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Research Progress on Chinese Silkworm Germplasm Resources and Variety Breeding

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Abstract

As the birthplace of the world's sericulture and the original center of silkworms, China has a long history of silkworm breeding and widely distributed sericultural areas. After long- term artificial selection and natural elimination, silkworm varieties have been differentiated and multiplied, making China abundant in silkworm germplasm resources. We have summarized the research actualities of Chinese silkworm germplasm resources as follows: at present, there are more than 4,500 silkworm germplasm resources, which are stored in 32 scientific research and teaching institutions in 27 provinces and cities of China. The resources fall into several major categories, under which are local varieties, improved varieties, imported varieties, multivoltine varieties, germplasm innovation materials and basic materials, gene mutation systems, tester strains and near-isogenic lines. By use of various germplasm resources, the People's Republic of China had bred 204 new silkworm varieties by 2010 since its founding. According to usage, these resources are divided into 103 varieties for spring rearing and spring-autumn rearing, 85 varieties for summer-autumn rearing and 16 varieties for special-purpose rearing. Some of these varieties were as transient as a fleeting cloud, whereas some others have become classics and made outstanding contributions to the development of China's sericulture.

Keywords: Silkworm Germplasm Resources; Collection; Preservation; Genetic Breeding; Classic Varieties

Introduction

China has a history of mulberry planting and silkworm breeding of about 5,000 years[1]. In the long-term production practice, the Chinese people gradually realized the importance of eliminating the inferior and retaining the superior for high- quality silkworm variety breeding. Therefore, natural selection, which was carried out on the principle of survival of the fittest, coexisted with artificial selection, which aimed to improve economic characters by eliminating the inferior and retaining the superior, to meet the needs of production. The original silkworm varieties in all the national sericultural areas, geographically isolated from each other, underwent natural selection in different ambient conditions and artificial selection for different targets, with variations constantly expanded, accumulated and evolved into more varieties, gradually forming various kinds of

silkworm germplasm resources with different genetic characters. These germplasm resources have become the most important material basis for bioresearch, such as the genetic breeding of silkworms, genetic engineering and even cell engineering.

Since its founding, the People's Republic of China has made great achievements in the research of silkworm germplasm resources and the selection and promotion of practical silkworm varieties. The following is relevant information for reference by readers.

Increasingly extensive and intensive research on the collection, sorting, conservation, evaluation and utilization of silkworm germplasm resources.

There are sericultural areas widely distributed in China. Currently, sericulture production is carried out in 27 provinces (autonomous regions and municipalities), with Beijing, Tianjin, Tibet and Qinghai excluded, and there are 32 sericultural scientific research and teaching institutions across the country. These scientific research and teaching institutions keep most of the national silkworm germplasm resources, totaling over 4,500, including local varieties, improved varieties, imported varieties, multivoltine varieties, germplasm innovation materials and basic materials, gene mutation systems, tester strains and near-isogenic lines (some repetitive resources are ex-situ-conserved).

The Institute of Sericulture, Chinese Academy of Agricultural Sciences is China's only national professional institute that specializes in mulberry, silkworm and cocoon research. In its early days after establishment (1951), the Institute conserved 329 silkworm germplasm resources, most of which were domestic varieties collected from peasant families all over the country[2]. With several generations' hard work in the past 60 years, the Institute has built a silkworm germplasm resource bank that covers the main sericultural areas in all the Asian, European and African countries, with the four major geographical systems included. In 2006, it founded the "Silkworm Germplasm Resources Conservation Center, Chinese Academy of Agricultural Sciences". The Center now conserves 1,316 silkworm germplasm resources with various biological characteristics and production characteristics collected from the world's 4 major geographical systems. The resources consist of 110 rare local varieties, 158 foreign varieties, 280 improved varieties, 30 multivoltine varieties, 326 gene-mutated materials, 390 breeding materials and 22 castor silkworm resources, some of which are the only copy extant in the world. Both quantity and variety rank top in the world[3].

While collecting, sorting and conserving silkworm germplasm resources, the Institute evaluated and appraised dozens of characters of some germplasm resources including morphological characteristics, physio-biochemical characteristics, disease resistance, stress tolerance and production performance, and clearly explained the genetic regularity of many characters as well as the correlation among those characters, detecting more than 300 high-quality materials with more than 20 special characters and creating many types of new sex-limited germplasms, which are fluoride pollution-resistant, anti- BmNPV, anti-BmDNV, egg-rich, naturally loose-egg, and unique in larval markings and egg color and cocoon color[4-9]. The institute has set up a silkworm linkage system of 28 linkage groups and a gene mapping system, and fostered a near- isogenic line for silkworm linkage groups. The Institute has started building DNA fingerprints for silkworm germplasm resources using the modern molecular biology technique and finished the construction of fingerprints for 510 silkworm germplasm resources using 100 SSR markers that cover all the 28 linkage groups, making it possible to identify various silkworms at the molecular level, analyzing the molecular genetic distance and genetic relationship among different varieties according to the fingerprints of various varieties and creating a silkworm germplasm resource database[10-12]. Based on this, it has set up a national silkworm germplasm resource website (http://www.cnsilkworm.com), making it feasible to search the data information of silkworm germplasm resources online. The Institute of Sericulture, Chinese Academy of Agricultural Sciences has compiled and published Silkworm Genetics and Breeding (Science Press, 1981) and Records of Chinese Silkworm Varieties (Agricultural Publishing House, 1987); the National Sericulture Industry System Breeding and Silkworm Function Research Institute has

compiled and published a series of books including Practical Pedigree of Chinese Silkworm Varieties (Southwest China Normal University Press, 2015), used as important references for genetic breeding of silkworms and breeding of varieties. In addition, the Institute of Sericulture, Chinese Academy of Agricultural Sciences has formulated norms and standards including Technical Regulations for Investigation and Monitoring of Silkworm Germplasm Resources, Technical Regulations for Collection of Silkworm Germplasm Resources, Technical Regulations for Sorting of Silkworm Germplasm Resources and Data Standard s for Silkworm Germplasm Resources, initially establishing a technical system for the collection, sorting, conservation, evaluation and utilization of silkworm germplasm resources.

In the long-term production practice scientific research and technical exchanges, the related organizations of Zhejiang Province have bred and promoted many new silkworm varieties. Zhejiang Province boasts an increasing number of silkworm varieties, including the original local varieties and various varieties brought in different periods. With germplasm resources expanding constantly, Zhejiang Province has become one of the very important silkworm germplasm resource bases in China. In the face of numerous silkworm germplasm resources, Zhejiang Province conducted three large-scale general investigations respectively in 1981- 1982, 1990-1991 and 2008-2009. By the end of 2009, had been 809 silkworm germplasm resources in Zhejiang Province, accounting for 23.2% of the national total. The resources included 63 bred varieties, 495 breeding materials and 251 varieties for special purposes and local varieties. The varieties for special purposes included 60 of sexual linkage balanced lethal system, more than 20 of female silkworm parthenogenetic clones and more than 50 sex-limited egg color system and sex-limited skin spot system[13-14]. After general investigations of resources, Zhejiang Province compiled and published Records of Silkworm Varieties in Zhejiang Province (Hangzhou University Press, 1993) and Silkworm Germplasm Resources in Zhejiang Province (China Agriculture Press, 2014). Later in 2010, it established the "Zhejiang Province Silkworm Germplasm Resources. Information Platform and Database Query System", on which there are more than 800 silkworm varieties and more than 4,000 color genetic maps. Every silkworm variety has 71 characters, occupies about 70 fields and carries more than 800 records[15]. The system provides a powerful modern means for the collection, introduction, research and utilization of silkworm germplasm resources.

The Southwest University has established China's first silkworm gene bank and sorted out more than 1,000 silkworm germplasm resources collected, introduced and created from the 1940s to the late 1980s, including various gene mutants, chromosomal variation systems and characteristic genetic material. It has also built a recourse bank with a perfect conservation system by appraising and analyzing the morphological, physiological and biochemical characters of variety resources. In the bank are more than 600 silkworm genes, and the mutant varieties conserved account for above 90% of the international total. Among them, there are more than 100 rare mutants and more than 60 firstly discovered mutants [16, 17].

By a hybridization assay, linkage search, three-point test and mapping of the mutation system, they have established a perfect silkworm linkage marker system, containing 230 gene markers in 28 linkage groups; established a gene mapping system with all the linkage groups involved (a recessive gene synthesis system); found mutant egg colors with genetic complementation and Type-III maternal hereditary egg colors and recognized the universality of the epistatic effect of white egg mutators; bred 28 morphological mutator-marked and mutually independent near-isogenic lines; developed a series of highly usable new mutator breeding materials featured by high feed efficiency, gender marker, naturally pigmented cocoon silk, disease resistance, euryphagy and controllable single sex incubation; establish ed a comprehensive method and technical management system for sustainable conservation of silkworm gene resources[18].

In addition, the provincial R&D institutions in national key sericultural areas also conserve a large number of local varieties and improved varieties. For example, the institution in each of Guangdong, Shandong,

Sichuan, Xinjiang, Yunnan, and Shanxi conserves more than 100 resources with distinct local characteristics. To be specific, Guangdong conserve 34 multivoltine varieties while the Guangxi Sericulture Guidance Institute conserves 21 castor silkworm varieties. In addition, there are also more than 130 tussah varieties and abundant giant silkworm resources in Heilongjiang, Liaoning, Henan and Jilin.

The level of practical silkworm variety breeding has been continuo usly improved while newly bred va rieties have successively played a r ole in production.

Abundant silkworm germplasm resources are an important material basis for the innovative development of sericulture technology. The genes with different characters contained in these resources, which can be used as rich materials for genetic breeding and breeding improvement, have played a vital role in supporting the sericulture industry, promoting sericultural scientific research and teaching and helping the silkworm raisers get rid of poverty and become better off.

During the 12th Five-Year Plan, on the basis of researching and sorting national bred silkworm varieties, "the National Modern Sericulture Industry Technology System" compiled extant commercial varieties and excellent varieties applied at different historical stages into Practical Pedigree of Chinese Silkworm Varieties, which contains 204 varieties developed after the founding of the People's Republic of China. According to usage, these resources are divided into 103 varieties for spring rearing and spring-autumn rearing, 85 varieties for summer-autumn rearing and 16 varieties for special-purpose rearing[19]. When it comes to practical silkworm variety breeding in China, the past 70 years can be divided into three stages: 1950s-1970s, during which introduced varieties and local varieties were separated, sifted and utilized; 1970s- late 20th century, during which new varieties were independently developed, accelerating the breeding of varieties with excellent economic characters and applying these varieties to sericultural production; late 20th century-today, during which there are requirements for the breeding effect and diversity of silkworm varieties.

Stage of separation, selection and utilization of introduced varieties and local varieties (1949-1980)

When it had just been founded, the People's Republic of China had a weak national power and poor foundation, so there were only a few institutions engaged in the genetic breeding of silkworms and they had weak technical forces. According to statistics, at that stage there were only 9 silkworm breeding institutions across China (in 6 provinces) and only 26 pairs of silkworm varieties within 30 years, accounting for 12.75% of the total number of bred varieties, 204 pairs. Successfully bred varieties include Hua 8×Yinghan, Hua 9×Yinghan, Hua 10×Yinghan, which were used for production in all the national sericultural areas. The cocoon shell rate, silk yielding, filament length and neatness of fresh raw cocoons of these varieties were 20%, 15%, 1100m and 89 respectively[20]. In the 1970s, an increasing number of scientific research institutes and technicians began to work on silkworm variety breeding, developing a number of excellent new silkworm varieties, such as Huahe×Dongfei, Huahe×Dongfei·671, Su 17×Su 16, Hang 7×Hang 8, and 871×872·734 (Chuancan 4), whose output and quality were improved to varying degrees.

Meanwhile, the breeding of silkworm varieties for summer-autumn rearing achieved some development at that stage, gaining some valuable breeding experience and laying a foundation for the breeding of silkworm varieties for summer- autumn rearing in the 1980s-1990s. For example, at this stage, the breeding institution in Guangdong Province bred varieties that could be reared in a hot and wet environment, including 115 South×Jiuhaibai, 306×Hua 10 and East 34×Su 12. The Institute of Sericulture, Chinese Academy of Agricultural Sciences developed bred varieties for summer- autumn rearing, including Su 3·Autumn 3×Su 4, Su 3×Su 4[21]. Zhejiang Province bred varieties for summer-autumn rearing such as East 34×603 and Zhejiang Agriculture 1× Su 12. The breeding and promotion of these robust varieties for summer-autumn rearing played a positive role in stabilizing summer-autumn cocoon production in China.

Stage of independent variety innovation, accelerated breeding of silkworm varieties with excellent economic characters and application of these varieties to production (1981-1995)

China's cocoon production over took Japan, ranking itself first in the world in the 1970s. In the 1980s, China established a silkworm variety identification system. At this stage, China's sericulture industry achieved great development and a large number of new silkworm varieties were used for production. In 1981, throughout the country there were 361,095 hectares of mulberry orchards, 10.146 million silkworm eggs and 251,953 tons of cocoons produced. By 1995, there had been 1,269,107 hectares of mulberry orchards, 27.31 million silkworm eggs and 707,921 tons of cocoons produced[22]. During this period, the silkworm variety breeding work was named a key scientific and technological research project for the "Seventh Five-Year Plan", "Eighth Five-Year Plan" and "Ninth Five-Year Plan". A number of high-quality silkworm varieties with proprietary intellectual property rights were bred and used for production, bringing about a great increase in the production quantity and quality of raw cocoon materials in China's sericulture industry. At this stage, there were 32 silkworm variety breeding institutions in 16 provinces (autonomous regions and municipalities) across the country. During the period of 15 years, 81 pairs of varieties were bred and approved by the national or provincial committee, accounting for 39.7% of the total number of bred varieties, 204 pairs.

The cocoon shell rate, silk yielding, filament length and neatness of fresh raw cocoons of these varieties bred at this stage reached up to 25%, 20%, 1400m and 94 respectively, reaching the international advanced level. Some of the varieties are still widely used in production today, such as those for spring rearing including Jingson g×Haoyue, Chun·Lei×Zhen·Zhu, Su·Ju×Ming· Hu, Su·Zhen×Chun·Guang, 871×872 and Sha njian 4; the varieties for summer autumn re aring include Liangguang 2, Qiufeng×Baiyu, Furong×Xianghui and Xinhang×Baiyun. After bred and promoted, the above varieties won the National Invention Prize (Furong× Xianghui), the National Prize for Progress in Science and Technology (Liangguang 2, Chu n·Lei×Zhen·Zhu) and the Provincial Prize for Progress in Science and Technology (Qiufe ng×Baiyu, Jingsong×Haoyue).

Stage of improving the breeding effect and diversity of silkworm varieties (1996-2015)

Along with the social progress and the constant improvement of people's living standards, there appeared requirements for the breeding effect and diversity of sericulture, a labor-intensive industry. The silkworm variety breeding work ushered in a period of time of high breeding and diversity.

Fortunately, sericulture, paddy rice, corn, wheat, soybean and other industries were included in the modern agricultural industry technology system (involving 34 crop products, 11 animal products and 5 aquatic products) during the "Eleventh Five-Year Plan" (2006-2010, as the 11th Five-Year Plan Compendium of the People's Republic of China for the National Economy and Social Development)[23]. As the central government continuously increased input in sericulture technology development, the technological forces were continually enhanced, the scientific research facilities were gradually improved, the breeding efficiency was steadily increased and the breeding speed was incessantly raised, with a great many new varieties bred one after another.

Soon afterwards, these newly bred silkworm varieties were promoted and applied in large-scale production, greatly enriching the silkworm germplasm resources, expanding the silkworm germpla sm resource gene bank and enhancing the effectiveness of genetic breeding. At this stage, there were 29 silkworm variety breeding institutions in 17 provinces (autonomous regions and municipalities) across the country. During the period of 15 years from 1996 to 2010, 97 pairs of silkworm varieties were bred and approved by the national or provincial committee, accounting for 47.55% of the total number of bred varieties, 204 pairs. Moreover, the breeding of these varieties was characterized by high effect and diversity[24].

Multiple crossbreeds (including three-way and four-way crossbreeds), which were developed in order to raise the breeding efficiency, were bred in abundance. Finally, 66 pairs were bred, accounting for 68.04% of the

total varieties bred at this stage, 97 pairs.

In order to cultivate robust varieties, some varieties could also be used for labor-saving spring-autumn rearing with less number of feeds a day; there were also varieties with some fluoride tolerance suitable for rearing in seriously fluorine- polluted areas; in addition, anti- BmNPV and anti-BmDNV were bred and promoted.

16 pairs of silkworm varieties for special purposes were bred, accounting for 7.84% of all the varieties bred at this stage, including 6 pairs of silkworm varieties with double sex-limited larval markings featured by easy sex discrimination; 3 pairs of colored cocoon varieties; 2 pairs of varieties featured by sex discrimination with cocoon fluorescence color; 1 pair of fine size trimolter varieties; 1 pair of sex-limited varieties.

In addition, 3 pairs of male silkworm varieties were bred (male silkworm rate>99%). As is known to all, male silkworm varieties are characterized by strong constitution, high livability, high leaf texture conversion rate, good cocoon quality and excellent silk quality. Currently, it has been promoted to Zhejiang, Shandong, Yunnan, Sichuan, Jiangsu and Guangxi, etc., with every silkworm egg bringing about over 20% more benefits averagely. The breeding and promotion of male silkworm varieties has made China the only country in the world to specialize in the large-scale rearing of male silkworms and the production of male silk in the world. The achievement won the Provincial Prize for Progress in Science and Technology by Zhejiang. Meanwhile, a large number of lines and varieties with a sex controlled gene have been bred into sex- linked balanced lethal lines, sex-limited egg color lines and female silkworm parthenogenetic clones, filling in the domestic gap, greatly enriching the national silkworm germplasm resource bank. These resources are precious ones for long-range research and utilization of silkworm breeding. This is one more technical leap in the development history of sericulture after the promotion and application of the first-generation crossbreed.

Along with the rapid development of molecular genetics and molecular biotechnology since the beginning of the 21st century, new techniques and achievements have been successively applied to animal breeding, e.g., molecular markers such as RFLP (restriction fragment length polymorphism), RAPD (random amplification of polymorphic DNA), AFLP (amplified fragment length polymorphisms), SSR (simple sequence repeats) and SNP(single nucleotide polymorphism) have been applied to the genetic breeding of silkworms one after another[25]. These molecular markers and silkworm genomics provide new ideas and targets for carrying out genetic breeding of silkworms without the limits of traditional resources. By use of the silkworm transgene technology, some targets have been successfully converted to the genetic breeding of silkworms, accumulating a large amount of transgene materials in terms of output, quality and resistance, and opening up new application fields including bioreactor and pest control[26].

National silkworm variety identification and approval work has been institutionalized and standardized

After its founding, the People's Republic of China kept improving and perfecting its mulberry silkworm variety identification and approval work, greatly promoting the development of silkworm production. In 1952, the East China Institute of Sericulture (now known as the Institute of Sericulture, Chinese Academy of Agricultural Sciences), drew up *Detailed Regulations for Silkworm Varieties*. After several years of practice, the Institute revised the draft of the *Detailed Regulations for Silkworm Variety Identification* in 1955 for implementation by all the breeding institutions in China. In 1958, the Institute of Sericulture, Chinese Academy of Agricultural Sciences organized Jiangsu, Sichuan, Zhejiang and Shandong to jointly identify 30 varieties, picking out Su 16×Su 17, etc., exerting some effects on silkworm production.

In 1980, he Ministry of Agriculture issued the *National Regulations for Silkworm Variety Identification* and the *National Detailed Regulations for Silkworm Variety Identification*, and founded the National Committee of Silkworm Varieties. Later, a great many new silkworm varieties passed the national identification and got extended to the whole country. In 2005, the state promulgated the Animal Husbandry Law of the People's Republic of China, which went into implementation in 2006; at the same time, silkworm was included in the adjustment range according to the Animal

Husbandry Law. In June 2006, the Ministry of Agriculture released and implemented the Measures for Administration of Silkworm Eggs in accordance with the outline of the Animal Husbandry Law. According to Article 11 of the Measures for Administration of Silkworm Eggs, before promotion, newly bred silkworm varieties should pass the national or provincial identification. A silkworm variety that isn't identified or fails to pass the identification shall not be put into operation or promoted in advertising. From then on, the national identification of silkworm varieties took the road of institutionalization and standardization, producing a far-reaching influence on the breeding of silkworm varieties in China.

Some typical varieties and their main characteristics

The breeding of new silkworm varieties has always been the core content of sericulture technology and the symbol of the development level of sericulture technology in various periods of time. Over the past 60 years since the founding of the People's Public of China, especially since 1980, when China established a silkworm variety identification system, China's silkworm variety breeding work has made significant progress, breeding, promoting and utilizing a great number of practical silkworm varieties. With strong adaptability and good economic characters, some varieties remain widely used in production and have become classics.

"Jingsong×Haoyue", a high-quality and high-yield variety for spring rearing

It was bred by the Institute of Sericulture, Chinese Academy of Agricultural Sciences and approved by the National Crop Variety Approval Committee in 1982. The Chinese parent "Jingsong" was bred of the female parent 781, which was constitutionally strong, easy-to-rear and capable of producing a bigger cocoon, and the male parent 757, which was featured by strong constitution, high moultinism, high livability, good appetite for mulberry leaves, high neatness and good combining ability, by several generations of breeding[27]. The Japanese parent "Haoyue" was bred of 782, which constitutionally strong and capable of producing a bigger cocoon, and 758, which was featured by high silk quality, high silk yield, high reliability and good combining ability, by several generations of breeding.

This variety has excellent economic characters, especially known for its high silk yield and high silk quality. Its promotion and application have contributed to the fourth time of upgrading of Chinese high- silk-yield varieties, and it has been China's No.1 high-silk-yield variety for more than 30 years. According to incomplete statistics, from 1982 to 2008, about 60 million eggs of Jingsong×Haoyue were promoted, making it the most highly promoted Chinese variety for spring rearing[28]. It is also a control variety for new silkworm variety identification, and its parents have been widely introduced into major breeding institutions in China as a basic material for new variety breeding.

Qiufeng×Baiyu, a fluoride-resistant variety for summer-autumn rearing

It was bred by the Institute of Sericulture, Chinese Academy of Agricultural Sciences and approved by the National Crop Variety Approval Committee in 1989. Later in 1990, it was approved by the Zhejiang Provincial Variety Approval Committee.

With the acceleration of urban industrialization and the booming rise of township enterprises in the late 1980s, there was increasingly more fluorine in the industrial waste gas, whereas fluorine pollution control was relatively lagging. In this context, mulberry leaves were polluted more and more seriously by fluorine (according to the research by the department concerned of Tongxiang City, Zhejiang Province, the fluoride content in mulberry leaves generally ranged from 40 to 80mg/kg, or up to 50~110mg/kg in in autumn), posing a serious threat to the whole country, particularly Zhejiang. Therefore, breeders decided to breed a fluoride-resistant silkworm variety.

In addition, to improve the breeding efficiency of the parent variety and reduce the labor intensity of pupa sex determination, the variety was bred into a Chinese skin-pattern sex-limited race. So, the Chinese skin-pattern sex-limited race 755 was chosen as the parent and hybridized with the Chinese variety 37 (a plain silkworm). After several generations of breeding, the hereditary character "skin-

pattern sex-limited" was fixed, breeding Qiufeng[29].

In the breeding process of this variety, each generation was fed with mulberry leaves rich in fluorine. The fluorine content in mulberry leaves was above 40mg/kg in spring and above 60mg/kg in autumn. After many generations of breeding with mulberry leaves rich in fluorine, Qiufeng×Baiyu acquired high fluoride-resistance, and for the Chinese parent variety, the sex could be determined by markings at the fifth instar. Owing to the above characteristics and more, such as large cocoon (average whole cocoon weight and yield of cocoons produced by then thousand silkworms reach up to 2.02g and 20.31kg respectively), high silk quality (average reliability >80%), and stably high cocoon filament quantity and neatness (>95), the variety is widely reared in summer and autumn in the Yangtze River Basin. It is reared throughout the year in Zhejiang Province; it has become a control variety for the national identification of silkworm varieties for summer-autumn rearing.

Liangguang2(932·Furong×7532·Xiang hui),a silkworm variety for summer autumn rearing

Bred by the Guangxi Zhuang Autonomous Region Sericulture Guidance Institute (focused on high temperature resistance and silk quality) and the Institute of Sericulture, Guangdong Academy of Agricultural Sciences (focused on fluoride and disease resistance), this variety was approved by the Guangxi Zhuang Autonomous Region Crop Variety Approval Committee in 1992 (Approval No.105) and by the National Mulberry Silkworm Variety Identification Committee (GS11002-1995) in 1995.

Liangguang 2 (932·Furong×7532·Xi anghui) is a four-way crossbreed for summer-autumn rearing of duovoltine- polyvoltine "China·China×Japan·Japan". The parents of this variety are easy to rear and breed and lay plenty of eggs; the reproduction coefficient is 20%~25% higher than the previous varieties for summer-autumn rearing, with the benefits of silkworm egg production greatly improved; featured by high livability, stable yield and high silk quality, the crossbreed is suitable for summer-autumn rearing in many provinces in South China including Guangdong and Guangxi[30].

As the first four-way crossbreed to be developed in South China, Liangguang 2 has been used as the No.1 variety in South China including Guangdong and Guangxi since the 1990s. Applied on so large a scale and having brought about so great economic benefits, it has rewritten the history of varieties for summer-autumn rearing. Moreover, it is promoted and applied in Sichuan, Fujian and Guizhou in hot seasons; in recent years, it has been introduced into East China, including Jiangsu, Anhui and Shandong, for summer- autumn rearing. It has been used in some Southeast Asian countries, such as Vietnam, as well as Laos, Thailand, and Cambodia, for many years. Since its promotion, the variety has occupied over 70% of the sericultural market in Guangxi and Guangdong, making a significant contribution to the development of sericulture in South China and even the whole country[31].

"Qiu·Hua×Ping 30", a male silkworm variety

Bred by the Institute of Sericulture, Zhejiang Academy of Agricultural Sciences, the variety was approved by the Zhejiang Provincial Variety Approval Committee in 2005 (2005-024). The Chinese parent Qiu•Hua is a crossbreed bred of the skin- pattern sex-limited varieties "Qiufeng" and Huaguang. Only female moths were utilized for breeding of a male hybrid; to reduce the cost of male silkworm egg production, male white silkworms were eliminated on the second day of the 4th instar while female colored silkworms were fed alone.

Ping 30 is a new silkworm sex-linked balanced lethal line with excellent economic characters bred of the original silkworm sex-linked balanced lethal line S-14, introduced from Russia, as the donor parent and the Chinese practical variety Baiyun as the receptor parent using the self-designed silkworm sex-linked balanced lethal gene transduction method[32].

Qiu·Hua×Ping 30 is a three-way crossbreed bred of a pair of bivoltine tetramolter varieties for summer-autumn rearing. Since it's a hybrid of balanced lethal male silkworms, there is only the direct cross and no reciprocal cross. Almost all female eggs die at the embryonic phase, and the rest meet a natural death in the 1st- 2nd instar after hatching while only male silkworms can achieve normal development. The percentage of male

silkworms is above 99%. Male silkworms are robust and easy to rear. The dried cocoon shell weight is 2~3 grades higher than common varieties and silk yielding is 2~3 percentage points higher. The cocoon can be made into 5A and 5A-grade raw silk. With a high leaf-silk conversion rate and economic benefits significantly higher than other common conventional varieties, the variety has obvious social and economic benefits and broad application prospects[32].

Nuclear polyhedrosis-resistant variety Huakang series (Huakang 1, Huakang 2 and Huakang 3)

In the 1990s, with the development of China's economy and the acceleration of urbanization construction, a change took place in the rural labor force structure, confronting sericultural production with a number of problems such as rural productive labor reduction, extensive rearing and difficult implementation of silkworm disease prevention and control technology[33]. As a consequence, silkworm diseases broke out one after another, and nuclear polyhedrosis was the principal silkworm disease. 86.92% farmers reported this disease during the rearing of silkworms[34]. What's worse, this disease was very hard to prevent and control upon outbreak, thus leading to serious yield reduction and even zero yield. It was widely believed that the best solution to this problem was to breed a high-quality and high-yield silkworm variety highly resistant to nuclear polyhedrosis.

Huakang series are new silkworm varieties highly resistant to BmNPV bred by the researchers at the Institute of Sericulture, Chinese Academy of Agricultural Sciences in order to stop the great losses caused to sericultural production by the frequent outbreak of nuclear polyhedrosis. Of the series, Huakang 1 is an anti-BmNPV variety for spring-autumn rearing that can be reared in the Yangtze River Basin and southwestern China; Huakang 2 is an anti-BmNPV variety for summer-autumn rearing bred of Qiufeng×Baiyu, a variety for summer- autumn rearing, with major genes resistant to BmNPV imported into the body[35]; Huakang 3 is a high- quality high-yield anti- BmNPV variety bred of Jingsong×Haoyue, a high-silk-yield variety for spring variety, with major genes resistant to BmNPV imported into the body. Huakang 1 and Huakang 3 were approved by Sichuan Province in March 2011 and March 2018 respectively. Huakang 2 was approved by Guizhou Province and the Guangxi Zhuang Autonomous Region in July 2013 and August 2016 respectively.

Being popular with the market and silkworm raisers, Huakang series were promoted to 18 provinces (autonomous regions and municipalities) quickly within just a few years. Now more than 4.6 million eggs of the series have been introduced into 2/3 of the major sericultural areas across China, bringing in direct economic benefits of RMB20.77 billion and a profit of RMB2.26 billion; at present, as a major achievement in the national modern agricultural industry technology system (sericulture), the Huakang series are playing an increasingly important role in sericulture industry structure adjusting, targeted poverty alleviation, rural revitalization and the implementation of other relevant national strategies.

Conclusion

Great achievements have been made in the collection and preservation of China's germplasm resources. Some soil species in remote areas have been salvaged, a number of rare and mutated gene resources have been excavated, genetic, physiological, ecological and systematic studies have been carried out on the germplasm resources, a number of new gene resources have been created by using modern biotechnology, and a number of professional talents have been cultivated.

Silkworm breeding science has made remarkable achievements, cultivated more than 200 varieties, realized five large- scale renewal of practical silkworm varieties in China, guaranteed the sustainable development of China's sericulture industry, and maintained the world dominance of China's cocoon and silk industry.

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