linolenic acid content and its excellent nutritional properties (Seiler and Jan, 2010).

Confection sunflower is developing a new trend in sunflower market segmentation, either used inshell (roasted or salted) for snack, or hulled for baking (Pilorgé, 2020), and has been commonly consumed in many countries, such as China, Russia, Ukraine, Hungary, Israel, Spain, and Turkey (Hladni and Miladinović, 2019). China has a tradition of eating (cracking) sunflower seeds representing almost half of the market consumption (Pilorgé, 2020). Sunflower seeds are processed either by dry roasting only (original flavor) or boiling and seasoned with different flavors. Sunflower seeds have long been the first choice in China for leisure, social events, and holidays due to its nutritional value, cheaper price compared to other nuts, and the unique cracking style of eating one seed at a time. The Chinese public prefers seeds that are large and long, with a dark black color with white stripes, and bright seed coat without scuffs on the shell. With its reputation as a healthy nutritional snack, consumption of confection sunflower is expected to increase following the growing demand in China and the overseas markets.

It is known that wild sunflower was first used by Native Americans for food and domesticated in the eastern U.S. by selecting tall, single-headed landraces in the 16th century, and subsequently spread throughout Europe. However, the sunflower did not succeed as a crop until it reached Russia around the end of 16th century and was quickly adopted as an oil crop (Seiler and Jan, 2010). Confection sunflower breeding has not received much attention until very recently. In 1999, the All-Russia Research Institute of Oil Crops (VNIIMK) initiated a special confectionary hybrid breeding program (Gontcharov and Beresneva, 2011). About the same time due to a sustainable market demand for confection sunflower, the Institute of Field and Vegetable Crops (IFVCNS), Serbia, began a dedicated confection breeding program, and has released a series of superior NS hybrids in recent years (Hladni and Miladinović, 2019). In the United States, high oil content

of oilseed sunflower has always been a major breeding objective and has been very successful. In contrast, non-oilseed hybrids were not introduced into the U.S. until 1974 (Seiler and Jan, 2010). Breeding for non-oilseed was less emphasized evidenced by the minor production ranging from 10–25% of the total production (USDA and NASS, 2018).

In view of its breeding history, sunflower is quite unique in that it has been bred for distinctly different uses, as an oilseed crop, or as edible food for confection use (Seiler and Jan, 2010). Sunflower breeding programs in Europe, America or other countries, whether in terms of germplasm resources or research professionals has mainly focused on oilseed sunflower. Other genetic materials or germplasms, for example, low oil types which could have been useful for confection sunflower were eliminated and abandoned (Gontcharov and Beresneva, 2011).

In China, breeding programs for confection sunflower were started very recently. However, due to its growing demands of the domestic and global markets, coupled with the increasing contributions from the private sectors, China has developed a series of elite confection hybrids with high yield and superior quality, and accounts for nearly half of the total planted areas worldwide (Tab. 1). Meanwhile, during more than 30 years of cultivation practices, various effective production technologies have been established. However, most of the breeding achievements and cultivation practices were published in Chinese, limiting their availability to the global sunflower community. By summarizing the progress of the entire industry chain of confection sunflower in China, including breeding, cultivation, production, processing, and marketing, it will help to facilitate and promote the sustainable development of the global sunflower industry.

2 Confection sunflower breeding in China

Confection sunflower is a new emerging economic crop in China. The breeding of confection sunflower has gone through different developmental phases, including growing old landraces in small patches, large-scale cultivation of open-pollinated varieties, predominately foreign hybrids, and more recently the emergence of proprietary domestic hybrids.

2.1 Farmer's selection of adapted landraces (1950–1990)

Sunflower cultivation in China has a long history dating back as early as the middle or late Ming dynasty (Zeng, 2005) around 1620 (Zhang, 1996). However, before 1950, sunflower was only grown in small patches for family use or as a garden flower. Baicheng Academy of Agricultural Sciences in Jilin was one of the earliest Institutes that had a sunflower breeding

Table 1. Recent planted areas of confection sunflower in the major producing countries.

Country	All types (M ha)	Confection type (ha × 10000)	Percentage of confection type (%)	References
Russia	8.50	100.00*	12	Demurin (2018)
China	0.59	56.00	95	Zhang (2020)
Ukraine	6.40	19.00	3–5	Hladni and Miladinović (2019)
Turkey	0.78	9.82	12	Tan and Kaya (2019)
USA	0.56	6.27	11	USDA and NASS (2018)
Argentina	1.86	3.00	2	Castaño (2018)
Serbia	0.22	1.15	5–10	Terzić <i>et al.</i> (2017); Hladni and Miladinović (2019)
Spain	0.70	0.70	1	Estimated

* The planting area of confection sunflower in Russia needs to be further verified.

program in China, initiating a conventional breeding program in 1955. Using introduced landrace Hungarian No. 1, the first variety Baikui No. 3 was released in 1962 and became a very popular dual-use variety in Jilin and other provinces (Jin *et al.*, 2008). In 1961, Taiyuan 80-day, another edible type released by Shanxi Academy of Agricultural Sciences and it was widely cultivated in the province (Liang, 1961) (Tab. 2). Due in part to the Cultural Revolution and political pressure, sunflower breeding was discontinued for almost 10 years from the end of 1965 until 1973. This may partly explain why Chinese sunflower breeding did not keep up with the rest of the world since the beginning. Instead, in Europe or the U.S., sunflower was widely accepted as a new oil crop with considerable interest as evidenced by the first International Sunflower Conference (ISC) held in College Station, Texas, U.S. in 1964.

Since the founding of the People's Republic of China, for over 40 years, the scientific research and breeding effort on sunflower was mainly devoted to oilseed sunflower due to its economic importance. A number of oilseed hybrids including Baikui No. 1, Neikuiza No. 1, Liaokuiza No.1 and Shenkuiza No. 1 were developed in the 1970s–1990s (Wang *et al.*, 1989; An *et al.*, 2006). The area planted to sunflower also increased rapidly. In 1985, it reached its first peak of 1.47 M ha, with a total production of 1.7 MT and an average yield of 1175 kg/ha. Heilongjiang was the leading province both in planted area and production. In contrast, confection sunflower as a snack food did not receive much interest in China. Most research Institutes did not establish independent confection breeding programs so very few varieties were developed. However, participatory breeding or on-farm selection by farmers over time generated a series of popular landraces in different growing regions, such as Sandaomei (Fig. 1), Xinghuo, Heilaoguzui, Baiyouke, Changling, Heidapian, Cunke, Shuokui, with farmers growing these indigenous varieties mainly for family consumption (An *et al.*, 2006; Zhang and Zhang, 2018; Yang *et al.*, 2019).

2.2 Large-scale cultivation of open-pollinated varieties (1990–2000)

The old landraces had good adaptability to local environments and strong disease resistances, but most of them were tall and branched, lacking uniformity in height and flowering,

and had low seed set. By the late 1970s, in response to an increasing market demands for edible sunflower, a group of research Institutes initiated independent confection sunflower breeding programs, and a large number of elite OPV were released (Tab. 2). The first OPV of commercial production, Gankui No.1 was developed by the Gannan Sunflower Research Institute, Heilongjiang, in 1989 using the mass selection method on a group of Chinese landraces. The area planted to this single variety reached 0.13 M ha in 5 years and became the most desirable variety for the roasting market (Sun and Liu, 1996). Since then, a series of OPV with higher yield and greater uniformity in plant and seed type have been produced, such as Gankui No. 2, Gankui No. 3, Baikui No. 6, Longshikui No. 1 through the population selection approach utilizing local or foreign landraces (Tab. 2) (Liu *et al.*, 2000; Guan 2003). Many of these became the leading local cultivars for that time. During this period, the major production areas were mainly concentrated in Heilongjiang, Liaoning, Jilin, Chifeng of Inner Mongolia, Yili and Tacheng of Xinjiang, with an annual planting area of 0.81 M ha, and an average yield of 1730 kg/ha (NBSC, 2021).

2.3 Foreign hybrids dominated the domestic market (2000–2010)

The very large kernels of confection sunflower can be widely used for direct human consumptions and be more profitable than that of oilseed types. In response to the market demand, the area planted to confection sunflower increased rapidly. In Heilongjiang province, the area under sunflower cultivation was around 0.25 M ha, with more than 95% non-oilseed (Fan, 2013). Similar changes occurred in Xinjiang and other regions, with confection production increasing annually. However, the most predominant varieties used in the domestic market at the time were still OPV. In contrast, since 1980, commercial hybrids with high yields and extremely uniformity were widely grown all over Europe and the U.S. replacing the OPV (Gontcharov and Beresneva, 2011; Hladni and Miladinović, 2019). Motivated by the considerable demands of the consumer markets, many Chinese seed companies began to introduce confection hybrids from the U.S. and European countries (Wang *et al.*, 2011). These hybrids had large seed size, uniformity of height and maturity and increased yield, and

Table 2. Characteristics of the OPV or hybrids released mainly by public research institutes prior to 2016.

ID	Variety	Variety (Chinese)	Released by	Year released	100-seed weight (g)	Seed length (cm)	Seed width (cm)	Kernel ratio %	Seed protein (%)	Maturity (day)	Yield (kg/ha)
OPV											
1	Taiyuan 80-day	太原80天	SXAAS	1961	7.6	–	–	60.5	–	81–91	2047
2	Baikui No. 3	白葵3号	BCAAS	1962	7.1	–	–	59.0	–	106	2587
3	Gankui No. 1	甘葵1号	GNSRI	1989	12.0	–	–	60.0	12.2	110	2025
4	Jinkui No. 3	晋葵3号	SXAAS	1991	12.5	1.9	–	60.0	24.6	–	2595
5	Jinkui No. 4	晋葵4号	SXAAS	1994	–	–	–	58.5	28.9	–	2041
6	Gankui No. 2	甘葵2号	GNSRI	1998	14.4	–	–	56.0	23.7	113	2073
7	Baikui No. 6	白葵6号	BCAAS	2001	13.0	1.7	0.83	56.5	20.3	120	1729
8	Longshikui No. 1	龙食葵1号	HLJAAS	2002	17.0	3.0	–	53.5	35.8	115	2450–3180
9	Chikui No. 2	赤葵2号	CFAAAHS	2003	23.0	2.5	0.90	51.0	26.4	120	3141
10	Longshikui No. 2	龙食葵2号	HLJAAS	2003	19.0	2.5–3.3	–	52.3	33.7	117	2649
11	Gankui No. 3	甘葵3号	GNSRI	2004	17.7	–	–	52.1	28.3	115	2637
12	Jinkui No. 7	晋葵7号	SXAAS	2005	12.3	2.0	–	56.3	–	–	2156
13	Longshikui No. 3	龙食葵3号	HLJAAS	2007	19.0	2.5–3.0	0.90	51.0	30.4	115	2404
14	Jinkui No. 10	晋葵10号	SXAAS	2009	14.0	2.3	–	51.0	26.2	97	3300–3750
15	Chikui 219	赤葵219	CFAAAHS	2010	18.5–20.0	2.4	1.00	–	–	115–120	3000–3750
16	Chikui 301	赤葵301	CFAAAHS	2012	16.6	2.1	0.9	48.9	–	115	3000–3750
Hybrids											
17	Liaokeza No. 1	辽磕杂1号	LNAAS	1995	12.9	2.2	–	58.0	31.2	96	3141
18	Liaokeza No. 2	辽磕杂2号	LNAAS	2006	17.1	2.3	–	55.4	21.6	105–115	3426
19	Longshiza No. 1	龙食杂1号	HLJAAS	2007	18.4	2.5	–	55.3	31.8	107	2716
20	JK102	JK102	BCAAS	2008	14.0	2.2	0.90	49.0	15.8	94	2131
21	Bakui 118	巴葵118	BAAAHS	2008	12.9	1.6	0.61	58.3	16.2	102	3008
22	Fengkuiza No. 1	丰葵杂1号	HBFK	2008	22.0	2.4	0.90	–	–	–	2625–3750
23	Keyang No. 5	科阳5号	IMAAAHS	2008	15.5	2.0	–	54.8	27.3	95	3937
24	Baikui No. 12	白葵杂2号	BCAAS	2009	11.0	1.9–2.0	0.76	50.2	16.5	97	3020
25	Keyang No. 1	科阳1号	IMAAAHS	2009	19.0	2.0	0.87	52.0	16.9	105–110	3603
26	Keyang No. 3	科阳3号	IMAAAHS	2009	15.8	1.9	0.80	56.5	16.4	100	3186
27	Longshiza No. 2	龙食杂2号	HLJAAS	2009	17.4	2.5–3.0	–	54.1	33.0	106	2661
28	T33	T33	IMAAAHS	2010	21.6	2.1	0.95	49.0	16.2	95	3620
29	Bakui 138	巴葵138	BAAAHS	2010	11.9	1.8	0.68	56.7	17.5	103	2956
30	Keyang No. 7	科阳7号	IMAAAHS	2010	16.0	2.0	0.87	53.0	16.1	95–100	3006
31	JK105	JK105	BCAAS	2011	12.7	2.0	0.85	51.7	15.2	95	1936
32	Liaokeza No. 5	辽磕杂5号	LNAAS	2011	12.8	1.9	0.80	–	–	–	3213
33	Taishi 762	太食762	SXAAS	2011	13.0–14.0	1.6–1.7	–	62.0	29.2	110	3000–3750
34	Xinshikui No. 7	新食葵7号	XJAAS	2011	–	1.9	0.77	59.9	15.1	104	3458
35	JK103	JK103	BCAAS	2012	15.2	2.1	0.82	51.1	16.0	103	3378
36	Xinshikui No. 8	新食葵8号	XJAAS	2012	14.3	–	–	53.3	16.1	105–110	3355
37	Xinshikui No. 9	新食葵9号	XJAAS	2012	14.3	2.0	0.86	55.8	17.0	105	3227
38	Chikui 2008	赤葵2008	CFAAAHS	2013	13.9–15.6	2.1	0.80	58.8	–	95–100	3300–3750
39	Chikui 2009	赤葵2009	CFAAAHS	2013	13.2–14.9	–	–	–	–	90–95	3300–3750
40	Chikui 5002	赤葵5002	CFAAAHS	2013	14.2–16.1	2.2	1.10	–	–	83–90	3000
41	Longkuiza No. 4	陇葵杂4号	GSAAS	2013	15.6–20.2	–	–	50.0	34.2	105–115	3847
42	Longshikui No. 4	龙食葵4号	HLJAAS	2015	17.6	2.2–2.8	–	52.5	33.6	106	3001
43	Longshikui No. 5	龙食葵5号	HLJAAS	2016	17.8	2.2–2.8	–	52.1	31.4	107	2782

BCAAS: Baicheng Academy of Agricultural Sciences; GNSRI: Gannan Sunflower Research Institute; HLJAAS: Heilongjiang Academy of Agricultural Sciences; IMAAAHS: Inner Mongolia Academy of Agricultural and Animal Husbandry Sciences; SXAAS: Shanxi Academy of Agricultural Sciences; LNAAS: Liaoning Academy of Agricultural Sciences; BAAAHS: Bayannur Academy of Agricultural and Animal Husbandry Sciences; XJAAS: Xinjiang Academy of Agricultural and Reclamation Sciences; GSAAS: Gansu Academy of Agricultural Sciences; HBFK: Harbin Fengkui Agritec Co., Ltd; CFAAAHS: Chifeng Academy of Agricultural and Animal Husbandry Sciences.



Fig. 1. Seed characters of representative old local landraces Sandaomei, black seed with white stripes.

quickly dominated the preferred market, with a price of \$15–30/kg for hybrid seed, some of them with even a higher price (Wei, 2008; Wu, 2011).

Market demand and profitability encouraged the emergence of numerous commercial seed companies. In 2007, there were around 41 large scale and many small scale seed companies in Bayannaoer that collaborated with around 20 companies from the U.S., Australia, Israel and other countries. More than 100 hybrids were introduced and released every year. Bayannaoer became the preferred field trial location for worldwide hybrid testing (Hou and Qiao, 2012). In Xinjiang during 1990–2010, of 55 hybrids marketed, 29 were introduced from overseas (Liu *et al.*, 2011). Similarly, during the 2006/2007 annual national production trials, among nine certified varieties, six were U.S. hybrids, including DC6009, RH316, 757C, 135, DK119 and RH1122 (Wei, 2008). DK119 was the first confection hybrid registered in Inner Mongolia. LD5009 due to its large seed (2.3 cm long) and high yield became one of the most popular hybrids grown in China accounting for about 133,000 ha in 2007 (Zhang and Zhang, 2018). SH316, SH909, 3638C, DC6009, DK88, X3939, RH1122, and RH3148 were also grown extensively nationally prior to the availability of domestic hybrids. The potential yield of new hybrids reached 3750 kg/ha, at least doubled than that of the OPV (~1730 kg/ha) and more than doubling the farmer’s income. The market share of hybrids reached 95% with the U.S. being the largest supplier of confection sunflower hybrids in China (Wei, 2008).

During the period, the area planted to sunflower in China remained stable at around 1.0 Mha with a total production close to 2.0 MT and an overall national average yield of roughly 2000 kg/ha, which was certainly not too high considering the probability of the coexistence OPV and hybrids for the time period (NBSC, 2021).

2.4 Sharp increase of domestic proprietary hybrids (2010–2020)

With the increase demand of consumers for seed quality, the weaknesses of the introduced foreign hybrids with thick hull, relatively small size (not suitable for cracking), less

flavor, and poor adaptability encouraged China to develop their own hybrids. Moreover, the price of imported hybrid seed was 5–10 times higher than that of domestic hybrids increasing the farmer’s costs (Wei, 2008; Tan *et al.*, 2010). In order to maintain a satisfactory level of self-sufficiency for the oilseed crop, the “China Sunflower Industry & Technology System” was launched in 2008. The System consisted of 110 team members from 10 provinces, which had the largest number of professionals from public Institutes in the history of sunflower research in China. Consequently, a large number of superior proprietary hybrids were released (Tab. 2). More recently a central government supported program, “China Special Oil Crop Research System” was established in 2017 through a joint collaboration among the scientists of sunflower, sesame and flax. With more policy support at the national level, leading private companies, as well as small seed companies began investing more in their own breeding programs. Initially, to solve the bottlenecks of limited breeding materials, a straightforward approach frequently used was the direct utilization of introduced foreign hybrids in the breeding process. For example, using their own elite inbred lines cross with the selected segregation progenies of foreign F₁ hybrids (*e.g.* DK118, LD5009), a new A/B-line with desirable performances could be selected through 5–6 cycles of selfing or back-crossing, similar to R-lines development (Li *et al.*, 2011, 2018; Pan *et al.*, 2019; Yang *et al.*, 2019; Lei *et al.*, 2021). According to statistics, among the hybrids registered in 2017–2019, about 68% possesses foreign-derived germplasm resources (Li *et al.*, 2021).

With benefits from advanced germplasm (particularly horizontal resistances in oilseed types) and breeding technologies worldwide, China has been making great strides in confection sunflower breeding. Since 2010, a series of high-yielding, premium quality and large seed size hybrids have been released, including SH363, SH361, JK601, Shuangxing No. 6, HZ2399, Ximeng 16, Gufeng 70, Liyuan No. 1, Tonghui No. 33, Xiya No. 1, etc. (see the recommended list for local growers by Bayannaoer government, BSMS, 2020) and many others, showing a sharp increase of available hybrids in the market. It is worth mentioning that among the above hybrids, SH363 has been the most popular since its release by Sanrui Agritech Co., Ltd. in 2013. SH363 (Fig. 2) has a mid/late maturity of 115 days, black seed with white stripes, bright color, and thin hull, particularly a unique crispy and tasty flavor, making it the most popular hybrid in the roasted seed market (with original flavor). With an annual planted area of 73,300 ha, SH363 has become a benchmark for confection sunflower production worldwide (Tian and Wang, 2018). The area planted to confection hybrids reached 0.77 Mha in 2016 (Zhang, 2018), the most area for confections in history.

With the rapid increasing of domestic hybrids, special issues of marketing supervision immediately stood out. Since 1980, in accordance with Chinese Seed Law, varieties of eight crops including sunflower have been mandated to be certified (at least two-year trials in multiple locations) to define the plant breeder’s rights and ensure the availability of high-quality seeds for growers before they are legally approved for marketing (Zeng, 2014). Starting in 2017, in accordance with Chinese Seed Law, the “Variety Approval System” was shifted to a “Registration System” for 29 non-major crops including sunflower (Zeng, 2014; Li *et al.*, 2021). Due to the simpler



Fig. 2. The leading hybrid of confection sunflower SH363, showing the head and commodity seeds.

market access for breeders, about 1280 confection sunflower hybrids were registered within 2017–2019, and approximately 90% of them released by private companies (Li *et al.*, 2021). Interestingly, more than 58% of varieties were registered by the Gansu province alone (38°09′–42°48′, Northwest China), a well-known experimental location for sunflower breeding and seed production. However, among the registered hybrids only a very few dominated the market with a majority planted in small areas or not even released. Sharp increases in the number of registered hybrids may not be attributed solely to the leading role of seed companies in hybrid development; it also reflected an imperfect registration system and lax market supervision. A considerable number of registered varieties may have been counterfeit or pirated, fake labels, or duplicate labels. In 2021, variety identification using molecular marker was officially implemented in sunflower (NY/T 3752-2020, MARA, 2020) providing a significant technological platform for variety protection and marketing supervision.

In summary, over the past 30 years, sunflower production has shifted from east to west (Fu *et al.*, 2019). The areas in northeast regions including Heilongjiang, Liaoning and Jilin significantly decreased in response to the threats from *Sclerotinia sclerotiorum* (Liu *et al.*, 2016b). Currently, sunflower production in Inner Mongolia ranks first in the country, and Bayannaer city (frost-free period 135-day, annual precipitation 188 mm, 14–18°C difference on day-and-night temperature) accounts for about 70% of the planted area in Inner Mongolia. Xinjiang ranks 2nd with the fastest growing area as evidenced by the many new regions of sunflower production. The total area of the sunflower production in China has ranged from 0.88 to 1.28 M ha, but total yields up to 3.2 MT have been obtained with an increased average yield of 2700 kg/ha. More than 95% of the total production is confection sunflower, and the foreign hybrids represented by the U.S. have been basically eliminated from the Chinese market.

2.5 Current situation and future direction of confection sunflower breeding

Being a new emerging crop in China, sunflower has been facing many challenges. As with most crops, seed yield has always been a main objective of breeding programs. The potential yield of sunflower hybrids was at least a 150% increase over that of the OPV (Vear, 2016). However, under competition from more profitable crops, such as GMO maize and soybean, sunflower has been pushed toward marginal and less favorable production regions (Fu *et al.*, 2019), similar to what happened in Argentina or Western Europe after 1992 (Castaño, 2018; Vear, 2016). Current yields of hybrids cultivated in a low input agricultural system are not stable, and the development of new genotypes tolerant to stress conditions needs to be emphasized. There are about 6.7 M ha of arid and saline alkali land in China. Sunflower is the most competitive crop suitable for less fertile soils. Therefore, development of new genotypes tolerant to stress conditions needs to be emphasized to ensure stable yields even in the low input agricultural systems. For the time being, more attention should be paid to high seed quality free of diseases driven by the demands of the ever-changing consumer markets.

2.5.1 Seed quality continues to be the top priority

Seed characteristics, particularly seed size, defines confection sunflower prices in the consumer market. For the roasting market, commodity seeds with uniform large size, premium quality, dark black seed color are more preferred with significantly higher prices. For the dehulling market, seed size and color are not strictly required, but high kernel to hull ratio and high protein content are preferred. Nowadays, the desirable commercial characteristics of confection type seeds include seed length \times width $> 2.3 \text{ cm} \times 1.0 \text{ cm}$, dark black seed with white margin, full-filled, crispy taste, 100-seed weight $> 20 \text{ g}$,



Fig. 3. Seed scarring characterized by spots on the shell. A: normal seeds; B: scarring seeds.

kernel ratio > 50%, high protein content (> 25%) and low oil content (< 35%); and the ideal plant height of about 190 cm (tolerant to lodging) and optimal maturity suitable for different regions.

Beside the seed characteristics mentioned above, improved oil content or composition are also desirable qualitative traits for confection sunflower (Demurin, 2018). Compared to the oil type sunflower, confection sunflower seeds have lower oleic acid (Li *et al.*, 2015b; Liu & Su, 2021) and vitamin E content (Dong *et al.*, 2005). Breeding for high oleic acid and/or high vitamin E content with better oxidative stability have long been a top priority for oilseed sunflower breeding and have been very successful (Demurin *et al.*, 1996; Haddadi *et al.*, 2012; Wen *et al.*, 2017; Alberio *et al.*, 2018; Hulke *et al.*, 2017; Hulke and Winkler-Moser, 2019). The broad genetic variabilities of the traits and the key genes associated with fatty acid biosynthetic pathway or vitamin E biosynthetic pathway in oilseed types provides valuable germplasm for improving oil quality in confection sunflower (Dong *et al.*, 2005, Li *et al.*, 2013). Progress in molecular technologies also provide promising tools to alter the fatty acid composition of the seeds for better quality for this crop (Subedi *et al.*, 2020).

2.5.2 Disease and stress resistance breeding

Confection sunflower has a stronger heterosis in many agronomic characters, such as plant height and head diameter, than that of the oilseed type (Li *et al.*, 2019). However, due to limited genetic diversity, confection sunflowers are more vulnerable to a majority of disease pathogens and stresses compared to the oilseed type. Currently, broomrape (*Orobanche cumana* Wallr.) has become the most limiting factor for sunflower production nationwide (Bai *et al.*, 2018), and *Orobanche* race E and F have become dominant biotypes in most production regions with new emerging races being observed (Zhang *et al.*, 2018). Recently, a series of elite hybrids with resistances to race F or higher races have been

released and would be the right choices for broomrape infested area. Additionally, due to the rapidly evolving of *Orobanche* virulent races, Clearfield Plus[®] hybrids with imidazolinone herbicide resistance used globally in oilseed sunflower (Sala *et al.*, 2008; Szalay, 2014; Castaño, 2018; Hladni and Miladinović, 2019) should be seriously considered for confection sunflower breeding (Hladni, 2016). *Sclerotinia* head rot is considered the most serious constraints to sunflower production in northeast provinces and Chifeng region in eastern Inner Mongolia (Huang, 2005; Bu *et al.*, 2014). So far, no commercial hybrids have an acceptable level of resistance to this pathogen (Wang *et al.*, 2019). Integrated disease management is still a practical choice of control in most cases. However, in Bayannoer, one of the most quality-limiting factors in this main production region is “seed scarring”, characterized by numerous spots on the shell (Fig. 3). A preliminary study showed that insect pests, particularly thrips, are suspected to be the most likely leading cause of seed scarring by scraping the ovaries during flowering (Dang *et al.*, 2019). Application of low-toxicity pesticides (hand or drone sprayer) significantly reduced the seed scarring and improved seed quality. Preliminary data from field trials showed that a few hybrids had much less severe symptoms under the same climatic condition (data not shown). Thus, future research for breeding hybrids with resistance to seed scarring is promising for sustaining sunflower production, particularly in the Bayannoer region. There are other diseases causing the significant damage to confection sunflower including *Sclerotinia sclerotiorum*, *Septoria helianthi*, *Alternaria helianthi*, *Diaporthe (Phomopsis) helianthi* and *Verticillium dahlia*.

2.5.3 Germplasm resource utilization

Diverse germplasm has been a valuable source of resistance genes for many common pathogens of cultivated sunflower and is considered an important strategic resource of agricultural production (Terzić *et al.*, 2020). A recent



Fig. 4. The provinces of concentrated sunflower production in China, with the main areas in orange.

pan-genome analysis of 493 sunflower accessions provided further supports for the contributions of wild species-derived introgressions for disease resistances (Hübner *et al.*, 2019). Currently, about 3200 sunflower germplasm accessions are maintained at the National Mid-term Genebank for Oil Crop (0–4 °C) in Wuhan with the majority of domestic self-bred lines and landraces, and about 13% of the introduced germplasms (Tan *et al.*, 2011). Due to the limited foreign germplasm exchange and introductions, the Chinese confection sunflower has an extremely low genetic variability and high genetic vulnerability, which also leads to the high similarities of the many hybrids seeking registration. Efforts in the collection and preservation of old local landraces, OPV, and introductions of foreign germplasms needs to be continued. The increasing attention of utilization of diverse germplasm has encouraged research Institutes and leading seed companies to create their own facilities for the *ex situ* germplasm conservation. More importantly, in-depth investigation of different agronomic traits, diseases and stress resistance in all germplasm collections needs to be emphasized to create a long-term phenotypic database relevant for gene discovery and genomic breeding. Development of highly resistant varieties by utilizing various resistance genes in wild *Helianthus* species, landraces and oilseeds types is crucial for the continuing success of confection sunflower.

2.5.4 Molecular technologies modify breeding procedures

Genetic improvement for confection sunflower in China still largely employs classical breeding targeting yield and quality. New discoveries and progress in molecular technology

and genomic sequencing in sunflower have modified traditional breeding methods and shorten the hybrid development process. Utilizing the public high-density SNP molecular map data (Bachlava *et al.*, 2012; Talukder *et al.*, 2014), a set of ~1500 high-quality (average PIC = 0.44) KASP markers in preference for confection sunflower has been developed recently through a collaboration between Sanrui Agritech Co., Ltd. and Huazhi Biotech Co., Ltd. (unpublished data). Such resources will provide a useful tool for background selection, marker-assisted selection, seed purity identification, and variety identification using fingerprint technology.

3 Cultivation and production technology

Sunflower production in China is largely distributed from northern latitude 35° to 50°, including Heilongjiang, Liaoning, Jilin, Inner Mongolia, Hebei, Shanxi, Shaanxi, Gansu, Ningxia and Xinjiang (Fig. 4). Approximately 77% and 18% of production are in Inner Mongolia and Xinjiang, respectively (Zhang, 2020). According to the national statistical data, from 1978 to 2018, the total sunflower area planted, including oilseed and non-oilseed types was relatively stable with minor fluctuations (NBSC, 2021) (Fig. 5). However, there is no separate statistic for the two types. In 1978, oilseed production accounted for about 10%. From 1980 to 1986, oilseed type was up to 60%. After 1990s, the proportion of oilseed has not exceeded 20% (Huang *et al.*, 2004). This was due to the high profit margin of the confection sunflower, with the areas of the oilseed type dropping significantly, and the confection

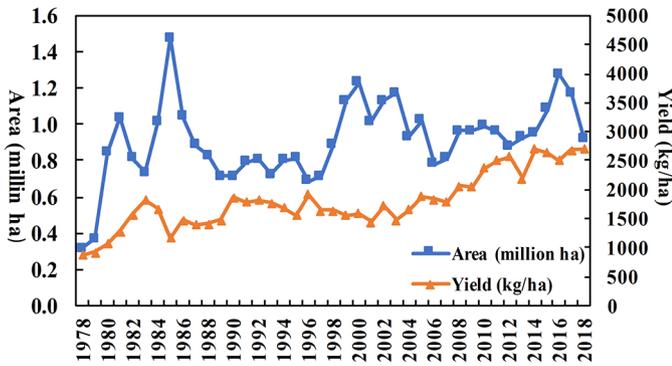


Fig. 5. Planted acreages and average yields of sunflower in China during 1978–2018.

production increasing to 95%. Over the past 40 years, the average yield has increased steadily from 1077 kg/ha in 1980 to 2707 kg/ha by 2018 (Fig. 5), with the highest yield up to 3800 kg/ha (Tab. 2), which is similar to modern NS hybrids (Hladni and Miladinović, 2019). This improvement was largely attributed to the availability of genetically improved hybrids, and the adaptation of advanced cropping practices.

3.1 Optimal sowing date

In China, sunflowers are sown from early April through mid-June, and the ideal sowing date varies with soil temperatures ($>10^{\circ}\text{C}$), climate conditions and variety maturity. Generally, mid-April is the most suitable sowing time for eastern Xinjiang and Gansu (Liu *et al.*, 2011), and Heilongjiang starts in the middle of May (Huang *et al.*, 2004). The optimal sowing dates for Inner Mongolia, Shanxi, Shaanxi and Hebei are from the end of May through early June (BSMS, 2020). Relatively late sowing is highly recommended within the long frost-free period, so that the flowering period (more susceptible to diseases and pests) does not coincide with high temperature, or to avoid rainy season during maturation (Tian and Wang, 2018).

3.2 Cultivation technology and planting density

Sunflower has a reputation of being “hard on the soil” and is mainly produced on less fertile dryer lands with low inputs. In the middle and west of Inner Mongolia, Gansu, Shanxi and other production regions, the growers commonly adopt the pattern of double row spacing using a plastic film covering (Fig. 6), and hand sowing. The inter-/intra-row spacing are 90 cm and 40 cm, respectively, with ~ 57 cm plant spacing, and a theoretical seedling population of 18,000–28,500/ha. In northwest China, plastic film is widely used for preserving temperature, soil moisture and grass control, and has a remarkable effect on increasing yield. For large acreage cultivation, such as Chifeng of Inner Mongolia and Xinjiang, integrated management of water and fertilizer covered with plastic film and mechanized seeding are a more common practice. Generally, seed size is closely related to plant density, the less density the larger the seed size. Some growers prefer late planting and lower planting density ($\sim 15,000/\text{ha}$), which

greatly improve disease management and seed quality. Sunflower cultivation is mainly single cropping system. However, in some regions, double cropping has become more attractive, such as cropping with wheat, melons, beans, potatoes, increasing net profitability (Dong *et al.*, 2013; Liu *et al.*, 2016a; Zhang and Zhang, 2018).

3.3 Harvesting and post-harvest management

About 40 days after anthesis, when the back of the head turns yellow, the bracts are yellowish brown, and the lower leaves are dry, then it’s time to harvest. Early harvest will reduce the yield, but late harvest is also not recommended due to seed shattering or head rotting, which seriously affects the commodity value. A practical natural drying technique or harvesting methods called “head cut and air-drying” was discovered by local growers and widely used in Inner Mongolia and Xinjiang. The procedure is once the sunflower has matured, first the head is cut off, then the stem is cut to half, and the head is placed back on the stem for natural drying (Fig. 7). After 3–5 days of drying, the heads are manually picked for mechanized threshing (Li *et al.*, 2015a). This hands-on method not only speed up disk dehydrate and post-maturation, but also preserves the seed quality and reduces impurities and molds. For large-scale producer, using modified combine for harvesting is becoming the trend due to the high labor costs.

4 Industrial development and regional advantage

Sunflower production in China is mainly concentrated in northwest regions and has obvious advantages. Due to the unique climate environments and high profitability of the sunflower crop, the potential for increased sunflower cultivation remains optimistic in those regions. Also, sunflower is marketed mainly after processing, which further promotes the establishment of an advanced industrial supply chain of producing, processing and marketing in the highly concentrated production regions to take advantage of local distribution.

4.1 Production and commodity stocking

Since the 21st century, the OPVs have been largely replaced by hybrids in China, and the areas planted to confection sunflower reached a record high in 2016 with total production of 3.2 MT (Fig. 5). This evolution with increases in both area and yield, coupled with decreased seed quality influenced by diseases and insect pests directly contributed to the huge production stocks in the market. As a result, the production prices dropped significantly, and farmers were reluctant to sell. At the end of 2016, nearly 60% of products were stored by farmers indicating an excess supply and reduced demand (Zhang and Zhang, 2018).

In 2018, the top hybrids planted were SH361 series (45%), SH363 series (30%), and other series (25%) such as JK601 and 3638C. In the consumer market, there are high-end commodity and regular commodity classes. High-end commodities



Fig. 6. Sunflower field showing double row spacing and plastic film covering.



Fig. 7. The natural drying method “head cut and air-drying”.

represent the seeds with characteristics of 100-seed weight >21 g, bright seed color and crispy taste. The distributor’s cost for those commodities (SH363) was \$1.0–2.2/kg, and the growers could have a better profitability compared to regular one (\$0.94–1.25/kg). After the Spring Festival of 2018, due to the sharp increase in foreign trade exports, the majority of domestic processing companies (roasting) had basically depleted their stocks (Chen, 2019). In 2020, due to the adverse weather, diseases and other factors in major production regions, the high-quality products were in short supply. The sunflower production of 2020 was 1.43 MT, and the market price of commodities had also decreased (Zhang, 2020).

To further reduce the market risk, “contracted production” is highly recommended and a wide collaboration among scientific researchers, farmers and enterprises should be considered. The breeding objectives should fully consider the needs of the consumer market, growers, and processing enterprises, to maximize the value of products.

4.2 Processing and trade

Compared to other oilseeds crops, confection sunflower is special in that it is largely processed (roasted or dehulled) in the production regions. It is well-known that Bayannaer of Inner Mongolia has the highest sunflower production and has

become the largest sunflower commercial center in China. There are 55 trading markets with an annual trading capacity of 1.43 MT. Among them, Hongding Agricultural Trading Market in Wuyuan County is the largest in western China, which integrates buying, sorting, processing, packaging and transporting into a complete cycle of the supply chain. The annual processing capacity is 0.65 MT (Wu, 2011; Zhang and Zhang, 2018; Zhuo *et al.*, 2019). In recent years, owing to its ideal climate conditions, Xinjiang has become the second largest sunflower producer following Inner Mongolia. Also, due to the short history in sunflower cultivation and proper cropping rotation in Xinjiang, sunflowers from this region have been commonly recognized for their premium quality and is the choice for high-end raw materials. Furthermore, industries near the production sites have allowed for the development of local brands such as Shalaoa, Tianshan, and Dingshan to expand outside of Xinjiang.

The annual value of sunflower hybrid seed sales is about \$94 M, the commodity product value is ~\$2.0 B, and \$4.7 B at the consumer level. There is no doubt that China has become the world's largest producer and consumer of the confection sunflower, and highly competitive in global market. China's confection sunflower products are exported to England, USA, Germany, Turkey, Iran, Egypt, Iraq, and many other countries. With "the Belt and Road Initiatives", China's sunflower export has been increasing year after year and has become the world's largest exporter of confection sunflower seeds (Zhuo *et al.*, 2019; Zhang, 2020). According to national statistical data, total sunflower production of China was 3.15 MT in 2017, 2.49 MT in 2018 and 2.66 MT in 2019 while the export volume of sunflower products reached 0.41 MT in 2017, 0.44 MT in 2018, and 0.46 MT in 2019 (NBSC, 2021; Zhang, 2020).

4.3 Potential boost to value added by-products

Sunflower can be used in the development of many high value-added by-products. With the increase of consumer's demand for animal products, demand for animal feed stocks will certainly follow. Sunflower stalks, heads and meals are all high-quality feeds of livestock, rich in crude fat and protein (Liu *et al.*, 2011). Meanwhile, the sunflower head is a good source of low ester pectin, which is widely used in food and medicine industry (Zhao *et al.*, 1996; Wang *et al.*, 2019). The natural active substances such as flavonoids, polysaccharides, alkaloids and chlorogenic acid extracted from sunflower heads can be widely used in health products and food industry (Liu *et al.*, 2011; Zhang *et al.*, 2020). The stalk residue can be used for fiberboard, package materials and sound insulation board (Wu, 2011). By integrated utilization of sunflower by-products, it is expected to further extend the industry supply chain and increasing farmer's income (Lu *et al.*, 2021).

5 Conclusions

Over the past 40 years, evolution of confection sunflower varieties in China has been quite dynamic, from old landraces to modern hybrids. The superiority of hybrids over open-pollinated populations in terms of uniformity, productivity, yield stability, oil content, and tolerance to pests and diseases shifted the breeding emphasis from population improvement to heterosis

breeding. Huge increases in improved proprietary hybrids in the recent two decades made China the top country in confection sunflower production representing almost half of the total acreage worldwide (Tab. 1). Nowadays, sunflower breeding programs have been developed through collaborations between private and public sectors aiming to increase the availability of more productive hybrids adapted to local conditions, making it a better crop for less fertile agricultural environments. Integration of classical breeding and genomic selection will certainly shorten the breeding cycle with molecular marker utilization no longer a bottleneck in sunflower research. In the future, global germplasm exchange should be encouraged for development of new hybrids with high quality, healthy, multi-resistance, versatile products to meet the ever-changing market demands. The complete cycles for the production chain from research breeding, production, contract growing, processing and marketing have been established, which would further promote the rapid and sustainable development of sunflower industry in China and worldwide.

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