With support from

Federal Ministry of Food and Agriculture

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GFA CONSULTING GROUP
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Berlin Office

Sino-German Agricultural Centre, 2nd Phase

中德农业中心
Deutsch-Chinesisches Agrarzentrum

Study:

Investigation on the Value Chain of Soybean in China

From Breeding, Planting to Processing

By Li Yumei

Beijing, March 2020

Implemented by

IAK AGRAR CONSULTING

IAMO Leibniz Institute of Agricultural Development in Transition Economies

In partnership with

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Published and edited by:

Sino-German Agricultural Centre

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List of Abbreviations

CAAS	Chinese Academy of Agricultural Science
CNV	copy number variation
CO_2	carbon dioxide
CPC	the Communist Party of China
GDP	gross domestic product
GWAS	genome-wide association study
IPCC	Intergovernmental Panel on Climate Change
MG	maturity group
PAV	presence/absence variation
PLC	Programmable Logic Controller
PRS	photoperiod response sensitivity
PTCRS	light temperature comprehensive response sensitivity
QTL	quantitative trait locus
SL	reconstructed lipids
SRES	Special Scenario Emission Report
t/d	ton/day
TRS	temperature response sensitivity
WTO	World Trade Organization

1. Status of Genetic Resources of Soybean in China

1.1. Genetic Resources of Soybeans in China

The cultivation of soybean originated in China about 5000 years ago, leading to the richest diversity of soybean in the world. Until the year 2000, more than 23,000 cultivated soybean germplasm resources have been collected in China, which preserved the most abundant genetic resources of soybean in the world[1]. Wild soybean species are widely distributed in China, and the domestication of soybean is not clarified yet[2]. In the early research, the origination of soybean was explored mainly by referring to historical data and agricultural archaeology. It was proved that soybeans mainly originated in the north of China, especially in the mountains and basins of Liaoning, Hebei and Shanxi provinces[3]. In the 20th century, the rapid development of modern molecular biology provided useful measurements for the study of seeds and genetic resources, e.g. with the application of high-throughput sequencing technology, researchers have conducted a series of studies on the origin and evolution of soybean at molecular levels[4]; synchrotron radiation X-ray microscopy and other technologies such as quantitative trait locus (QTL) and genome-wide association study (GWAS) technology have measured and reconstructed the pore structure of modern and ancient carbonized soybeans[5]. Qiu Lijuan, the leader of Genetic Resources of the Soybean Group of the Institute of Crop Science, Chinese Academy of Agricultural Science (CAAS), has been engaging in the collection, evaluation and innovation of soybean germplasm resources for a long time. Her group systematically clarified the genetic diversity of soybean resources, constructed a representative series of core germplasm, which has been widely used in the research of excellent germplasm identification and genome mining. They also improved the quality of soybean resources by first constructing wild soybean pan-genome. The characteristics of intraspecific structural variations (such as copy number variation (CNV), presence/absence variation (PAV)) of soybean were clarified at the whole genome level, and the marker /QTL related to important characteristics were explored. The molecular markers or functional genes were developed, and resources were identified, which promoted the transformation of resource identification[6].

1.2 Status of Soybean Breeding in China

Because of the huge area of China, the planting of soybean varies according to the local climate. Han Tianfu, National Engineering Laboratory for Crop Molecular Breeding, the Institute of Crop Science, Chinese Academy of Agricultural Science, investigated that the soybean planting areas could be divided into different blocks according to two degrees of longitude and latitude based on 784 sampling points from 29 provinces in China[7] as illustrated in Figure 1. The dominant soybean production areas in China are concentrated in the Northeast Plain of China, especially in Heilongjiang Province. In addition, the Yellow River Basin, located southwest of Shandong Province, Henan Province, Southern Anhui Province, Eastern Qinghai Province, Ningxia Province, Northern Guizhou Province and central Guangxi Province are also soybean planting areas. According to the maturity system and the climate zones, three different types of soybean are planted in China: Spring soybean in the northeast, summer soybean in Huang Huai Hai Plain and multi-cropping breeds in the south of China.

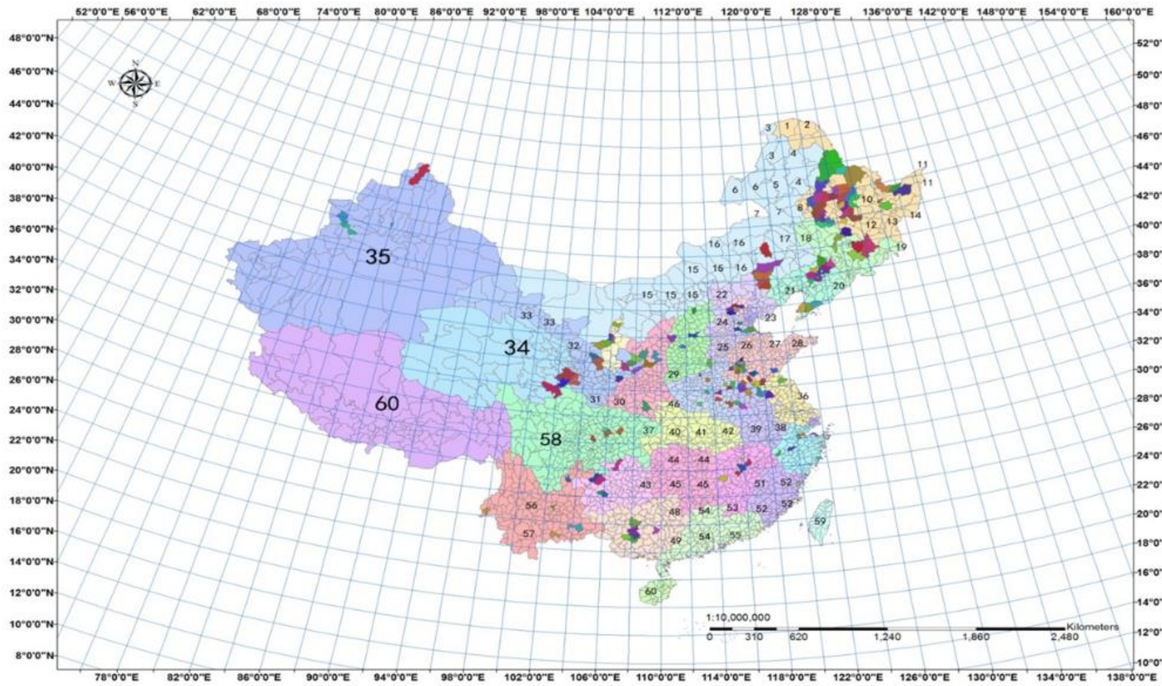

Figure 1: Distribution of soybean planting technology system projects in national science and technology demonstration counties (provided by Han Tianfu) , The dark color mark in the picture represents the soybean demonstration county

According to the current planting and production situation of China's soybean production, the soybean breeding in China mainly takes the following points into account.

1.2.1 High Yield

In recent decades, the soybean production cannot meet the increasing consumption demand in China, and hence, there is the need to import soybean from other countries. Therefore, yield increase has been in the focus of soybean breeding and production development for a long time [7].

1.2.2 Breeding According to Different Areas and Planting Habits

The distribution of different soybean breeds is mainly affected by their specific adaptability to light and temperature. Soybean breeding needs to consider the local planting areas and habits[8]. Due to the limitation of light and heat resources, the following early maturing breeds are mainly planted in Northern China, among them the super early maturing breeds: Heihe 27, Fengshou 24, Heihe 38, Beidou 5, Heihe 43, as well as the early maturing breeds: Heinong 43, Heinong 44, Hefeng 45, Hefeng 50. The soybean type planted in the Huang Huai Hai Plain (North China Plain) are Yudou 22, Zhonghuang 13, Zheng 92116, Handou 5, Xudou 9. During spring, summer and autumn, soybean can be planted in the southern multi-crop production areas, currently, the main breeds include early and medium maturing breeds: Edou 4, Edou 8, Chuandou 15; late breeds: Sudou 07-6, Nandou 22, Huaxia 3. Therefore, soybean breeds with a strong, high level of adaptability are popular. At present, the wide adaptability breeds mainly include Zhonghuang 13 and Zhonghuang 39, which can be planted in the areas that include both the multiple cropping and monoculture areas in in the north to the south of Liaoning Province.

1.2.3 Soybean Breeding for Specific Use

Soybean pulp, which is strongly relevant for the quantity and quality of meat protein, is the main raw material for the feed industry[9]. In recent years, the rapid increase of feed soybean consumption also caused a fast advance in feed-oriented soybean breeding. Feed soybean is often grown in mixed cultivation systems together with other feed crops. Therefore, the soybean types to have a high grade of resistance. For example, the feed soybean N071 approved by the Grass Variety Approval Committee of Inner Mongolia Autonomous Region in 2017 can be mixed with feed corn[10].

1.2.4 Quality

Improving the quantity and quality of protein and oil in soybean and coordinating the ratio of them are also important criteria for soybean breeding. Tangkang et al., [4] systematically introduced the origin and evolution of soybean protein coding genes, which is of great significance to understand the macro-evolution process of soybean genomes and to provide the basis for molecular breeding of soybean.
Overall, the main objective for soybean breeding in China is to select breeds with a strong resistance, forage breeds, an adaptability to intercropping and crop rotation, and breeds with different maturity groups. China has its unique advantages on soybean breeding, but at the same time we should learn from the advanced breeding experience and technology of developed countries and other crop. Firstly, we should fully explore China's great advantages as the country of origin of soybean, and explore the diversity of wild soybean germplasm resources, carry out genome and phenotype group analysis of China's unique original resources, and build a database of soybean breeding core resources. Secondly, the development of molecular biology, genomics, systems biology, synthetic biology and the continuous progress of biotechnology accelerate the process of soybean breeding. The molecular design breeding technology, which is promoted by the combination of disciplines, plays an important role in modern breeding work. The application of modern breeding methods has greatly increased the yield of corn, wheat and rice as well as soybean abroad. On the other hand, at gene level, compared with other crops, gene mining in the key growth process of soybean is relatively deficient, and therefore, there is a lot of potential to enhance gene mining. In order to select soybean breeds with a strong resistance and wide adaptability, some soybean research teams in China have carried out national soybean experiments. For example, the *National Soybean Breeding Cooperation Network* was established in 2007 and the participating units are distributed in the Northeast Plain, the Huang Huai Hai Plain, and the Southern multi-cropping areas (Table 1).

Table 1: Departments and key workers of the National Soybean Breeding Cooperation Network

Region	Leader	Department
Spring Soybean Cooperation Network in North	Liu Lijun	Northeast Agricultural University
Summer Soybean Cooperation Network in Huang Huai Hai plain	Zhang Mengchen	Oil Crops Research Institute, Hebei Academy of Agriculture and Forestry Science
Soybean Cooperation Network in South	Zhou Xinan	Oil Crops Research Institute, Chinese Academy of Agricultural Science
Vegetable Soybean Cooperation Network	Xing Han	Nanjing Agricultural University

Led by the Institute of Crop Science, CAAS, the multi-point test of a regional soybean breeding cooperation network has been established since 2011; the cross regional soybean breed test was started in 2018, with the participation of Tieling Academy of Agricultural Sciences; Chifeng Academy of Agricultural and Animal Husbandry Sciences; Institute of Crop Science, Chinese Academy of Agricultural Science; Institute of Crop Science, Chinese Academy of Agricultural Science (Xinxiang); Institute of Economic Crops, Academy of Agricultural Sciences of Shanxi Province. The establishment of the experimental area has provided a good experimental basis for soybean breeding in China and also played a key role in promoting China's soybean production.

2. Adaptation of Soybean to Climate Change and Agricultural Geographical Zones

2.1 Research on Adaption of Soybean to Climate Change

2.1.1 Climate Change Trends

According to the Intergovernmental Panel on Climate Change (IPCC) Report 2007, climate change means increasing temperatures, modified precipitation, and increasing frequency of extreme weather event11. Increasing temperatures generally accelerate crop phenological development and shortens the growing period, which may reduce crop productivity. In addition, drought can also threaten crop growth. According to the forecast of the Special Scenario Emission Report (SRES), global CO_2 concentrations will increase by 40% to 110% between 2000 and 2030. The increase of CO_2 concentration will lead to a global temperature rise and the change of the rainfall distribution in the world. In the 20th century, global precipitation on land increased by about 2%, but the actual changes in different regions can vary. In the past 47 years, China 's average precipitation has been increased slightly, but in the Huang Huai Hai Plain in the northeast, central and southern North China and the Shandong Peninsula, the Sichuan Basin and in parts of the Qinghai-Tibet Plateau, precipitation has shown different degrees of decline. The negative trend in the Shandong Peninsula is the most significant. Under future climate change scenarios, surface runoff in high latitudes, some humid tropical regions as well as densely populated East and Southeast Asia will increase by 10% to 40% until the middle of the 21st century. Due to the decrease in precipitation and increase in evaporation, surface runoff in some arid high-latitude regions and tropical regions will be reduced by 10% to 30%. In China's mid-latitude regions, a temperature rise of 1°C might increase irrigation water demand by 5% to 6%. In the next 10 to 50 years, climate change will increase the amount of natural water in northwestern China, but global warming will increase the demand for water in the ecosystem as well as in the agricultural sector. CO_2 is a substrate for photosynthesis, and a regulator of primary metabolic processes in plants (stomatal response and photosynthesis). Furthermore, it is responsible for the distribution and formation of photosynthetic compounds. Temperature conditions affect almost all biological processes in plants. Water availability is the basic condition for plants to grow and develop normally. Therefore, the increase of atmospheric CO_2 and temperature in addition to a changing water availability have extremely important effects on physiological processes, biomass, yield and quality of plants.

2.1.2 Effect of Increased CO2 Concentration in Soybean Cultivation

Effect on Physiological Indexes of Soybean

A short-term increase of the CO_2 concentration enhances plant photosynthesis, but in the long term, a stable, high concentration of CO_2 leads to an adaptation of plants to CO_2 concentration. As a result, the short-term increase of the plant photosynthetic rate will gradually reduce due to a high concentration of CO_2 over a longer time.

Effects on Soybean Growth and Yield

Increased atmospheric CO_2 concentration promotes plant photosynthesis, improves plant water use efficiency, and is beneficial to plant growth and yield improvement[12].

Effect on Soybean Quality

As the CO_2 concentration increases, crop photosynthesis increases and the root system will absorb more mineral elements, which will help to improve the quality of agricultural products such as sugar, citric acid and specific viscosity in fruits. However, due to the increase of carbon content and the relative decrease of nitrogen content in plants due to the increase of CO_2 concentration, the protein content will also decrease, which may reduce soybean quality.

2.1.3 Effects of Temperature on Soybean Growth and Yield

Increasing temperatures speed up plant growth and development, shorten the growth period and also increase plant transpiration, leading to a decline in crop yield. Excessive temperatures will also cause a decline in photosynthetic rate. The effect of rising temperatures on soybean differs by region. In warmer areas, further increases in temperature will affect soybean growth negatively and reduce production, whereas in middle and high latitudes and high-altitude regions, the increase in temperature is beneficial to soybean growth.

2.1.4 Effects of Interactions Between CO_2 Concentration, Temperature and Water Stress on Soybeans

Effect of CO_2 Concentration Increases and Temperatures

Within a certain temperature range, elevated CO_2 concentrations and high temperatures can enhance plant phenology. They can also accelerate the growth process of crops and reduce biomass, but the impact on the yield structure of different crops varies. An increased CO_2 concentration is beneficial to the growth and development of crops and has a certain compensation effect on high temperature damage. In short term, it is also conducive to reducing the adverse effects of high temperature stress (greater than 40℃) and insufficient sunlight on crops. However, in a certain temperature range, the negative effect of high temperatures on crops is greater than the positive effect of high CO_2 concentrations.

Effect of Increased CO_2 Concentration and Water Stress

The increase of the CO_2 concentration boosts the photosynthetic rate of the crops, which can improve the water use efficiency as well as the drought resistance. The doubling of CO_2 concentrations alleviates the oxidative damage caused by drought to a certain extent. Soil drought also partially inhibits the effect of increased CO_2 concentration on plant fertilization. With an increase of the CO_2 concentration, water use efficiency increases, and soy drought resistance is enhanced.

Effects of CO_2 Concentration and Temperature Increases and Water Stress

Soil water stress is conducive to improving crop quality, whereas an increase in CO_2 concentrations accompanied by high temperatures is not conducive to improving the quality of crops and will inhibit the improvement of crop quality under drought conditions. High temperatures increase the transpiration rate of soybeans and decrease the plant's water use efficiency, while the increase of CO_2 concentration can reverse the effect. Zhu Dawei et al.[13] investigated that even though the soybean output in Northeast China could increase due to global warming, the increase in future climate variability will affect the soybean output and weaken the yield stability. If appropriate measures are taken in high latitude areas, soybean yield can increase.

2.2 Study on Soybean Breeds Adapted to Agricultural Geographic Regions

Soybeans are commonly planted in China, mainly including the two main producing areas of the Northeast Spring Soybean Area[14] and the Huang Huai Hai Basin Summer Soybean Area, including Heilongjiang, Jilin, Liaoning, Hebei, Henan, and Anhui Provinces. More than 80% of China's soybean production comes from these provinces.[15]

2.2.1 The Close Relationship between Soybean Growth and the Environment

Han Tianfu and others observed the correlation between temperature and the soybean growth cycle and soybean quality. Fei Zhihong and others also believe that there is a clear interaction effect of photoperiod and temperature on soybean development. With increases in temperature, the effect of short daylight on the development of soybean is strengthened; with the shortening of sunlight, the high temperature accelerates the development. The photoperiod response sensitivity (PRS), temperature response sensitivity (TRS), and light temperature comprehensive response sensitivity (PTCRS) of tested northern spring soybean breeds were all lower than those of Huang Huai Haixia soybean breeds. The sensitivity difference and the photoperiod response sensitivity difference under different temperature conditions are higher than the Huang Huai Hai summer soybean breeds, indicating that the light and temperature interaction effect of northern spring soybean breeds is stronger[16]. Therefore, photoperiod and temperature play a particularly important role in soybean growth (Table 2).

Table 2: Relationship between soybean quality and temperature. The sum of crude soybean protein, water-soluble protein and egg fat had a significant positive correlation with accumulated temperature ≥ 15 degrees and the average daily temperature, and a significant negative correlation with the temperature difference between day and night. Crude fat shows the opposite trend.

Quality traits	≥15 ℃ accumulated (AT_{15})	Daily average temperature (MDT)	Day and night temperature difference (DTR)	Cumulative sunshine hours (HS)	Rainfall (RF)
Crude protein	0.304**	0.355**	-0.431**	-0.209**	0.109**
Crude fat	-0.071*	-0.102**	0.190**	0.120**	-0.047
Water soluble protein	0.323**	0.422**	-0.443**	-0.486**	0.057
Total egg fat	0.369**	0.422**	-0.468**	-0.208**	0.119**

2.2.2 Distribution of Soybean Production Areas in China

The growth of soybean is closely related to the light and temperature environment and different geographical areas usually offer different light and temperature conditions. Therefore, the geographical distribution of soybean in agriculture shows certain characteristics:

North American scholars classified soybean breeds according to their light and temperature response. Soybean breeds were divided from north to south into different categories, such as 000, 00, 0, I, II to X, in a total into 13 groups. At the same location, under the same seeding conditions, there were 10 to 15 days of difference in the number of breeding days of each group. The maturity group (MG) has become an internationally common method for grouping soybean breeds. In China, according to the geographical distribution of breeds of the same maturity group in the early stages of development, the 0 to III maturity group is divided into the North Asian Group of the Qinling Huaihe Line and the South Asian Group of the Qinling Huaihe Line, resulting in 16 types of maturity which are categorized as 0000, 000, 00, 0, I, II, III,…, XI. Due to the concentrated soybean sowing area in China, it can be divided into the main spring soybean production areas in northeastern China, the main soybean production areas in Huang Huai Haixia and the main production areas in the south.

China has a long history of soybean cultivation of 5000 years. The area of soybean cultivation is widely distributed, and the ecological conditions of different production areas and the ecological types of soybean vary greatly. Bu Muhua and Pan Tiefu (1982) divided China's soybean production areas into three cultivation areas and 10 subregions. Wang Yuesheng and Gai Junyi (2000) made amendments based on this and divided the Chinese soybean cultivation area into six cultivation districts, 10 subregions. Since then, Hu Guohua et al. (2016) made further adjustments on the basis of Bu Muhua and Pan Tiefu (1982) and divided the soybean production area into three cultivation areas and 9 subareas. Specifically, these include: (1) the northern spring soybean area, including Heilongjiang, Jilin, Liaoning, Inner Mongolia, Ningxia, and Hebei, Shanxi, Shaanxi, Gansu, and the northern regions of Xinjiang. It can also be subdivided into the Northeast Spring Soybean subregion, the North Plateau Spring Soybean subregion, and the Northwest Spring Soybean subreagion; (2) the Huang Huai Basin summer soybean region, including Beijing, Tianjin, Hebei, Shanxi, and Shaanxi, south of the Great Wall, Shandong; the whole provinces of Henan, Anhui, Jiangsu, north of Huaihe and southern Gansu. It can also be subdivided into summer soybean subregion in Haifen Basin and summer soybean subregion in Huang Huai Basin. (3) The southern region includes the Yangtze River Basin and southern regions. It can also be subdivided into spring and summer soybean subregions in the middle and lower reaches of the Yangtze River, central and southern spring and summer soybean subregions, Southwest Plateau spring and summer soybean subregions, and tropical four season soybean subregions in Southern China[17]. The representative super-early breeds of northern spring soybeans include Dongnong 36, Dongnong 41, Dongnong 41c, Dengke No. 2, Heihe 11, Heihe 14; the northern spring soybean breeds include Dongnong 40, Mengdou 32, Heihe 27, Mongolia Dou 5; representative medium and late-maturing breeds include Heinong 56, Dongsheng 9, Red Dou 3, Dan Dou 6. Huang Huai Hai summer soybean breeds include Ludou 11, Ludou 4, Zhonghuang 35, Gaofeng 1, Shanning 16. Representative early-to-maturity breeds in the main production areas of the South include Fengcheng black beans, Zhongdou 36, Sichuan beans 15, Guichun 10. Late-maturing breeds in the southern cropping areas include: Baishui beans, Ruijin small soybeans, southern black beans 26, southern beans 22.

3. Yield and Quality of Major Soybean Breeds in China

3.1 The Main Breeds of Soybean in China

Different types of soy generally refer to characteristics of its seeds. According to the seed coat color and grain shape of a soybean, it is classified in five categories: yellow soybean, green soybean, black soybean, other soybean and feed beans.

Yellow soybean is the most cultivated soybean breed. Yellow soybeans are most used to make various soy products, brew soy sauce and extract proteins. Bean dregs or ground meal are also commonly used in livestock feed. Flowering takes place from June to July, fruiting from August to October.

Green soybeans have a greenish seed coat. According to the color of its cotyledons, it can be divided into two types: green peel, green kernel soybean and green peel, yellow kernel soybean. Green soybean is rich in unsaturated fatty acids and soybean phospholipids. Furthermore, it is rich in saponin, protease inhibitors, isoflavones, molybdenum, selenium and other anti-cancer ingredients. It is also rich in protein and fiber, vitamin A, vitamin C and vitamin K, and one of the main sources of vitamin B foods.

Black soybean is the black seed of legume soybean. Also known as cowpea, black bean, it has a flat and sweet flavor. Black soybeans are high in protein and low in calories, with a black outer skin and a yellow or green inner skin. Blackbeans are kidney-shaped or round. The surface is black-red or purple-red, shiny, the seed coat is thin and brittle, and it is easy to break. The seed kernel is yellow and white, weak in qi, sweet, flat, and non-toxic.

Fodder beans: Generally, the grains are small, oblong, the two leaves have sunken dots, and the seed coat is slightly shiny or matte.

3.2 China's Soybean Production

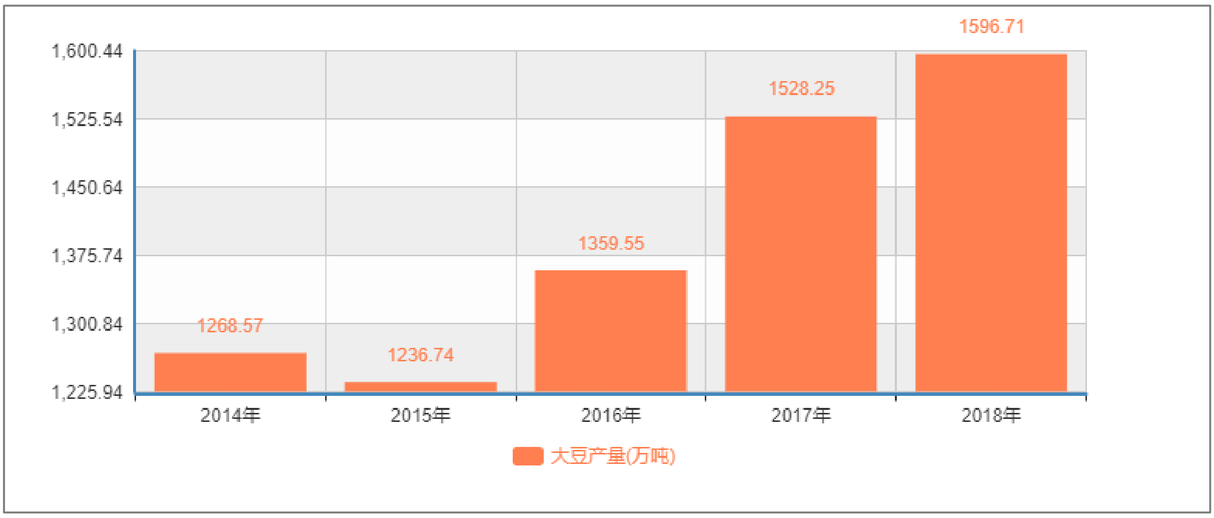

Figure 2: China's soybean production in the past five years in 10,000 tons.
Data source: National Bureau of Statistics

3.3 Components of Soybean Yield

The grain yield of soybeans is the product of the number of plants per unit area, the number of pods per plant and the weight of 100 grains, that is: the yield of grains = [ha of plants*number of pods per plant*number of pods per hundred grain]. Any change in any of the components of the output will result in an increase or decrease. The ideal yield composition implies that the four yield components increase at the same time; however, the four yield components restrict each other. In the same variety, it is difficult to combine the advantages of multiple pods per plant, multiple seeds per pod and large seeds. In general, among the four components of grain yield, the number of plants per unit area varies widely depending on soil fertility and cultivation conditions. the number of seeds per pod and the 100-grain weight are genetically stable. Only the number of pods per plant is a factor that has a large variation. Therefore, in breeding, the number of pods per plant should be paid attention to. At the same time research results in China and abroad confirm that the number of pods per plant is significantly related to yield.

The number of pods per plant is limited by the number of effective nodes and branches. Therefore, to obtain a high yield of soybean, the effective number of nodes must be increased to coordinate the relationship between the main stem and the branch. It is worth noting that a high yield of soybean requires coordinated development of the yield components and measures that take into account and hence, that the development of only one or two yield components will not achieve the expected high grain yield. Soybean breeds have different plant types and different requirements for nutrients and Therefore, the suitable planting density of different breeds is not consistent.

Breeds with lush growth, round and large leaves, many branches and large angles are generally not suitable for dense planting. Breeds with plant type convergence, narrow and small leaves, few branches, and small angles are generally suitable for dense planting. Only by dense planting, more pods, fewer pupae and full grains, the soybean productive potential can be realized, and the grain yield increased.

3.4 Insufficient Domestic Production of Soybean, Continuous Growth in Imports, and Increasing Import Dependency

Domestic soybean supply mainly consists of domestic production and imports. From 2001 to 2015 and since joining the World Trade Organization (WTO), the domestic soybean planting area and soybean production showed an overall "double decline" trend: from 9.5 million ha (142 million mu) in 2001 and 15.4 million tons in 2001, respectively, it decreased to 6.5 million ha (98 million mu) and 11.78 million tons in 2015. As national policies promoted crop rotation and initiated a reduction of the corn planting area, the soybean planting area and output increased significantly between 2016 and 2018. The planting area increased by 1.2 million ha (18 million mu) and 3.06 million tons, respectively. However, from 2001 to 2017, soybean imports continued to grow rapidly, from 13.94 million tons in 2001 to 95.54 million tons in 2017 (Figure 3). In 2018, due to the Sino-US trade war, downward pressure on the domestic economy and African Swine Fever, the consumer demand for meat and poultry fell, resulting in a decline in feed protein and soybean meal demand, which also affected domestic soybean demand. Influenced by factors such as an increase in supportive policies, soybean imports fell for the first time since 2011, but still reach 88.06 million tons[18].

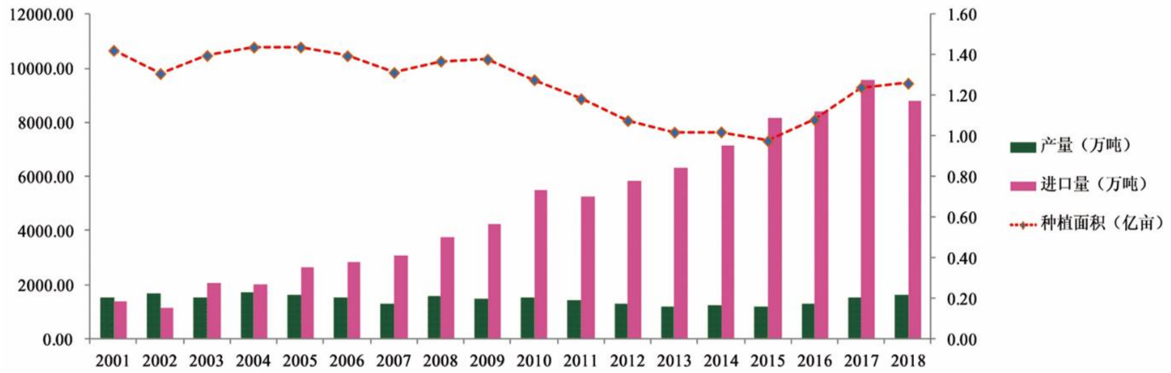

Figure 3: China's soybean planting area (dash line in 100 million mu = 6.67 million ha), yield (black bar in 10,000 tons) and import volume (red bar in 10,000 tons) changes from 2001 to 2018

Source: 2001-2017 data from China Statistical Yearbook (2002-2017), 2018 data from agriculture Ministry and the General Administration of Customs of China.

4. Core Value-Added Procedures in the Soybean Processing Industry

4.1 The Status of China's Soybean Processing Industry

China is an important soybean producer and the largest soybean consumer in the world. With the increasing demand for soybean, the number of domestic soybean processing enterprises also increases every year. Due to the long-term impact of a large number of soybean imports, the external dependence of China's soybean industry is increasing year by year. Hence, transnational capital seriously affects the development of the domestic soybean industry as well as the pricing power, leading to many challenges.[19] The processing of soybean in China results in increasing external dependency and the domestic soybean prices are greatly influenced by the international market.

4.2 Structure of China's Soybean Processing Industry

Processing is the key element in the soybean value chain and is also an important way to increase the soybean value added. Soybean processing includes soybean oil pressing, soy protein processing and by-products from several processes, such as the use of technology including oil biological processing technology, protein biological processing technology, comprehensive utilization of by-products and biological activity material processing and traditional as well as emerging fermented soy processing technology. The processing and utilization of the downstream part of the industrial chain can meet the needs of diversified markets and increase the added value of products. The main processing methods of soybean in China are the following:

4.2.1 Soybean Oil Pressing

Soybean Crushing Products

Crushing is the main part of soybean processing, with soybean meal and soybean oil as its most important products. Soybean oil is highly used by Chinese people. 90% of the domestically processed soybean oil is used in the food industry and 10% in the processing industry. The domestic demand for soybean oil reached 14.9 million tons in 2017. The demand is expected to increase due to the steady growth of domestic consumption of soybean oil and the gradual decline of alternative rapeseed oil.

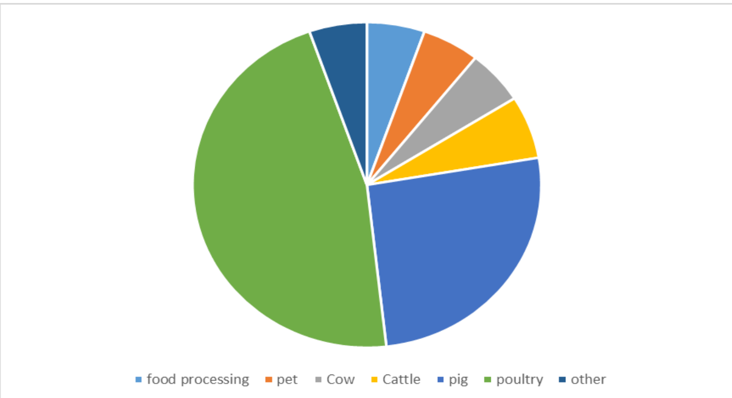

Figure 4: The consumption and the proportion list of soybean meal
Data source: China Industry Network

While extracting edible soybean oil by pressing, soybean meal is a by-product, which has a wide range of uses. As shown in Figure 4, soybean meal is mainly used for livestock feeding, accounting for 94%, comprised of 52% for poultry, 29% for pork, 7% for beef cattle and 6% for dairy cattle, while food processing, pets and other accounts for 6%. Therefore, soybean meal can not only be directly used as livestock feed, but also can be processed into mixed feed.[20]

In general, the production of soybean meal in China has been increasing year by year, but the growth rate fluctuates. Basically, the supply can meet the consumption demand, as shown in Figure 5. Before 1996, both the domestic soybean meal production and demand were below 10 million tons, afterwards, production and demand were growing quickly. In 2015, China produced 61.2 million tons of soybean meal, accounting for about 26.92% of the world's soybean meal production. Over the last few years, China's animal husbandry has developed rapidly, and the demand for meat, eggs and milk has increased greatly. Therefore, the output of soybean meal will be continuously increased to meet the growing market demand.

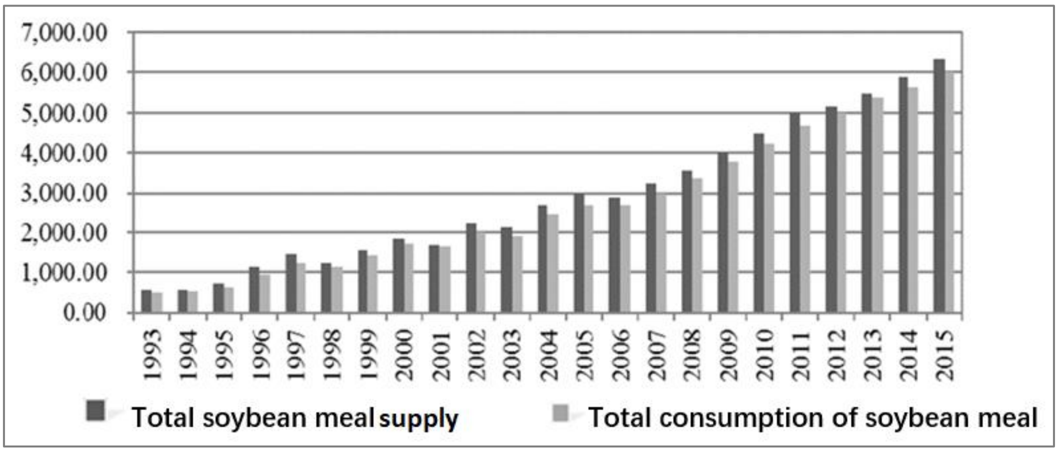

Figure 5: Soybean meal supply and consumption in China (1993-2015)
Data Source: China industry information network

Current Situation and Technology of Soybean Oil Crushing Industry

The science and technology of oil processing and the oil industry are interdependent. The development of oil technology promotes the development of the oil industry, and the development of oil industry promotes the progress of oil processing technology. Despite rapid technological developments in the soybean oil processing industry over the last ten years, the majority of Chinese soybean processing enterprises expanded without corresponding investments in modern equipment leading to high production and operation costs and low product quality.

Use of the New Fluidized Bed Boiler to Reduce Coal Consumption

Coal burning is the main production cost in the soybean oil industry, accounting for more than 50% of the costs. In the 1990's and early 2000's, coal-fired chain, coal-fired furnace and boiling furnace were prominent and at the same time the fat industry experienced a rapid development. Coal-fired chain, coal-fired furnace and boiling furnace had the advantage of low investment and a high construction speed, but the biggest drawback was the low thermal efficiency with an average of only 65%. The new type of fluidized bed boiler has lower carbon emissions and reaches a thermal efficiency of more than 82%. Calculating with a 3000 t/d soybean production line, investment costs of 4 million RMB could be recovered within one year[21].

Use of New Power-saving Equipment to Reduce Power Consumption

The oil and fat industry has a high energy consumption. A 3000t/d soybean production line can consume 23 million kWh of electricity annually, with an input cost of 14 million RMB. The average reactive power consumption of electric power equipment accounts for more than 30% of the electric energy consumption. Especially in the oil industry, fans, pumps, stirring containers and other equipment with a high reactive power consumption are used and the equipment capacity accounts for more than 1/3, thus saving more power.

High Automation of Soybean Oil Production Process

Product indexes can be quickly detected online, and the process can be adjusted automatically in time. Changes in product quality indicators (such as residue of meal, water, protein, residual oil, urease, fiber content and ash content, oil residue, moisture, acid value, smoke point, color and phosphorous) can be identified during the normal production process. The impurities, moisture and oil content of phospholipids are timely fed back to the Programmable Logic Controller (PLC) computer centralized control system, and the system automatically controls the adjustment of the corresponding production process. This proceeding can not only maintain a high stability of product quality, but also make the quality index of each product close to the set value. The product quality index will not cause quality problems, because it is lower than the standard, nor will it cause the loss of enterprise profits, because it is too high above the standard. The soybean oil industry belongs to the class of explosion-proof enterprises, which has high requirements on safety. It is the foundation of all production branches to ensure the continuous and safe operation of equipment and the intact safety facilities. In addition, it is also necessary to conduct centralized monitoring of equipment operation.

High-Performance Process Equipment

High-performance equipment such as the DTDC machine can improve the effect of soybean germ puffing, achieve a full passivation of antinutritional factors, improve the percolation leaching effect, reduce the soybean meal residual oil, increase oil production and profit, improve the quality of soybean meal, and reduce the steam consumption by 30%. Furthermore, the efficient DTDC can also avoid the denaturation of soybean meal protein due to high temperatures. The high-quality embryo rolling machine has a high degree of automation and a low failure rate, which can ensure quality stability of the embryo sheet and a subsequent production optimization.

Introduction, Research and Adoption of Technologies

The neutralization reaction of refined alkali tends to be "long-mix". By increasing the reaction time of the acid reaction, the alkali dosage and the residue of phospholipids and soaps of alkali refining are reduced to improve the quality of oil and reduce the production cost. The amount of clay can be reduced by improving the decolorization efficiency. At present, two new decolorization methods are prevailing; first, before adding clay, the hydrated silica gel is mixed with oil to adsorb soap, phospholipid and trace gold, and then the decolorization of clay is carried out, which can save 50% to 60% of clay. Second, waste clay treatment reutilization technology can reduce the amount of clay by more than 50%. Low-pressure operation and packed tower deodorization tower can reduce the steam consumption of deodorization process, reduce the deodorization time and ensure the content of linolenic acid and sulfurous acid in the primary oil better than the plate deodorization tower used by most enterprises at present. Cryogenic vacuum technology can effectively reduce the consumption of steam and improve the environment. "All-in-one" deodorization tower, namely degassing, heating, stripper, deodorization, heat exchange, heat recovery and cooling operations are combined in the same tower, which can greatly reduce energy consumption and ensure the stability of product quality, but needs further research and improvement. Although the introduction and use of new technology and new equipment will temporarily increase the fixed investment expenses of enterprises, it is necessary and worthwhile to invest in soybean oil industry and the long-term development of enterprises during the current situation of fierce competition.

4.2.2 Deep Processing of Soybean Oil By-Products

Extraction of Phospholipids from Oil Foot and Saponin Horn

Soybean phospholipid is an important functional component of soybeans, amounting to 1.2% to 3.2%, the highest content of phospholipid in common oil seeds. Soybean phospholipids are known as "brain food", "blood vessel scavenger" and "edible cosmetics". Mainly used in the development of health products and drugs, as well as the development of food additives and other functional aids, industrial aids such as emulsifiers, brightening agents and lubricants, such as advanced cosmetics soap, shampoo, lipstick and sunscreen. Mixed fatty acids can be prepared from the soaps, and natural vitamin E, sterol and fatty acid methyl ester can be separated from the deodorization distillate (mainly fatty acid) of soybean, and about 50% of the natural vitamin E concentrate can be obtained from the industrial production. Vitamin E, or VE, is a fat-soluble vitamin which is one of the major natural antioxidants that cannot be produced in the body. Vegetable alcohols have medicinal and health benefits such as preventing coronary atherosclerosis and promoting the degradation and metabolism of cholesterol. 57% of the world's fatty alcohols are produced by fatty acid methyl ester, which is a major surfactant. Soybean peel is rich in cellulose and lignin, which is not only used for biomass energy and animal feed, but also can be used for extracting xylose oligomer, producing furfural, processing into activated carbon products, used in the production of edible fungi extraction tackifier.

Enzyme Technology

Enzyme engineering technology and microbial fermentation technology are widely used in oil processing industry. Enzymatic preprocessing is the use of complex cellulase processing plant tissue, to break down the plant cell wall cellulose skeleton. As a result, the effective components in the plant cells are fully free, which improves the extraction rate of oil. Enzymatic oil refining can improve the content of unsaturated fatty acids, reduce pesticide residues and ensure the safety of oil.

Soybean Lipid Reconstruction Technology

Soybean lipid reconstitution is a new modification technique to improve the nutritional properties of soybean lipids. Reconstructed lipids (SL) are a new type of fat obtained by lipid reconstruction technology. Their fatty acid composition, fatty acid species and their position on the glycerol carbon skeleton are different from the starting material. Due to the change of composition and structure, it has significant changes in physical properties, chemical properties and physiological functions. SL can improve the absorption capacity of the body to lipids, reduce the heat energy of fats and promote the absorption of essential fatty acids.

4.2.3 Development of Soybean Protein Products

Soy is rich in protein, four to five times more than cereals. The amino acid composition of soybean protein is similar to that of milk protein, with the exception of slightly lower methionine, whereas the content of amino acids required by human body is relatively high. It is a complete vegetable protein with rich nutrition and no cholesterol. It is one of the few breeds of plant protein that can replace animal protein and hence, the processing of soybean protein is the main goal of soybean deep processing. Soybean protein processing is the most potential and promising field in soybean intensive processing, and most of its products are high-technology products with high added value, such as protein separation, tissue protein, protein concentrate, hydrolyzed protein, defatted protein powder, phosphorylated modified protein powder[22].

Soybean Protein Isolate

Soybean protein isolate is a kind of food raw material with a protein content above 90% and full value, which is produced from soybean meal at low temperatures. Because of its emulsification, hydration, oil absorption, gelation, foaming and conjunctival properties, it has been widely used in meat products, dairy products and flour products and other food industry. In recent years, soybean protein isolate processing has developed rapidly with an annual processing capacity of nearly 500,000 t.

Soy Protein Concentrate

Soybean protein concentrate is a soybean protein product containing more than 65% (dry) protein, resulting from the removal of water-soluble or alcohol-soluble non-protein parts in high-quality soybean meal. Alcohol protein concentrate without wastewater contamination, water consumption, low production cost, is the main trend of development.

Soybean Peptide

Soybean peptide is a polypeptide mixture obtained by acid or enzymatic hydrolysis of soybean protein. Soybean peptides can not only enhance muscle strength, cholesterol, blood pressure, but also reduce hematic fat and blood sugar, and affect physiological functions such as reducing weight. Furthermore, they have no bean smell, nor protein denaturation or acid precipitation. In recent years, soybean peptide is a hot topic in the deep processing of soybean protein. Although the processing cost is high, the development of soybean peptide has good prospects on the market for health products.

Extraction and Utilization of Soybean Saponins and Soybean Isoflavones

Soybean contains 2% saponins and isoflavones, among which isoflavones account for 0.1% to 0.5%. Isoflavones and saponins contained in soybeans have very strong drug activity, which can treat and prevent a variety of diseases. The development and utilization of soybean isoflavones and saponins is a hot topic in current research and development. The product containing 40% soybean isoflavones is extracted by aqueous alcohol solution and purified by resin adsorption combined with physical chemistry. At the same time, we can produce soybean isoflavone products with 20% to 80% content according to market demand.

Soybean Tissue Protein

In the production of organic soybean protein thermoplastic extrusion technology is used to give soybean protein a certain structure or shape and then the product can be directly used in food processing as ingredients and has a good stability. The production of tissue protein has no high requirements for raw protein quality, so defatted soybean powder, concentrated protein and separated protein can all be used as raw protein, and the production equipment is simple. The final product has a lower cost than defatted soybean powder or concentrated egg white matter, which can meet the demand of most producers.

4.2.4 Application of Biotechnology in Soybean Deep Processing

Application of Enzyme Engineering in Soybean Deep Processing

In the production process of soybean oil, the enzyme engineering is applied to extract soybean oil. The treatment conditions are relatively mild to effectively control the denaturation of soybean protein and to further improve the extraction efficiency of soybean protein as well as the extraction rate of oil. The application of enzyme engineering in the soybean protein peptide production uses the enzymatic hydrolysis of soybean protein to get a reasonable proportion of amino acids, and to change soy protein composition and properties. As a result, products not only have a low viscosity, and but also a good dispersion, easy digestion and absorption by the human body, compared to pure big bean protein. In the specific application process, the selection and reaction conditions of enzymes need to be scientifically determined, and the amount of enzymes and the cost of selecting enzymes need to be specifically considered. Enzyme engineering can also be applied in the production of soybean oligosaccharides. At present, there is a large demand for dietary fiber in the international market. Because of the complexity of soybean dietary fiber as a mixture, the glycosidic bonds, polymerization degree and branched chain structure in the fiber molecules have great influence on the functional characteristics of the corresponding components in human body. The traditional production method to extract soybean dietary fiber could be enhanced by using enzyme technology; for instance, using the right amount of protease can remove remaining proteins in soybean dregs and allows the extraction of dietary fiber with a high purity.

Application of Fermentation Engineering in Soybean Deep Processing

The application of fermentation engineering in the production of soybean protein peptide can combine fermentation with enzymatic hydrolysis and effectively improve the hydrolysis of soybean protein. While soybean dregs can be used for the preparation of dietary fiber, they can also be used in fermentation to produce feed. In order make an ideal feed additive, fermentation bacteria require suitable cultivation conditions, under a certain temperature to obtain higher content of protein. In addition, in the deep processing of soybean, it is inevitable to produce wastewater. A large amount of soybean milk and organic ingredients are mixed in the wastewater, which cannot be discharged freely. In this case, we can use fermentation engineering to select suitable bacteria to ferment the organic components of soybean wastewater, which can not only reduce the COD value in the emissions, but also produce biogas energy, achieving the effect of environmental protection and energy saving.

4.2.5 Comprehensive Utilization of Soybean Processing By-Products

Soybean Phospholipids

The study of phospholipids began in Germany in the 1930s, and its industrialized production began in other developed countries in the 1960s. The United States and Europe annually produce about 60 percent of the world's phospholipids. As different companies have different production methods and different soybean breeds as raw materials for phospholipid production, there is no uniform product standard and classification. At present, soybean lecithin products developed out of enzyme phosphate-solubilizing intermediate products such as fat, enzyme lecithin and phospholipids fat nutrient solution. They are used for injection, artificial skin, artificial white plasma membrane, people made dialysis membrane and compound nutrition bags of new products. Soybean phospholipid products are listed as safe and natural food additives, leavening agents, antioxidants, grain variety refiners and nutrition agents for fortified foods in the world. They are widely used in food, medicine, petrochemical, textile, rubber, paint, pesticides, plant protection products, feed and cosmetics industries[23].

Soybean Oligosaccharides

Soybean oligosaccharides are mainly derived from whey, which is the by-product of soybean protein separation and protein concentration. There are various methods to extract soybean oligosaccharides from whey, including ultrafiltration and membrane integration, acid precipitation, microwave extraction and microbial fermentation. The production of soybean oligosaccharides by the membrane method is characterized by a simple production process, easy operation and low operating cost. The recovery and purification of soybean oligosaccharides from wastewater produced in the production of soybean isoflavones can not only reduce environmental pollution and turn waste into wealth, but also bring new profit growth point to the enterprise.

Functional Dietary Fiber

In the 1980s to 1990s, dietary fiber was widely used in food, medicine and health care products in Europe, America and Japan, with annual sales of more than 30 billion US dollars. However, due to the restriction of economic development in China, dietary fiber only began to be used in recent years. At present, in China, the crystal and particle structure of non-water-soluble dietary fiber in soybean dregs are improved by means of ultramicro-grinding technology. Many new products were successfully developed, such as soybean dregs dietary fiber chewable pieces, high dietary fiber breakfast cereals or high dietary fiber biscuits. Soybean fiber polysaccharides and their soluble polysaccharides are prepared from soybean active fibers by means of biotechnology.

Soybean Whey

Soybean whey is the by-product of soybean protein separation by alkali soluble acid precipitation process, which contains whey protein, oligosaccharides, isoflavones and other functional components. Some bioactive factors can be extracted and used in the production of children's food and health food because of their anti-cancer and hypoglycemic effects. According to statistics, domestic soybean protein separation production enterprises discharge more than 3 million tons of soybean whey every year, and most of the enterprises do not apply treatment or recycling measures but discharge it directly as a wastewater. This not only wastes useful resources, but also causes environmental pollution.

Soybean Hulls

Soybean skin accounts for 6% to 8% of the total grain mass of soybean, while containing 32% of the iron of a soybean. In addition, soybean skin also contains about 86% dietary fiber and carbohydrate, 8.8% crude protein, 1.2% crude fat and other trace components. The application of dietary fiber of soybean skin in bread, biscuits and other products needs to undergo high temperature treatment first. On the other hand, the iron in the skin of soybeans is less phytic acid, which has less effect on the absorption of iron in the body. According to the test, adding 5% of the soybean peel powder to bread will increase the iron content from 0.70mg/100 g to 1.89mg /100 g, so soybean peel is a food source for the treatment of iron deficiency.

Soybean Germ

Soybean germ is the reproductive organs of soybean, accounting for 2.5% of the total quality of a soybean. Soybean germs are nutritious, containing 28% protein and 10% fat, and an unsaturated fatty acid content as high as 80%. Furthermore, they also contain a variety of physiological active substances, such as soybean isoflavones, soy saponins, soybeans, oligosaccharides, vitamin E and sterols. Soybean germ oil is rich in unsaturated fatty acids, including linolenic acid and linoleic acid. Due to the fatty acid composition, soybean germ oil has a high nutritional value, because its two fatty acids are essential to maintain the function of human tissues and normal activities. Soybean germ oil is rich in vitamin E, containing 190 mg/100 g and also contains a lot of phytosterol (0.37%).

Large Soybean Meal

Soybean meal is a by-product of soybean oil extraction. According to different extraction methods, it can be divided into two types of soaked soybean meal. The by-product of extracting the oil by pressing it first and then by soaking it is called double-dipped soybean meal. Soybean meal is irregular, yellowish to light brown in color, with roasted soybean flavor, containing 40% to 48% protein, 2.5% to 3.0% lysine, 0.6% to 0.7% tryptophan, and 0.5% to 0.7% methionine. As a high protein source, soybean meal is a major ingredient in livestock and poultry feed, as well as in bakery foods, health foods, cosmetics and antimicrobial ingredients[24]. Studies have shown that soybean protein and its hydrolysates have the function of lowering cholesterol and blood lipids and can effectively prevent obesity and cardiovascular diseases. In addition, soy protein will not cause excessive calcium in urine and therefore, it can be used to prevent osteoporosis. Soybean protein processing is the most potential and promising field in soybean deep processing.

Soybean Dregs

Soybean dregs are the main by-products in the production of tofu, soy milk and soybean protein isolate, accounting for about 5% to 20% of the total dried soybean mass. The main components are protein 22.56%, fat 19.6%, sugar 37.98%, cellulose 14.62%, ash 6.16%, in addition to calcium, phosphorus, iron and other minerals. After drying, the content of dietary fiber is as high as 50%. Soybean protein isolate is a high scale product of modern soybean processing, which can produce 30% to 35% of soybean residue. Soybean residues have a high nutritional value, but they have not been well utilized for a long time. In addition, as soybean dregs contain a certain amount of water, storage and transportation are not convenient, especially in summer.

Soybean Oil Foot

Soybean oil foot is the by-product of the lipid products obtained from vegetable oil plants. Generally, it refers to the precipitate of the crude oil after hydration and after long-term standing of the oil. The oil foot and the soap foot account for about 5% to 10% of the crude oil. The main components of soybean oil foot are phospholipid, neutral oil, water and other lipids. In addition, there are small amounts of proteins, sugars, waxes, pigments, and organic and inorganic impurities.

Wastewater from Soybean Products

During the processing of soybeans different types of wastewaters occur. The soaking water, yellow slurry water and water of soybean whey belong to the organic wastewaters of high concentration with a COD value of more than 2000 mg/L. Soybean wastewater contains monosaccharides, oligosaccharides, potassium, phosphorus, calcium, iron, vitamins, organic acids, water-soluble egg whites, amino acids, lipids and other nutrients. It is characterized by relatively concentrated discharge of wastewater and high concentration of organic matter. In biological treatment, the ratio of BOD5/COD is high, reaching 0.6 to 0.7, and the average of carbon/nitrogen/phosphorus is 100:4.7:0.2. With the exception of a low pH, there are few toxic or harmful substances. If we make comprehensive use of it, we can not only reduce the environmental pollution, but also recycle the nutrients and get economic benefits. Soybean oligosaccharides, as a bifid factor, can be extracted from wastewater by reverse osmosis and nanofiltration technology. The solid content of yellow pulp water and soybean milk clear water is only 1%, and the content of various functional components is very low. Due to technical limitations, the development and utilization of soybean wastewater has not been industrialized. However, due to the continuous expansion of soybean production scale in recent years, the problem of water pollution is becoming more and more serious.

5. Potential of China-Grown Soybean for Reduction of Imports

5.1 Improve the National Soybean Production

As mentioned in the previous sections, soybean imports to China have annually grown over the past two decades. One solution to reduce soybean imports is to enhance the national soybean production. Increasing yield mainly depends on larger sowing areas and higher soybean yields per unit area. According to the report of the *2019 China Agricultural Outlook Conference*, the soybean cultivation area is expected to be increased by about 10 million mu in 2019, to 140 million mu in 2020, 149 million mu in 2025 and 149.9 million mu in 2028, benefiting from the implementation of the "Soybean Revitalization Plan". Undoubtedly, the expansion of the soybean cultivation area is an important factor to increase soybean yield, which is also supported by national policies.

Increasing yield per unit area is the main method to enhance soybean yield in the present planting area. The average yield of soybeans per hectare in the world's leading soybean producers, the United States, Brazil and Argentina, has reached 2,945.7 kg/ha, while the average yield in China is only 1,787.4 kg/ha[25], which shows that China still has the potential to improve soybean yield per unit area.

The method to increase yield per unit area of soybean involves the specific agronomic scientific cultivation method of soybeans. Based on scientific methods, it is necessary to consider how to popularize the technology in a large area, where China can cooperate with Germany.

The first way to increase yield per unit area is the improvement of soybean breeding. The per-acre yield of soybeans in China was 123.57 kg in 2017 and 126.53 kg in 2018[26]. In 2019, the yield per mu of the soybean variety "Henong 71" reached 447.47 kg, setting a new record for China's soybean yield per mu, indicating that excellent breeds can dramatically improve the yield per unit area.

The second way to increase yield per unit area is improving planting techniques and applicate techniques such as intercropping and interplanting, three-row cultivation, isometric hill-seeding, close planting and so on. Close planting in narrow lines is an important approach to significantly improve the yield of soybean per mu. A more detailed description of soybean cultivation methods in narrow lines can be found in the works of Lu Jingliang and Yue Derong from the Institute of Soybean at Jilin Academy of Agricultural Sciences.

The third way to improve the yield per unit area is to control pests and diseases. According to the statistics of soybean yield per unit area in three provinces in northeast China, the main soybean producing areas in China in recent 30 years, the average soybean yield per unit area in Heilongjiang province decreased over the past 10 years, which was mainly caused by the reintroduction of stubble.

5.2 Improve the Quality of Soybeans

The main uses of soybean in China are for human consumption as soybean oil or as soybean meal for animal feed, which requires various qualities. In addition to nutritional value, food safety and taste should also be taken into account. It is important that quality of soybean meets the respective requirements for different uses; for instance, the main use of imported soybean is to make feed, which requires high protein content, while domestic soybean has low protein content and therefore, domestic soybeans are less suitable for soybean meal production. However, in China the imported soybean breeds with high oil yield in are genetically modified. We should find the balance of quality standards and public interests.

5.3 Lower the Price

One huge challenge on the way to reducing soybean imports is the cost reduction of Chinese soybeans to improve their competitiveness. We need to reduce the cost of materials, labor, taxes and insurance, and general management in the cost of production, which will result in a series of economic and political issues. [27]

6. The Economic Potential of Soybean Production of Medium-Sized Family Farmers and Producer Groups / Village Level Economic Cooperatives

6.1. Current Situation of Domestic Soybean Production

In 2018, China imported 88.04 million tons of soybeans, and produced about 15.96 million tons of soybeans[28] (Figure 6). The self-sufficiency rate was lower than 20% in 2018, only 18.13%. The situation is grim. The high proportion of imported soybeans not only seriously threatens the safety of China's grain and oil supply, but also makes the feed industry, animal husbandry and food processing industry subject to human control, affects the healthy development of the national economy, and affects China's economic security and social stability. [29]

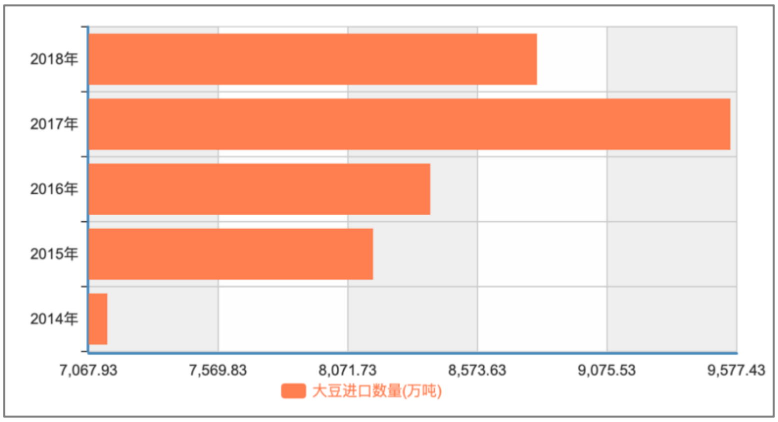

Figure 6: Soybean imports from 2014 to 2018 (10000 tons)
Source: National Bureau of Statistics

Soybean is a food, oil and feed crops, the market demand is rising rapidly, and the gap between supply and demand is expanding since 2018. According to the traditional view, due to the limited space for the development of a domestic soybean production, China has to import a large number of soybeans to meet the market demand for soybean oil and meal, making China the largest soybean importer and processor in the world. However, since 2018, the number of China's grain and oil markets has declined significantly, and the production price index has also fallen sharply, reflecting the weakness of China's soybean market, so the scale of soybean imports and processing should not significantly increase in the short term.

However, unlike consumption, the scale of soybean production in China did not shrink for a long time but expanded significantly. The total output did not decline but increased. Figure 7 shows the rise and expansion of China's soybean production after the fluctuation in 2015 to 2016.

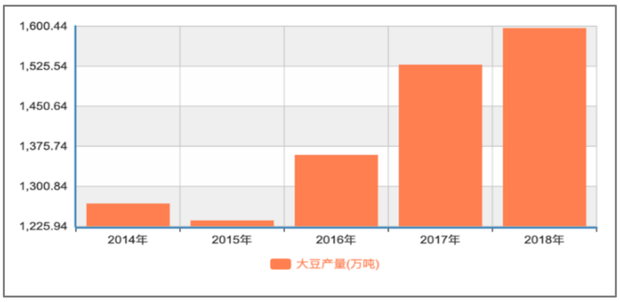

Figure 7: Soybean yield from 2014 to 2018 (10000 tons)
Source: National Bureau of Statistics

According to the suggestion of Mr. Han Tianfu, the way out for domestic soybean is as follows: First of all, we should accurately grasp the important position of soybean in China's agricultural production and grain and oil supply and make the development goals clear[30]. Firstly, complete self-sufficiency of edible soybeans should be ensured, secondly, production capacity of oil soybeans has to be maintained, and thirdly, the irreplaceable role of soybeans in the sustainable development of agriculture should be acknowledged. At present, we need about 11 million tons of edible soybeans every year, basically supplied by domestic soybeans. In the future, the number of edible soybeans will continuously increase. It is necessary to expand the production scale to meet the domestic market demand for edible soybeans, and actively expand the international market. China's oil soybean market is basically monopolized by imported soybeans, but we must not give up scientific research and the development of soybean breeds with a high oil content and maintain a certain scale in production ensure the production capacity of oil soybean and soybean oil fat supply in case of market changes and other factors. In addition, the high yields and low production cost of soybean are closely related to the rotation of corn and soybean[31]. China's agriculture should continue to develop and soybean should also be included in the crop rotation system. In terms of policy, it is suggested that the state's support policies for grain production should be equally implemented for soybean production. Finally, we should respect the right of farmers to choose technology and hence, Chinese farmers, like their foreign counterparts, have the right to benefit from the fruits of the world's new technological revolution[32].

6.2 The Current Situation of Medium-Sized Agricultural Operators

At present, the development of a new agricultural management in China is stable, the products have strong market competitiveness, and the scale of operation is expanding[33]. The State Council issued the opinions on supporting the development of leading enterprises of agricultural industrialization, the development of leading enterprises of agricultural industrialization and the support of new agricultural operation entities, mainly including family farms, large professional households, agricultural cooperatives and leading enterprises. Since 2016, the new agricultural management system has ushered in a new period of development. By the end of 2016, there were 417000 rural agricultural operation organizations in China, with an annual increase of 8.02%. Among them, there are about 130000 new agricultural organizations, with an annual growth of 1.27%. The annual total income is about 9.73 trillion yuan, with a year-on-year growth of 5.91%. The growth efficiency is significant. The number of all kinds of new main bodies continues to increase, showing a good development trend, and playing an increasingly prominent role in agricultural production. Family farms and large professional households are rising rapidly, leading enterprises of agricultural industrialization are growing, farmers' cooperatives are developing rapidly, and agricultural socialized service organizations are gradually increasing. In terms of soybean production, the comprehensive efficiency of leading enterprises is relatively high (0.77), followed by professional large households (0.54), and agricultural cooperatives (0.52).

The main reason for the differences is technical efficiency. Leading enterprises have obvious technical advantages due to technology accumulation and fixed investment in scientific research. Scale efficiency is the secondary cause. Agricultural cooperatives may focus on increasing the number of members, not on scale management, and the low efficiency of scale leads to low comprehensive efficiency[34].

6.3 System Design of Releasing Economic Potential

From 2004 to 2016, the Document No.1 of the Communist Party of China (CPC) Central Committee discussed agriculture in detail and concretely, but did not confirm that the old "field" agriculture and the new, capital and labor-intensive high-value-added agriculture operated under different institutional environment and principles. One is mainly the administrative mode, the other is mainly the laissez-faire market-oriented mode[35]. In addition, another model proposed by Document No.1 is the mode of professional cooperative, a kind of cooperative that imitates the American model and intends to organize pure economy around some professional products. But the development of cooperatives is not satisfactory.

In the current institutional environment and in the practice of the state, the two modes of administration or laissez-faire are more important. Each of the three models has its own advantages and disadvantages, which need to be combined with amendments: the laissez-faire market to continue to stimulate farmers' innovation, the state to lead and set up a more appropriate institutional environment, and the Comprehensive Agricultural Association rooted in the community to provide small farmers with the "vertical integration" service of processing and sales, and to ensure the rights and interests of farmers. [36]

Administrative Mode

Under a long-term strategy formulated by the state, China's grain planting is operated by the state to determine the "planning" of many grain "main production areas" and their production indicators, to ensure "food security" of the country[37]. Since the 1950s, the state has set up a huge institutional system for the collection, processing, storage and sale of grain, mainly grain management offices and supply and marketing cooperatives. The small-scale farmers who grow grain in the main production areas usually only need to transport the grain to the grain management office (or to the grain peddler for transport at a small price) after harvesting, and then the state agencies will process, store and sell the grain. This is very different from the small-scale farmers who are responsible for processing, transportation and sales. In addition, the state not only adopts the policy of "giving more and taking less" to encourage grain production by means of subsidies and fiscal transfer payments, but also sets a price limit, builds new granaries and other ways to stabilize grain prices, which is very different from the high value-added new agriculture, which often fluctuates violently. However, at the same time in administrative management the state has always stressed the importance of supporting and subsidizing grain farms on a large scale, believing that they are the key to the development of grain production. In the early 21st century, a series of policies, which had made grain farming unattractive to business, was reversed, and grain farming became an activity that could obtain certain benefits. However, in the next decade, new problems emerged: China's grain price has exceeded the international market price (Central Document No.1, 2015). This made the country paying more attention to "food safety" and international competition and actively involved in grain production. With continuous investments in modern technology, the rising cost of agricultural labor and the relatively low price of grain, the mode of administrative intervention might be the only way to maintain the vitality of grain production. The administrative subsidies by the government can stimulate the production willingness of rural production and operation organizations and expand the scale of natural soybean cultivation.

So far, China has not been overly rigid in maintaining "food security"[38]. Perhaps the best example is its action on soybeans in agriculture. If China wants to produce soybeans at equal amounts as its imports, it needs to use 400 million mu of arable land (one fifth of the total arable land), which is impossible to consider at all. As the low-cost imported genetic modified soybeans are more efficient than natural soybeans for feed, the long-term strategy of the country is to use imported soybeans to meet the increasing domestic demand for base materials, and the cultivated land released by imported soybeans is used to produce higher-value agricultural products. In short, cheap, imported soybeans are used in order to utilize scarce land resources more efficiently for high value-added agriculture, and to purchase imported soybeans by exporting high-value agricultural products. At the same time, China continues to produce natural soybeans, aiming to enter the international market of soybeans by offering high-value health food. Based on this, the medium-sized rural economic organizations in China can change their production ideas, shift their focus from the production of primary and low-end agricultural products to the production of refined and high value-added agricultural products, in order to avoid the monopoly of the primary soybean market.

At present, the national policy places its main hope for the future on large-scale farms[39]. In order to compete with the countries with rich land resources and highly mechanized agriculture on the international market, China must also rely on the scale economic benefits. Therefore, it mostly depends on agricultural companies and corporatized entities to support China's grain economy. The scale of new agriculture represented by production modes such as agricultural companies is generally smaller than that of "field" agriculture, which is more "capital and labor intensive". At present, new agriculture mainly produces vegetables, fruits, meat, eggs, milk and other agricultural products with higher added value than grain.

Laissez-faire Market Economy

The new agriculture and the old agriculture are operated in very different institutional environment. They are a laissez-faire market economy, which mainly depends on the power generated by the market economy[40]. The intervention of the state mainly lies in two aspects: one is to build some larger wholesale markets to "drive" the development of the market, but some places use the gathered economic benefits to promote the economic development of the development areas around some professional products; the second is to support their preferred "large leading enterprises" and "large households". Large professional farms can get government subsidies and other support. Although this ensures the production efficiency, it ignores the small producers as the majority of the main body. The key problem is the spontaneity of the market. The sharp fluctuation of price and the imbalance of supply and demand make the market easily saturated, which leads to the crisis of loss faced by most producers. Therefore, in order to release the economic potential of medium-sized rural production organizations, we should not only utilize the leading role of enterprises, but also attach importance to the rights and interests of the majority of production entities (families and other production groups), and support, guide and encourage them.

Professional Cooperative
Between administration and laissez-faire, there is a production mode of "professional cooperative"[41]. The professional cooperative is a kind of mutual aid economic organization that "producers and operators of similar agricultural products or providers and users of similar agricultural production and operation services voluntarily unite and democratically manage". Cooperative members have the right of "one person, one vote". However, there are many false entities that only use the cooperative name to meet the government's requirements, many of which are actually controlled by investors. They use cooperatives to pretend to be democratic, peasant cooperatives to win the recognition of the government, tax preferences and subsidies. In addition, cooperatives are designed as organizations that are totally separate from rural village communities, as separate economic and political social entities[42]. They are supposed to be "economic man" consortia in the pure free market economy, but they are actually separated from the administrative background of Chinese agriculture. Moreover, cooperatives cannot get loans from financial institutions, because in the existing property right system environment, farmers have no such assets, so their capital cannot be fully utilized. In practice, a small number of cooperatives that really achieve economic benefits are facing the risk of being sued by the companies they have cooperated with for "illegal fund-raising", but ultimately win the lawsuit due to the protection of the government (such as PuHan cooperatives in Yongji City, Shanxi Province).

It can be seen that if the Comprehensive Agricultural Association combined with finance can get clear recognition and support from politics, it can obtain market economic benefits in essence[43]. China should imitate the "East Asian model" of the semi-governmental Comprehensive Agricultural Association, rooted in the village community, which extends to the township (town), county (city), province, central government at all levels[44]. They mainly provide small-scale farmers with "vertical integration" of product processing and sales services, technical consulting and services, credit services, organization of agricultural funds supply and marketing, organization of community activities, and participation in national politics to safeguard the interests of small-scale farmers. As in the historical experience of Japan, South Korea and Taiwan, their per capita gross domestic product (GDP) and the relative proportion of industry and agriculture are roughly the same as that of today's China.

6.4 The Position and Potential of Medium-Sized Family Farmers and Producer Groups in the Industrial Chain

6.4.1 The General Situation of the Soybean Industrial Chain in China and the Position of Medium-Sized Family Farmers and Producer Groups in the Industrial Chain

Overview of China's Soybean Industrial Chain
China's soybean industrial chain is roughly divided into production, processing, trade and consumption. At present, China's soybean production is shrinking, but consumption, trade and processing are still booming. The main weak point of China's soybean production is the low per unit yield, and improving per unit yield is the key to enhance the competitiveness of China's soybean

industry[45]. In soybean trade and processing, the problems of low circulation efficiency and overcapacity in processing industry are more prominent[46].

The Position of Medium-Sized Family Farmers and Producer Groups in the Soybean Industrial Chain
Medium scale family farms and producer groups are the traditional main body of domestic soybean production. But in recent years, with the continuous development and improvement of family farms and cooperatives, they also have unique potential in soybean trade and processing.

6.4.2 The Economic Potential of Medium-Sized Family Farms and Producer Groups in the Soybean Industrial Chain

The Production of Green Natural Soybean is Expected to Fill the Gap in the High-End Market
Due to the strict restrictions on the production of genetically modified soybeans in China, all the domestic soybeans put into circulation are green natural soybeans. Against the background of the controversy of genetically modified soybeans and the rise of green food movement, non-genetically modified soybeans produced by middle-sized family farmers and producer groups are responding to the demand of "natural" and "green" markets.

Improve the Production Efficiency by Improving the Organizational Form of Production and Processing Units and the Circulation Facilities Between Them
The circulation of soybeans in China has basically formed the pattern of some main soybean producing areas and southeastern coastal areas, distributed over the whole country. Most soybean production and processing takes place locally, whereas soybean oil and soybean meal are mainly transported from processing and producing areas to selling areas. However, the circulation infrastructure of soybean is backward, and the circulation efficiency is low. According to the investigation in May 2012, the outstanding problem of soybean circulation in China is the inconsistency between soybean cultivation and processing areas. The north, represented by the northeastern regions, is the main soybean producing area in China, but the soybean processing area is mainly located near the southeastern coast and the developed areas in the south[47]. The backward and uneven distribution of storage facilities, the high cost of soybean circulation and the lack of railway transportation capacity restrict the improvement of soybean circulation efficiency. On the micro level, the main problems in the circulation of soybeans are the low price of soybean purchases, single circulation channels and inconvenient transportation[48].

However, in recent years, with the emergence of new circulation entities such as soybean cooperatives and brokers, and rural grain industrialization management enterprises, the communication and exchange between family farms and cooperatives in the main production areas is gradually turning more efficient. In view of the problems at micro level, family farms and agricultural cooperatives are expected to enrich the sale channels of soybeans, so that they are no longer limited to door-to-door purchase based sales. In addition, the development of Internet and the rise of e-commerce offer high potentials for agriculture. The direct connection of customers to the market provides a more convenient channel. Family farms and cooperatives can make use of their unique dominant position to make decentralized online sales, which is expected to integrate production points into a linear production chain through the circulation network, while causing an industrial agglomeration effect and obtain scale benefits.

Taking soybean cooperatives as an example: according to the requirements of scale, standardization and informatization of market economy, soybean cooperatives organize soybean farmers or provide most circulation intermediary services to soybean farmers. The development of soybean cooperatives makes the channels for farmers to sell soybean more diversified, improves the degree of farmers' organization, strengthens farmers' rights to speak in the market, and finally leads to better incomes due to increases of soybean price[49].

Develop Deep Processing of Soybean Products Through Cooperative Cooperation and Lengthen the Industrial Chain of the Producing Area

The main reason for the short industrial chain of China's soybean industry is the separation of processing land and production land. The soybean industry in the United States has a complete industrial chain, large-scale oil processing enterprises and soybean products production enterprises cooperate closely, and the upstream and downstream of the industrial chain interact closely. There are many soybean producing cooperatives in China, most of which are distributed in the vast northern plain. If the processing integration is carried out, the medium-sized production units are divided into production group and processing group, and if they can cooperate with each other, it is expected to expand the soybean industry chain in specific areas, and produce deep-processing and high value-added products.

Appendix

Data Collection for Agribusinesses in Soybeans for Human Consumption

Performance Chart of Soybean Production in China [54]

Category	**Output target**	**Comprehensive efficiency**	**Technical efficiency**	**Scale efficiency**
Professional large household	The gross annual value The unit area value The unit person value	0.54 0.41 0.43	0.56 0.41 0.54	0.96 0.84 0.80
Agricultural cooperatives	The gross annual value The unit area value The unit person value	0.52 0.46 0.38	0.65 0.57 0.50	0.80 0.81 0.76
Leading enterprises	The gross annual value The unit area value The unit person value	0.77 0.60 0.66	0.83 0.78 0.72	0.93 0.77 0.92

Comparison of Technological Level [55]

	China	**United States**
Number of patents for soybean production and processing technology	863	4687

Comparison of Soybean Production Costs [56]

Cost structure of soybean production in China Unit： yuan/mu					
Item	In 2000	In 2006	Item	In 2000	In 2006
Seed	10.08	10.85	Management fee	3.44	0.14
Fertilizer	9.71	18.48	Tax and premium	0	0
Pesticide	2.75	3.86	Depreciation of machinery	2.8	1.73
Tax	5.58	1.26	Land tax	2.39	1.16
Fuel, lube and electric charge	11.84	19.06	Unpaid labor costs	33.86	35.85
Repair charge	0.96	0.59	The expend beyond the cost	15.88	2.79
Employment cost	0	3.96	The sum	100	100
Water rate (other charge)	0.71	0.27	Direct cost	83.8	104.7
Interest	0	0	Indirect cost	117.4	86.9
			Total cost	201.2	191.6
Source: calculated from Compilation of national agricultural product cost data					

China's Major Soybean Processing Companies:

Company	**Main Business**	**Location of Industrial Chain**	**Enterprise Website**
COFCO Group	Soybean oil press, soybean processing by-products (such	processing, trade	http://www.cofco.com/cn/

	as soybean meal)		
China Storage Grain Group	Soybean Oil Press	Processing and Trade	http://www.sinograin.com.cn/indexWeb.html
Jiu San Group	Soybean Oil Press	Production, processing, and trade	http://www.93.com.cn/
Beidahuang Group	Soybean Oil Press	Production, trade, processing	http://www.chinabdh.com/
China Tex group (already merged with COFCO)	Soybean Oil Press	Trading, Processing	http://www.chinatex.com/
Yihai Kerry	Soybean Oil Press, Soy Protein Processing, By-products of Soy Processing (such as Soybean Meal)	Trading, Processing	http://www.yihaikerry.net.cn/
Donghai Cereals and Oils Industry (Zhangjiagang) Co., Ltd.	Soybean Oil Pressing, Soy Protein Processing	Production, Trade, Processing	http://10023267651.qymgc.com/index.html

Current Research Groups for Seeding Breeding of Soybean in China

Institution	Laboratory	Represent Researcher	Research Direction
Nanjing Agricultural University	National Center for Soybean Improvement Key Laboratory of Biology and Genetic Improvement of Soybean, Ministry of Agriculture, P.R.China	Gai Junyi（Academician）	Seed breeding, Genetical Resources and Omics Study of Soybeans
Institute of Crop Science, Chinese Academy of Agricultural Science	National Engineering Laboratory for Crop Molecular Breeding Branch of National Center for Soybean Improvement	Han Tianfu（Researcher）	Seed Breeding of Soybean, and Light and Temperature Adaptation
Institute of Crop Science, Chinese Academy of Agricultural Science	Genetical Resources of Soybean	Qiu Lijuan（Researcher）	Genomics Mining Technology
Institute of Ge netics and Developmental Biology, Chinese Academy of Science	Center for Genomics and Biology	Zhang Jinsong（Researcher）	Genomics Function of Soybean
Institute of Genetics and Developmental Biology, Chinese Academy of Science	Center for Genomics and Biology	Chen Shouyi（Researcher）	Genomics of Soybean
Northeast Institute of Geography and Agroecology, Chinese Academy of Science	Key Laboratory of Molecular Breeding of soybean, Chinese Academy of Science	Feng Xianzhong（Researcher）	Genomics, seed breading, an d Light and Temperature Adaptation of Soybean
Northeast Agricultural University	Key Laboratory of Biology and Seed Breeding of Soybean in Northeast, Ministry of Agriculture, P.R.China	Chen Qingshan（Researcher）	Seed breeding

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