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Progress and Perspective on Chinese State Field Trials for Sesame New Varieties in the Past 40 Years

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Abstract Chinese sesame state field trial began in 1983. Since then, 44 varieties have been recommended or approved by state sesame certification committee. Most of the listed varieties have been widely utilized in agricultural production. In this review, we summarize the main achievements in the past 40 years and point out existing problems in sesame regional field test after a brief retrospection in China. The advancement of sesame breeding was also summarized and highlighted by the performance of some representative new sesame varieties recommended by the national field trial. Then, the problems in sesame breeding and state field trial were discussed. Finally, we provided some suggestions for the sesame breeding and state field trial that may be of interest of the sesame community in future.

Keywords Sesame; State sesame regional field trial; Variety

Sesame (*Sesamum indicum* L.), also known as Sesamum, belongs to the sesame genus in the Apocynaceae family. It is an annual upright herbaceous plant growing in tropical and some temperate regions in the world (Ashri, 1998). Sesame is one of the major oil crops in China favored both by consumers and farmers because sesame oil is aromatic and having higher nutritional and economical values. Due to social progress and improving living standards, market demand for sesame product is rapidly growing (Yang and Huang, 2009). The annual cropping area of sesame is about 0.6 mha in China, accounting for one-tenth of the world. Moreover, the total sesame production in China is as high as 0.6-0.7 mt each year and accounted for one-fourth of the world's total yield. Therefore, China ranks first for both total seed yield and yield per unit, allowing sesame to be a preferred crop in the adjustment of agricultural structure and a traditional cash crop for exportation. However, the market demand for sesame in China is booming in the past decade, with an annual consumption of 0.8 mt sesame seeds. Of these, 0.2 mt are imported, making China a net import state. Therefore, the major objective for sesame breeders at present is to breed new varieties with higher yield and better quality to meet the market demand.

Sesame can grow all over China in the summer, especially in Henan, Hubei, Anhui and Jiangxi provinces. Currently, several serious problems exist in the development of sesame industry. First, the productivity of sesame is often low and unstable, plateauing at 1 050 kg/ha for a long time. Second, it has a poor disease resistance to stem blight and Fusarium wilt. So far, no accession is immune, or highly resistant. Third, poor quality (including seed appearance and low oil content) and thus less competitive in the consumption market. Fourth, poor lodging resistance and discrepant capsule maturity, which result in seed shattering and unsuitable for mechanized harvest. These problems often adversely affect seed yield and quality of sesame, causing up to 1/3 yield loss or even no harvest at all. Moreover, the growing area is decreasing since sesame is unable to be harvested by machine, and then hinders industry development.

Before extension and outreach of a new variety bred, it should be justified in the regional field trial for seed yield, quality, disease resistance, adaptability and stress resistance. The regional field trial is not only a connection

between breeding selection and variety extension, but also between variety certification and agricultural production. It can justify yield potential and adaptability and recommend a suitable area for a new variety. This information is key to the rational distribution of varieties and guarantees the safety of sesame production. In this review, we analyzed and summarized the sesame state regional field trial data in the past 40 years and discussed directions for sesame breeding and new variety certification (or identification) in the future.

1 History of Sesame State Regional Field Trial in China

1.1 Establishment of sesame state regional trial

As a traditional oil crop, sesame has been cultivated in China for more than 2000 years. In the early 1950s, the planting area of sesame in China fluctuated between 0.47 mha and 0.67 mha. Moreover, seed yield per unit was low and unstable, making sesame a 'small and unvalued crop'. However, much more attention has been paid to sesame in the 1960s after the foundation of a sesame department in the newly founded Oil Crop Research Institute (OCRI) attached to the Chinese Academy of Agricultural Sciences. Then research activities such as selection and breeding of new sesame varieties with high yield, high quality and disease resistance, germplasm innovation and related applied studies were carried out in OCRI. By field testing, road-showing and extension of a new variety, the transformation and application of sesame scientific and technological achievements were greatly promoted (Eds., OCRI, 2010, Annals of Oil Crop Research Institute, Chinese Academy of Agricultural Sciences, 1960-2009, pp. 118-119). In the first decay, the main task of OCRI is to evaluate sesame germplasm resources such as Landraces and breed new variety by systematic selection. Many varieties including Zhongzhi No.1 (1960, system selection from landrace 'Enshibaizhima'), Zhongzhi No.2 (1960, system selection from landrace 'Wuchangzhuganqing'), Zhongzhi No.3 (1964, system selection from landrace 'Wuchangzhuganqing') were bred within a short period (edit by OCRI, 1990, Chinese sesame variety, Agriculture Press, pp. 112-113). During the same period, Hebei Academy of Agricultural Sciences and Haikou Sesame Breeding Cooperative Group also began to carry out sesame breeding, leading to the release of Jizhi No.2 (old) in 1963 (selection from the cross 'Beijingbawangbian × Jiaohebawangbian'), Jiguang No.1 in 1963 and Jiguang No.2 in 1964 (system breeding of landrace 'Haizhima' after laser treatment) (Liu, 2015). In the 1970s, Xiongkou Agricultural Science Experimental Station of Qianjiang County, Zhumadian Agricultural Science Research Institute, Xiangyang Agricultural Science Institute as well as some other institutes began to work on sesame breeding. Xiongzhi No.1 (1972, system breeding from landrace), Zhuzhi No.1 (1973, selected from cross 'Nanyangliuleng × Shangcaizihuayeersan'), Xiangzhi No.2 (1979, system breeding from landrace 'Sanyeqi') and several other varieties were successively bred. All but one (Jizhi No. 2) Varieties bred in this period, however, failed to pass provincial field trials (Liu Hongyan et al., 2015). In the 1980s, large-scale sesame breeding was carried out in Henan, Hubei, Anhui, Hebei, Liaoning and other provinces and a considerable number of varieties were released. Accordingly, provincial seed administration authorities began to organize sesame regional field trials and new variety certification. Later, on behalf of the National Agricultural Technology Extension Service Center, OCRI began to organize and carry out nationwide sesame regional field trials. The regional field trial was initiated in 1983 by using two widely cultivated landraces as check varieties (CK). Until 1987, although none of the tested varieties was 5% higher in yield than the CKs, many of them were widely used in agriculture production to meet the requirement of farmers. From 1988 to 1989, Zhongzhi No. 5 and Zhongzhi No. 7 were bred by OCRI with outstanding performance. Both of them passed the state field trial and were certificated in 1990. They were the first two varieties released from state regional field trials.

After 1989, the procedure for the sesame regional experiment was optimized and standardized. The state sesame regional field trial was administrated by the Ministry of Agriculture Extension Service Center but managed by OCRI. At that time, only one zone (Jianghuai area) including 14 experimental locations spread across sesame main production provinces, including Hubei, Henan, Anhui, Jiangxi, Chongqing was set up in the regional field tests (during 1989-2001). From 2002 on, Chongqing was removed from the list and the total number of test sites reduced to 13. From 2007 on, all field experimental sites were divided into two ecological zones, namely Jianghuai zone (including 13 sites) and Huabei zone (8 sites newly added), both of which were managed by OCRI

but the later was hosted by the Hebei Academy of Agricultural and Forestry Sciences since 2008. As such, the framework and standard procedure for sesame state field trial were established.

However, the seed law of the People's Republic of China was amended in 2015 and implemented on January 1, 2016. As required by the law and to protect the legal rights and interests of breeders, sesame is no longer a crop that needs the official field trial for registration and certification. Therefore, the Agricultural Technology Extension Center did not host the state sesame regional test since then and all official field trials ceased.

1.2 Changes in state sesame regional field trial

In 1983, the framework and procedure for state sesame regional field trial were set up and carried out as planned. From 1989 to 2001, there were 14 experimental sites in Jianghuai zone but reduced to 13 from 2002 onward. During 1985 to 2006, there was only Jianghuai ecological zone in the regional test. In 2007, another ecological zone (Huabei) was set up, which included 8 experimental sites at the beginning but reduced to 7 one year later. Only yield, agronomic characters and disease resistance in field condition were investigated during 1985-2000. Quality traits such as seed oil content and protein content were measured from 2001 by the Oil and Product Quality Supervision, Inspection and Testing Center of the Ministry of Agriculture. Disease resistance was investigated in the lab by Henan Academy of Agricultural Sciences since 2007. Tu Lichuan, a professor from the Sesame Research Center in Henan Academy of Agricultural Sciences, introduced a male sterile line ms86-1 from the USA, by which the first hybrid sesame variety Yuzhi No.9 was bred by backcrossing (Tu et al., 1995, North China Agriculture, 10(1): 34-39). Then OCRI and Anhui Academy of Agricultural Sciences also made great progress in the breeding of sesame hybrid varieties (Liu and Zhao, 2010, Anhui Agricultural Science, 38(28): 15515-15516). Because the cost for hybrid seed production is high yet the seed yield per unit is low, a few sesame hybrid varieties (i.e. Yuzhi No. 9 in 2000, Wanzhi No.6 in 2013, and Wanzhi No.7 in 2014) were submitted to the state regional field trials and only Yuzhi No. 9 were approved. During the field trials, no suitable hybrid varieties could be used as CK for a long time, so the open-pollinated (OP) varieties were used instead in the hybrid variety field test, but with a higher approval standard (i.e. 10% higher seed yield than CK). Because of a small number of new varieties being tested and of a restrict standard, only Yuzhi No.9 (F1 hybrid) passed the state field trial in Jianghuai zone for 40 years. Although other varieties such as Wanzhi No.6 (registered in 2012), Wanzhi No.7 (registered in 2013) and Wanzhi No.10 (registered in 2014) passed the field trials in Anhui Province, they were grown and extended in a small scale.

The sesame industry boomed in the last two decades, which posed a new challenge to breeders. More emphasis was placed on the breeding of new variety with high-yield, good-quality and resistance to disease. Accordingly, along with seed yield, the seed quality and disease resistance traits were also concerned in the state sesame regional test. The criteria for registration of new sesame variety were upgraded from considering only seed yield trait to a comprehensive evaluation of seed yield, seed quality and disease resistance traits. Due to the high standard for new variety registration (seed oil content >58%, protein content > 25%, disease level <50% of CK), no variety with high yield, good quality and high disease-resistance was approved in the Jianghuai zone in the past 40 years.

1.3 Achievements of varieties registered in the state sesame field trials

Since the implementation of state sesame regional test, a number of elite varieties with outstanding characters have been approved and widely cultivated, which greatly promoted sesame industry and brought about remarkable social and economic benefits (Table 1). For instance, Zhongzhi No.11, Zhongzhi No.12 and Zhongzhi No.13 bred by OCRI received awards of Third-Class Prize of Scientific and Technological Progress of Hubei Province in 2007, Third-Class Prize of Scientific and Technological Progress of Hubei Province in 2012, First-Prize of Scientific and Technological Progress of Hubei Province in 2011 and First Prize of Scientific and Technological Achievement of the Chinese Academy of Agricultural Sciences in 2011, respectively. Yuzhi No.4, bred by Zhumadian Institute of Agricultural Sciences, was awarded the Second-Class Prize of Scientific and Technological Progress of Henan Province in 2004 (Zhang et al., 2017), and Zhenthi No.11 was awarded the Second-Class Prize

of Scientific and Technological Progress of Henan Province in 2006. Ezhi No.4, bred by Xiangyang Academy of Agricultural Sciences, was awarded the Third-Class Prize of Scientific and Technological Progress of Hubei Province in 2006. Ezhi No.5 and Ezhi No.6 were awarded the Third-Class Prize of Scientific and Technological Progress of Hubei Province in 2012; Ezhi No.7 was awarded the First-Class Prize of Scientific and Technological Progress of Hubei Province in 2016. Yuzhi No. 8 and Yuzhi No. 11, both bred by the Sesame Research Center of Henan Academy of Agricultural Sciences, were awarded the Second-Class Prize of National Scientific and Technological Progress (Zhang et al., 2017). Moreover, Yuzhi No. 9 (F1 hybrid) was awarded the Third-Class Prize of National Scientific and Technological Invention (Tu et al., 1994, Henan Agricultural Science, (5): 8-10).

Several new sesame varieties were recommended in the state sesame regional trials, which greatly improved the seed yield and disease resistance level. The seed yield increased from 750 kg /ha in the 1950s to 1350 kg /ha in the 1960s (Liu et al., 2019), and the stem blight index decreased by 40%. Three sesame varieties (i.e. Zhongzhi No.11, Zhongzhi No.12 and Zhongzhi No.13) with high yield, disease resistance and adaptability are suitable for growing in Hubei, Anhui and neighbor provinces. Of these, Zhongzhi No.11 has been widely extended and cultivated in large scale and brought about great economic and social benefits (China Science and Technology Project Innovation Achievement Appraisal Database, https://dbpub.cnki.net/). Meanwhile, Yuzhi series varieties are suitable for Henan and neighbor provinces, and Yuzhi No.8, No.9 and No.11 have been awarded national prizes (Zhang Teide et al., 2017). Yuzhi 4 was bred by Zhumadian Academy of Agricultural Sciences that exhibits high yield, stability and strong disease resistance, which was used as CK for a long time in the state regional field trials. It has also been widely cultivated for a long time and became a key parental line since from which as many as 21 new varieties were derived (Liu et al., 2015).

2 Main Achievements in the State Field Trial and Improvement of Test Methods

2.1 Forty-four new varieties registered

Since the state sesame regional field trial started in 1983, a total of 135 varieties has been tested, of which 32.5% (44) passed and were certificated. For the 135 varieties, 94 were tested in Jianghuai zone and 28 (29.8%) passed; the other 41 varieties were tested in the Huabei zone (later re-named as North China zone) and 16 (39.0%) were approved.

All the sesame varieties tested in Jianghuai zone were conventional white seedcoat color; except variety 96-137 (branched type), all were the non-branch type. Besides, apart from variety Wan9013-4 (exhibiting a mixture of 2,3,4 carpels), all varieties have 2 carpels. Unfortunately, neither of them passed the field trial examination. The conventional varieties tested in Huabei zone were a white or black color in the seed coat, and the majority was a non-branching type. Eighteen organizations are submitting new varieties to the field trials, of which 11 are research institutes and the rest of 7 are seed companies. Usually, seed companies withdraw from field trials 1-3 years later because of the poor performance of their candidate varieties. The competition of sesame breeding is mainly among those institutions engaging long-term research activity on sesame.

2.2 Optimizing field trial procedure

Once candidate varieties are submitted to the hosting organization, they were re-coded by giving a passport number, then re-distributed to each experimental site. The name and breeder of a candidate variety were decoded at state field trial meeting only when all tests finished so that the results are as objective and fair as possible. In the state field trial, a candidate variety must be subjected to two cycles of growth in small plots and one year of production in large scale. Only the outstanding varieties can pass the test and be registered.

Table 1 The list of new varieties released from state field trial and awarded by state or province in the past 40 years

Varieties	Source of parents	Breeder	Release year and approved by	Prizes or awards
Zhongzhi No.10	{Zhongzhi No.5 × [(Zihuayeersan × Zhongzhi No.1)×Suipingxiaozihuang] }×(Zhongzhi No.5×Tuochengtiegucha)	Oil Crops Research Institute, Chinese Academy of Agricultural Sciences	1997, National Sesame Variety Certification Committee	1996， Second Class prize, Wuhan City
Zhongzhi No.11	Yuzhi No.4 was induced by space flight	Oil Crops Research Institute, Chinese Academy of Agricultural Sciences	2003, Sesame Variety Certification Committee of Hubei Province and the state	2007, the Third-Class Prize of Scientific and Technological Progress, Hubei Province
Zhongzhi No.12	CLSU-9×Yiyangbai	Oil Crops Research Institute, Chinese Academy of Agricultural Sciences	2003, Crop Variety Certification Committee of Hubei Province; 2004, National Sesame Variety Certification Committee	2012, the Third-Class Prize of Scientific and Technological Progress, Hubei Province
Zhongzhi No.13	Yuzhi No.4 was induced by space flight	Oil Crops Research Institute, Chinese Academy of Agricultural Sciences	2005, National Sesame Variety Certification Committee	2011, First Class Prize of Scientific and Technological Progress, Hubei Province; 2011, First Class Prize of Scientific and Technological Achievement, Chinese Academy of Agricultural Sciences
Zhuzhi No.11	Zhu81043×Zhu7801	Zhumadian Academy of Agricultural Sciences	2003, National Sesame Variety Certification Committee	2006, Second Class Prize of Scientific and Technological Progress, Henan Province
Yuzhi No.8	Yiyangbai×Guanghuayitiaobian	Sesame Research Center, Henan Academy of Agricultural Sciences	Approved by Crop Variety Certification Committee of Henan Province 1993 and of Anhui Province in 1999; by National Sesame Variety Certification Committee in 2000	Second Class Prize of National Scientific and Technological Progress
Ezhi No.6	Ezhi No. 1×Yiyangbai	Xiangyang Academy of Agricultural Science	2007, National Sesame Variety Certification Committee	2012, Third Class Prize of Scientific and Technological Progress, Hubei Province
Yuzhi No.11	From the Yuzhi No.4 mutant	Sesame Research Center, Henan Academy of Agricultural Sciences	1999, Crop Variety Certification Committee of Henan Province; 2002, National Sesame Variety Certification Committee	Second Class Prize of National Scientific and Technological Progress

Continued Table 1

Varieties	Source of parents	Breeder	Release year and approved by	Prizes or awards
Yuzhi No.9	ms86-1×Danbage	Sesame Research Center, Henan Academy of Agricultural Sciences	1993, Crop Variety Certification Committee of Henan Province; 2000, National Sesame Variety Certification Committee	Third Class Prize of National Scientific and Technological Progress
Ji 9014	ZZM0273 heizhima×Jizhi No.1	Institute of Cereal and Oil Crops, Hebei Academy of Agriculture and Forestry Sciences	1998, Crop Variety Certification Committee of Hebei Province; 2009, National Sesame Variety Certification Committee	2000, First Class Prize of Scientific and Technological Progress, Hebei Academy of Agriculture and Forestry Sciences; 2000, Second Class Prize of Scientific and Technological Progress, Hebei Province
Fenzhi No.2	Jinzhi No. 2×Fen01-05	Institute of Economic Crops, Shanxi Academy of Agricultural Sciences	2009, National Sesame Variety Certification Committee	2020, Second Class Prize of Scientific and Technological Progress, Shanxi Province
Luozhi No.16	Zheng89H142×Yuzhi No.4	Luohe Academy of Agricultural Sciences	2006, National Sesame Variety Certification Committee	2007, First Class Prize of Scientific and Technological Progress, Luohe City; 2016, First Class Prize of Henan Agricultural Science System; 2017, Second Class Prize of Scientific and Technological Progress, Henan Province
Luozhi No.18	Luozhi No.12×Yuzhi No.4	Luohe Academy of Agricultural Sciences	2005, National Sesame Variety Certification Committee	2007, Second Class Prize of Scientific and Technological Progress, Henan Province

2.3 Testing more traits in the field trial

Being a summer crop, sesame can be cultivated all over the country, but mainly in Hubei, Henan, Anhui and Jiangxi provinces. Sesame is very sensitive to ecological conditions, so the variety can only grow well in the province where it was registered and nearby. The seed yield will decrease substantially if it is cultivated in a province with different climate conditions. Taking this into account, the National Agricultural Technology Extension Center set up new field trials (8 sites) in the Huabei zone (later re-named as North China zone) from 2007. The number of experimental sites reduced to 7 in 2008 and 2009, but increased to 9 after 2010, distributing in Jilin, Liaoning, Hebei, Shanxi, Shaanxi and Henan provinces. Meanwhile, the number of experimental sites in Jianghuai zone was 14 before 2001 but reduced to 13 from 2002, which spread in Hubei, Anhui, Henan and Jiangxi provinces.

Sesame shows various seedcoat colour. Varieties with white or black seedcoat are widely cultivated; black seeds are deemed to have higher nutritional value than the white ones. However, the yield of white sesame is higher than that of black sesame. To encourage the breeding of black sesame and make the test fair, a separate field trial was set up specifically for black-seed varieties within the Huabei zone by using black sesame line as CK. Since the beginning of field trials in Jianghuai zone, only white-seed candidate varieties were allowed to be tested. However, in the Huabei zone, both white- and black-seed varieties could be tested in the same regional field trials by using both black- and white- lines as CKs. The certification criteria are the same as that for white CK variety.

More traits, including seed quality (oil content and protein content) and disease resistance (charcoal rot and Fusarium wilt), were evaluated in the field trial. The level of disease resistance was either determined by investigating natural occurrence in the field or artificial identification in the laboratory.

2.4 Implementation of regional field trial

Each year, the organizer of the state regional field trial made a work plan and sent to all participants of the test in each experimental site. All key data specified by the guideline were collected regularly during the field experiment and a summary report was submitted to the host at the end of the experiments. The organizer of the field test randomly visited and inspected some of the experimental sites during plant growth to improve the field trial quality.

All data collected in the field trial were analyzed in the software termed ‘Special Analysis and Management System for Regional Test of Crop Varieties’ developed by the National Agricultural Technology Extension Center. Key parameters such as yield variant coefficients, ranking and stability were generated; a summary report is finally prepared, showing how good a candidate variety is in comparison to CK.

3 Extension of Representative Varieties Approved by the State Field Trial

3.1 Application of elite new varieties brings about huge social and economic impacts

Yuzhi No. 8 is a non-branching, medium-mature variety bred by the Sesame Research Center of Henan Academy of Agricultural Sciences. It is resistant to lodging, charcoal rot and Fusarium wilt, and having a high and stable yield. Yuzhi No. 8 were approved by the Variety Certification Committee of Henan Province in 1993, by Anhui Province in 1999, and by the National Sesame Variety Certification Committee in 2000. With wide adaptability, Yuzhi No. 8 was suitable for cultivation in the Jianghuai basin, Huanghuai basin and North China. Application and extension of this variety have significantly promoted the production of high-quality, high-yield and high-efficiency sesame in China.

Zhongzhi No.11 is selected from space mutated Yuzhi No.4 seeds in OCRI. It is a non-branching, white-seed, and having three flowers in each axis and 2 carpels in a capsule. Zhongzhi No.11 passed the national identification in 2003 and was awarded the Third-Class prize of Scientific and Technological Progress of Hubei Province in 2007. It has the largest area of extension and cultivation so far. The average seed yield of Zhongzhi No.11 was 1288.8 kg/ha in Jianghuai Zone Regional Trials, increasing by 11.82% than the CK, Yuzhi No.4. The highest seed yield hit 2283.6 kg/ha in the official field trial. Taken together, Zhongzhi No.11 was the best variety in term of seed yield and increasing rate since the “Ninth Five-year Plan”. This variety has been cultivated in Hubei, Anhui,

Henan, Jiangsu, Jiangxi, Hunan and other provinces over 43 mha in total, bringing about a social and economic benefit of 0.5 billion RMB (https://dbpub.cnki.net/).

Zhongzhi No.13 was also bred by OCRI from space mutated Yuzhi No.4 seeds, which has no branch, three flowers per axle, 2 carpels, and white seeds. It passed the state field trial in 2005 and was awarded the third-class prize of Scientific and Technological Progress of Hubei Province in 2011. It has wide adaptability and been widely cultivated in Hubei, Henan, Anhui, Jiangxi and other near provinces. Zhongzhi No.13 has the largest area of cultivation (73 mha) in China, providing the sesame industry with an economic benefit of > 0.6 billion RMB. The yield was 1014.15 kg/ha in the state field trial (Jianghuai zone), 13.04% higher than that of CK (Yuzhi No.4). It shows the highest amplitude of yield increase in the last decay (Chinese Science and Technology Project Innovation Appraisal Database, https://dbpub.cnki.net/). The whole-genome sequences of Zhongzhi No.13 have been published, providing huge genetic information for molecular breeding in future.

Yuzhi No. 4 was bred by the Zhumadian Academy of Agricultural Sciences. It was selected from the offspring of the cross 'Yiyang Bai × Zhuzhi No. 1' through improved seed selection method (Cao, 1991, Agricultural Science and Technology Communication, (11): 34). This variety was approved by the Anhui Variety Certification Committee in 1990, and by the State Crop Variety Examination Committee in 1992 (Liu et al., 2015). Yuzhi No. 4 possesses advantages such as drought resistance, waterlogging tolerance, charcoal rot and Fusarium wilt resistance, stronger adaptability and seed shattering resistance. The average yield of Yuzhi No. 4 per hectare is about 900 kg, which is suitable for planting in Huaibei and Jianghuai regions. It has been used as CK variety in Jianghuai regional trials for more than 20 years. It is also one of the most important parental lines to date, from which up to 21 varieties were bred (Liu et al., 2015).

Zhengzhi 98N09 was bred by the Cotton and Oil Crops Research Institute of Henan Academy of Agricultural Sciences using a combination method of crossbreeding and mutation breeding. After several rounds of pedigree selection, Zhengzhi 98N09 was bred, which has no branch, white seeds, three capsules per axle, 2 carpels per capsule and white flower (but light red on the base). The number of capsules per plant was 78 on average but as high as 150 under optimal growing conditions. Seed yield per plant is over 10 g. The seed is pure white with thin skin. One-thousand-seed-weight is about 3.0 g. Zhengzhi 98N09 has early maturity, high protein content in seeds, high yield and good agronomic characters. It passed the state field trial in 2004 and was recommended for cultivation in Henan, Anhui, Hubei, Jiangxi and neighbour provinces (Wei et al., 2004, Henan Agricultural Sciences, (10): 21-22).

Luozhi No.16 was bred by the Luohe Academy of Agricultural Sciences from the descendants of cross 'Zheng89H142 × Yuzhi No.4' using system breeding method. It is a white-seed variety with non-branch, three capsules per axle and 2 carpels per capsule. The plants can grow very fast, with plump capsules and fast-filled seeds inside. Luozhi No.16 was a new variety with high yield, high oil content, high efficiency and resistance to multiple diseases. It passed the state field trial in 2006 and was suitable for cultivation in Henan, Anhui, Hubei, Jiangxi and nearby regions (Zhang et al., 2007, China Seed Industry, (8): 56).

3.2 Breeding diverse varieties to cater to different consumers

Zhongzhi No.9, a black-seed variety with high yield and high quality, was bred by OCRI. It was certified by National Crop Variety Examination Committee in 1992 and approved by Hubei Crop Variety Examination Committee in 1993 (Chen Hexing et al., 1994, China Oil, 16 (4): 53-55). This variety exhibits black and large seeds, multiple branches, three capsules per axle and 2-4 carpels per capsule. Its yield exceeded 1500 kg/ha, and was awarded the second-class prize of Hubei Province (Yiming, 2001, China Agricultural Science and Technology News, 3 (4): 60)

4 Achievements and Problems in Sesame Breeding

4.1 Improvement in sesame breeding

Since the foundation of the People's Republic of China, sesame varieties have been upgraded for several times. With the application and extension of new varieties and cultivation technology, the production level of sesame has

been greatly improved. Most of the sesame varieties approved in the early stage are high- and stable-yield, high-resistance to diseases and high-seed-quality. For example, Zhongzhi No.7, Zhongzhi No.8 and Zhongzhi No.9 are the first batch of new varieties bred by crossbreeding. Zhonzhi No.7 is the first sesame variety bred by sexual hybridization between two lines in China, which has wide adaptability, high yield and strong resistance to disease (Editor-in-chief, Oil Crop Research Institute, Chinese Academy of Agricultural Sciences, 1990, Chinese Sesame Seed Variety Annals, Agricultural Press, P112-113). To solve the problem of waterlogging in sesame production, new varieties with high resistance to waterlogging were bred, including Zhongzhi No.10 (Gong, 1996, Hubei Agricultural Science, (1): 21-22), Zhuzhi No.11 (Sun, et al., 2006, Henan Agricultural Science, (5): 42-44), Yuzhi No.8 (Zhang et al., 2017) and Yuzhi No.9 (Tu et al., 1994, Henan Agricultural Science, (5): 8-10). Since the 1990s, sesame breeding has entered a new era, with emphasis on traits of high seed quality, high yield and high resistance to diseases. Several new varieties, including Ezhi No.6, Luozhi No.16 (Zhang et al., 2007, China Seed Industry, (08): 56), Zhuzhi No.11 (Sun et al., 2006, Henan Agricultural Science, (5): 42-44), Zheng 98N09 (Wei et al., 2004, Henan Agricultural Science, (10): 21-22), Zhongzhi 11 and Zhongzhi 12 were bred at this stage, which was the main varieties used in agriculture production at present.

4.2 Problems in sesame breeding

Breeding new sesame variety with high and stable seed yield has long been the primary target. To date, the frequently used breeding methods include system breeding, crossbreeding, disease resistance breeding, seed quality breeding and physical and chemical mutagenesis breeding. Some non-negligible problems were noted in sesame breeding, which included: (1) Narrow genetic basis in the breeding of new varieties. Most of the current bred varieties are related to the two key parental lines, i.e. Yiyangbai and Yuzhi No.4. According to the investigation of pedigree information, almost half of new sesame varieties are directly or indirectly derived from Yiyangbai or Yuzhi No.4 (Liu et al., 2015), indicating that the genetic basis of breeding materials is very narrow. (2) Breeding techniques and means is backward. In sesame breeding, traditional methods such as systematic breeding and conventional breeding were widely adopted but with low efficiency. A few varieties were bred by radiation mutagenesis, and no variety was bred by using distant hybridization (Zhongzhi 35, Yezhi2 and Yuzhi 4 were backcrossed repeatedly) and modern biotechnology. (3) Lack of diverse and groundbreaking varieties. Currently, no variety has been improved simultaneously for yield and quality, high oil and protein content, stress and seed-shattering resistance. (4) Ineffective utilization of germplasm resources. The State Medium Term GenBank of Oil Crop, the largest germplasm repository in the world, has conserved > 4000 sesame accessions but not yet been fully exploited. Therefore, elite sesame germplasm resources should be screened, identified and utilized in the breeding of new varieties with enhanced drought resistance and seed shattering resistance. (5) Lack of markers and technology for molecular breeding. Very few molecular markers are available for the marker-assist selection in sesame breeding practice. The efficiency of developing new molecular markers for traits of interest is low. In the future, more attention should be drawn to accelerating the application of modern biotechnology in sesame breeding.

5 Suggestions for State Sesame Field Trials

5.1 Sustainable funding for regional field test

Due to ever-increasing cost for experimental sites and labors, the existing funds are far from enough for field tests. Therefore, we suggested that steadily increasing financial input should be given to regional tails to maintain a stable team, improve the conditions of test sites and the quality of data collected in the test.

5.2 New organization for sesame variety certification (accreditation)

Since the implementation of the new Seed Law in 2016, sesame has been regarded as a minor crop, and the work for registration of new sesame varieties ceased. With the funds' support from Modern Agricultural Industrial Technology System, sesame state regional field trial is still running, but new variety examination and approval lag behind, leading to the fact that many breeders are inactive to submit new lines to regional trials. Therefore, a new framework should be set up as soon as possible; either the Sesame Industry Technical System or the Seed Association can be an organizer of sesame variety identification (registration). It will help the smooth transition to

a new framework of sesame variety certification, and then promote the breeding of new varieties and ensure the sustainable development of sesame industry.

5.3 Investigating more traits to enhance the breeding level

Sesame is sensitive to climate conditions. High temperature, water shortage, low temperature, rain and other adverse climatic conditions can bring about stem blight and Fusarium wilt. The poor performance of disease resistance, waterlogging resistance and drought resistance will directly result in the decrease of seed yield in sesame production. Therefore, traits related to the above-mentioned stresses resistance should be evaluated in the field trial, which will encourage breeders to pay more attention to the breeding of stress-tolerant varieties and thus ensure the safety of sesame production.

5.4 Reducing production costs by exploiting traits suitable for mechanized harvest

At present, the cultivation and harvest of sesame in China are still carried out mainly by hands, which is labour-intensive and cost-inefficient, and thus hinder large scale sesame production. To reduce the production cost, new sesame varieties should have traits suitable for mechanized sowing and harvesting. Moreover, the major breeding target should be focused on high yield, high seed quality and resistance to multiple stresses (diseases, drought, waterlogging, seed shattering, etc.).

5.5 Optimizing field trial sites

At present, the experimental sites in Jianghuai zone are relatively scattered, and the number of sites is also decreasing because field trial participants are unwilling to work on the field trial. Therefore, we should optimize the number and location of experimental sites and ensure the fairness of field trials.

5.6 Maintain a stable work team for field trials

To obtain good quality data from a field trial, stable work teams running the state field trials must be maintained. Moreover, the workers responsible for field trials should be regularly trained by experts from the administrative department, university and research institutes. Workers from each test site, should visit each other and exchanged their experiences to improve their professional ability as well as the quality of regional tests.

Author' contributions

Zhou Fang collected relevant literature, analyzed data and drafted the review. Zhao Yingzhong, Zhou Ting and Yang Yuanxiao participated in the analysis of data. Liu Hongyan conceived and supervised this project and finalized this manuscript. All authors read and approved the final manuscript.

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