Food Science of Animal Products

Review Article

# Development status and prospects of egg products industry in China

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**Abstract:** As a kind of food rich in high-quality protein, poultry eggs not only play the most basic nutritional role in national life, but also widely used in bread, pastry, baking and other food industry because of its excellent processing characteristics such as foaming, emulsification and gel properties, besides its active ingredients can also develop new egg products and functional foods. China, a large country producing and consuming of poultry eggs, has ranked first in the annual production of poultry eggs since 1985. However, the consumer market is dominated by fresh eggs, whose processing conversion rate is only about 12%, and it is mainly based on traditional egg products such as salted eggs and preserved eggs. Compared with Western countries, the market share of egg powder, egg liquid, dry egg products, egg drinks, convenient egg products and other new egg products is small in China. In recent years, China's egg industry has entered the mature stage of development, which takes a favorable trend. In 2022, the output value of China's egg processing industry has exceeded 400 billion RMB. This paper mainly updates and interprets the history, present situation and prospect of egg processing industry in China.

**Keywords:** poultry egg; egg products; processing technology; present situation

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## 1 Introduction

The three mainstays of China's food business are meat, eggs, and milk, all of which are essential components of a human diet. China is a major producer and consumer of chicken eggs. In 2023, the country produced 35.63 million tons of chicken eggs, ranking first in the world. Poultry eggs are a natural source of life energy and comprehensive nutrition, with a balanced mix of proteins, vitamins, minerals, trace elements, and other nutrients. Egg white contains all of the essential amino acids required to maintain life and promote growth and development, which is similar to the composition pattern of the human body. The digestibility of egg white in human body is up to 95% or more, and the essential amino acids can be obtained by the human body through the intake of poultry eggs, making it the ideal protein with a score near 100[1]. Egg yolk contains inorganic salts such as calcium, phosphorus, iron, and other nutrients such as vitamins A, D, $B_1$, and $B_2$, as well as lecithin, acetylcholine, immunoglobulin, and other active substances that aid in nervous system development and memory enhancement[2]. However, poultry eggs are difficult to transport, store, and preserve, hence poultry egg processing has become a significant issue. Poultry egg processing, on the one hand, can solve the problems above, and on the other hand, the nutrients therein undergo a series of changes in the process of processing, so that its nutritional value and flavor have been improved. New egg products can be created by working with different processing methods, as well as adding nutrients that the human body needs. In addition, egg products can be nutritionally altered and fortified to meet the demands of consumers, such as selenium- and iodine-enriched eggs. Furthermore, poultry eggs have outstanding foaming, gelation, and emulsification capabilities in bread, cake, cream, and other consumables, making them a popular study area among both local and foreign academics[3–5]. Besides all that, active peptides derived from eggs are currently receiving a lot of attention. These peptides can be processed to create a wide range of health food products, including those that are blood pressure lowering, antioxidant, and antibacterial, and all of their health care ingredients fall within a controlled range[6–8]. In conclusion, China's poultry eggs are primarily fresh, have less deep processing than other countries, and have not yet reached all their additional value potential. How to increase the degree of deep processing while also promoting the industry's long-term and healthy development has become a key focus for people.

## 2 History of egg processing industry in China

Raising poultry has been a sideline in rural of China for two to three thousand years[9]. As early as in the Warring States period of ancient China, Confucian scholar Mencius and his disciples had thought about "the chicken or the egg first" but did not get a clear answer. In 2005, a small number of eggshell remains of eggs and duck eggs were found in the original porcelain jar unearthed in the Western Zhou Dynasty tombs in Jurong County, Jiangsu Province. In the book, Sixie Jia, an agronomist in the Northern Wei Dynasty, summarized the techniques of raising poultry and processing poultry eggs. Besides the ancient processing method of salted duck eggs was recorded as "dipping ducks for a month, boiling and eating them"[10]. Although the time span of the production and processing of poultry eggs is not as old as meat, it has at least two thousand years. With the progress of the times and the development of economic construction, people's demand for poultry and poultry eggs continues to grow, and the animal husbandry gradually develops and grows, which has become one of the important agricultural products in China.

Since ancient times, the Chinese working people have invented and created many traditional egg-processed flavor foods unique in the world. According to relevant research, the salted duck eggs of the Northern Wei Dynasty have a history of more than 1 400 years. The Songhua eggs of the Yuan Dynasty have a history of nearly 700 years. The creation of dried eggs in Pinghu City, Zhejiang Province, have a history of more than 200 years. Although the history of Chinese egg products is long, its technical research and industry development are relatively slow.

Before the 20th century, due to the low productivity of the whole society, the development of eggs was also affected to a certain extent. At that time, egg production and processing have been in the backward manual operation, whose development has been greatly restricted. Initially, the processing and sale of poultry eggs were operated by salted fish houses and local goods houses. With the increase of market demand, China's egg processing industry gradually developed and grew. However, China's deep processing of eggs was late compared with Western countries.

In the 1930s and 1940s, the industrialized production of eggs in China began to take shape. In 1929, the Egg Products Trade Association was established in Shanghai, China, with an annual production of more than 10 million eggs. By around 1936, the number of manufacturers specializing in eggs had grown to dozens, with an annual production of around 27 million eggs.

After 1949, China's agriculture had a relatively rapid development. In order to improve the theoretical cognition of egg processing industry and accelerate the development of the industry, the state actively organized all kinds of egg science and technology exchange activities. In 1954, the central government held a meeting to compile technical information on egg products, which summarized the existing egg processing technology and experience in China; in 1956, China Egg Quality Improvement Committee was set up, which provided a platform for the development of egg processing technology and scientific research; in October 1960, the first egg processing factory after the founding of new China–Tianjin Egg Factory was officially opened with an annual output of 10 000 tons of iced egg products. Taking Tianjin Egg Factory as the first one, egg processing plants were established all over the country, and egg processing technology and equipment were greatly improved and perfected.

Since the reform and opening up, China's agricultural science and technology research and popularization work have developed tremendously, and agricultural productivity has exponential increased under the strong support of science and technology vigorous development. At the same time, egg processing industry in a relatively short period of time has also been the rapid development, which began to move towards the direction of large-scale, intensive development, and entered the industry growth stage.

In recent years, with the further development of the economy, China's egg processing industry has gradually developed in the direction of automation and modernization, and is gradually moving towards the maturity of the industry. In 1985, China's total output of poultry eggs was 5.347 million tons, which surpassed the United States for the first time and became the world's first large country of poultry egg production. China's total output of poultry eggs has been maintained at more than 30 million tons for seven consecutive years since the beginning of 2016. Affected by the epidemic of 2021, China's poultry egg production was 34.09 million tons, a year-on-year decline of 1.7%. It rebounded to 34.56 million tons in 2022 when the global total poultry egg production was about 95.2 million tons, who accounted for 36.3%. The rise of the egg processing industry will bring very considerable economic benefits to Chinese agriculture and broaden the path of development.

## 3 Development status of egg processing industry in China

### 3.1 Annual poultry egg production is steady and improved

Since 1985, China's egg production has ranked first in the world for 38 consecutive years. According to the data from Food and Agriculture Organization of the United Nations (FAO) and China Statistical Yearbook, China's total annual egg production accounts for about 40% of the world combined (Figure 1). In recent years, due to the impact of the epidemic, the percentage of China's annual production of poultry eggs has a decline with its growth rate fluctuating (Figure 2). Eggs and duck eggs are common and have high comprehensive value[11]. They are also the main categories of China's egg supply, while the consumption of goose eggs, quail eggs, and pigeon eggs have started to show an increasing trend in recent years. Regionally, China's large poultry egg production is concentrated in six provinces, Henan, Shandong, Hebei, Liaoning, Jiangsu, and Hubei, which together accounts for about half of the country's total annual poultry egg production (Figure 3).

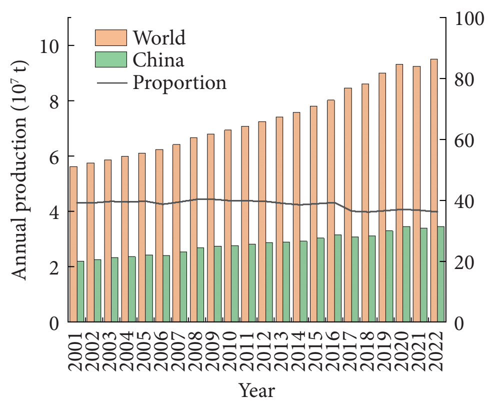


**Figure 1** Annual production and proportion of poultry eggs from 2001 to 2022 in world and China (from UN data and the National Bureau of Statistics).

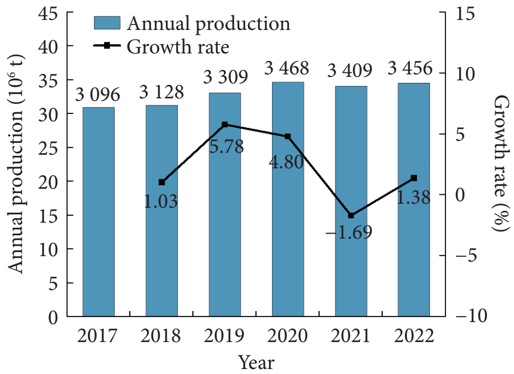


**Figure 2** Poultry eggs annual production and growth rate from 2017 to 2022 in China (from the National Bureau of Statistics).

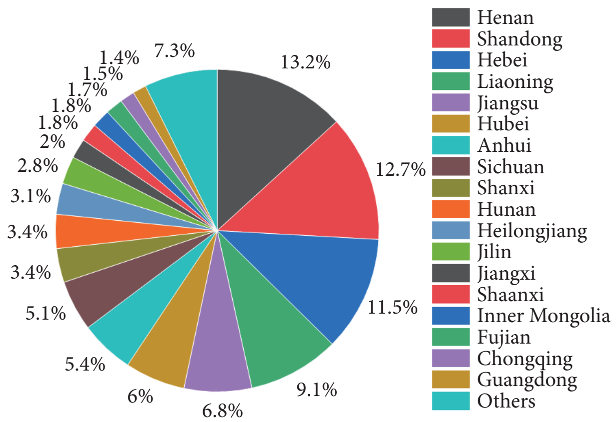


**Figure 3** Poultry egg production by region in 2022 in China (from China Statistical Yearbook 2023).

## 3.2 Egg consumption upgrades but market is single-category

Although China is a large poultry egg country, and the per capita egg consumption has exceeded the world average level, its egg processing products account for very little of the total egg products and the proportion of export trade is relatively small, which is contrary to the current situation of egg consumption in developed countries. A torrent of data from the China Statistical Yearbook 2022 issued by the National Bureau of Statistics of China shows that the egg consumption of national residents from 2016 to 2022 (except for 2018) shows a yearly growth trend, with the growth rate in rural areas being more obvious. The per capita egg consumption of national residents rose from 9.7 to 13.5 kg per year (Figure 4). At the same time, it rose from 8.3 to 13.0 kg per year in rural areas. However, the consumer perception is still dominated by the fresh eggs, followed by preserved eggs, salted eggs, marinated eggs and other traditional egg products. Consumer acceptance of egg powder and egg liquid is not high, which are mainly used as a food raw material or additives for the re-processing and production of other foods.

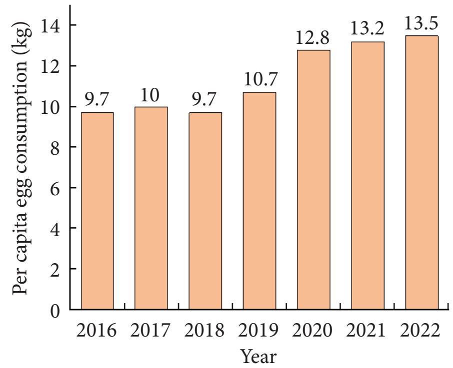


**Figure 4** Per capita egg consumption of national residents from 2016 to 2022 in China (from the National Bureau of Statistics).

## 3.3 Share of poultry egg exportation rises significantly

China has experienced rapid growth in its import and export trade in recent years. Poultry eggs are mostly exported, with very few imports. The number of exports has been increasing annually, and the exported eggs are divided into 11 categories (Table 1), primarily consisting of fresh eggs, preserved eggs, and salted eggs. China exported $16.68 \times 10^4$ t of poultry eggs in 2023 (Figure 5), which accounted for approximately 0.48% of the nation's annual production. The export value of the poultry eggs was 340 million dollars. Of these, 132 500 t of fresh eggs, 79.4% of the total export volume, were sent to Hong Kong, China and Macao, China. A total of approximately 13 000 t of salted eggs and 8 000 t of preserved eggs were exported. In terms of export destinations, China now exports poultry eggs to the United States, Japan, South Korea, Singapore, Australia, and Canada. However, China imported only 95 kg of poultry eggs from the United States under the category other shelled poultry eggs in 2023.

**Table 1** Egg product export category and data of 2023 in China.

| Commodity code | Name of commodity | Quantity (kg) | Amount of exports (dollar) |
|---|---|---|---|
| 04071100 | Fertilised hen eggs for incubation | 126 900 | 949 376 |
| 04071900 | Fertilised others eggs for incubation | 0 | 0 |
| 04072100 | Fresh hen egg | 131 940 057 | 222 793 382 |
| 04072900 | Others fresh poultry egg | 554 409 | 1 356 018 |
| 04079010 | Salted egg | 13 130 025 | 38 269 978 |
| 04079020 | Preserved egg | 8 048 300 | 24 781 484 |
| 04079090 | Unlisted pickled or cooked poultry eggs | 233 257 | 657 857 |
| 04081100 | Dried egg yolk | 708 628 | 7 019 616 |
| 04081900 | Others dried egg yolk | 1 593 568 | 14 552 534 |
| 04089100 | Dried shelled poultry egg | 791 247 | 6 307 865 |
| 04089900 | Others dried shelled poultry egg | 9 647 987 | 23 862 977 |

Note: The data comes from the General Administration of Customs of the People's Republic of China.

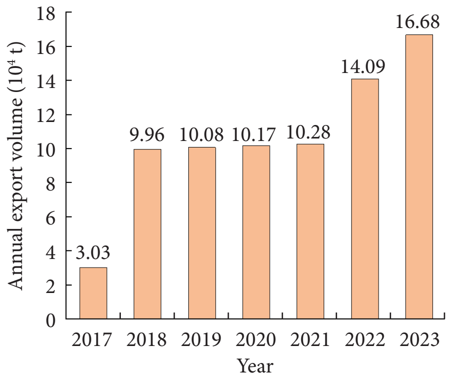


**Figure 5** Annual export volume of poultry eggs from 2017 to 2023 in China (from the General Administration of Customs of the People's Republic of China).

## 3.4 Status of poultry egg industrialization

China is the birthplace of traditional duck egg products represented by preserved eggs and salted eggs, and traditional egg products represented by marinated eggs and tea eggs. At present, China's processed egg products are still dominated by traditional egg products, which account for up to 80%. In 2022, China's egg processing market size of 450 billion RMB, of which the market size of the egg is as high as 280 billion RMB. The industry maintains a stable and improving development trend.

According to the latest report, three Chinese companies have entered the world's top 30 egg producers (based on the number of laying hens) in 2023, with Beijing Deqingyuan Agricultural Technology Co., Ltd. ranked 5th globally, Sichuan Sundaily Farm Ecological Food Co., Ltd. and Shanxi Jinlong Breeding Co., Ltd. ranked 13th and 17th, respectively. Currently, the top five egg brands in China are Red Sun, Shendan, Qinyou, Goosun egg industry and Deqingyuan. In addition, many emerging egg companies are also thriving. Suzhou Ovodan Foods Co., Ltd. is founded in 2004 and is the first company in China to introduce pasteurized liquid egg products. Later on, the company introduces ultra-long shelf life egg liquid products, hot stabilized egg powder and liquid, egg white beverage, and salted egg powder mayo, among other innovative products, which has advantages in product innovation and technological innovation. It was successfully listed on the Beijing Stock Exchange in January 2023, which also marks the official birth of China's "first share of egg products" and the country's egg products industry is poised to embark on a new phase of growth. Founded in 2019, the raw egg brand–Yellow Swan stands out in many extensive egg categories with the key technology of "introducing Japan's 38-year-old raw edible egg guidelines, which are more certain to be safe for children and pregnant women to eat and free of *Salmonella*". Furthermore, a number of businesses, including Taizhou Meixiang Food Co., Ltd., Hubei Jiuzhu Egg Industry Co., Ltd., Shandong Weishanhu Economic and Trade Industrial Co., Ltd., Zhejiang Wufangzhai Industrial Co., Ltd., Jiangxi Hongmen Industrial Group Co., Ltd., and others, are keeping an eye on things. They are also expanding the production scale and enriching the market for modern egg products like lysozyme, immunoglobulin, liquid eggs, and egg powder. However, China's egg industrialization as a whole is characterized by a high egg yield but a low fraction of processing. There are many processing firms but they are tiny in scale. As evidenced by the market sector's industry consultancy research and Egg Industry China's publications, egg products processing ratio is about 12% in China, while egg products processing ratio of the United States is 33%, Europe accounts for 20%–30%, Japan is as high as 50%, which shows that China and foreign developed countries have a great disparity, but also shows that China's egg processing industry has a lot of room for the rise of the market for a long time in the future, with a broad prospect.

## 3.5 Present situation of poultry egg processing technology

In recent years, due to the rapid development of the poultry industry, the increase in egg production and the rapid development of egg processing science and technology have contributed positively to promoting the development of the egg industry. China can produce more traditional egg products due to advancements in processing technology, growing consumer awareness of egg powder and liquid, and getting foreign advanced processing equipment by some domestic manufacturers. Chinese scientists and technicians are on the egg resources for the depth of development, and have now researched some of the relevant new technologies and goods, with the goal of achieving industrialization as quickly as possible.

### *3.5.1 Advanced technology and equipment are being used to produce and grade poultry eggs*

Based on EMQ (Erlang MQTT Broker), the poultry egg monitoring system may gather real-time data on the production of chicken eggs and the warehouse egg reserve. This data can then be transmitted to the cloud, where it will be processed and stored on the platform. Enterprise users can view monthly, quarterly, and yearly production data and poultry egg storage in different warehouses through electronic devices, and the software also provides basic data analysis and statistical results, which makes it easy for enterprises to keep track of poultry egg storage and minimize losses[12]. In terms of clean eggs, China's clean egg production line is mostly MOBA products. Eggs are sent to complete sets of equipment through conveyor belts for conveying, sorting, loading, cleaning, drying, oil spraying, sterilizing, coding, packaging and other complete set of processes, realizing the need for mechanized production[13]. China's first independent research and development of clean egg production line has also been put into use. The production line first uses a cleaning and disinfecting agent to quickly clean and sterilize the fresh eggs, and then applies a natural preservative, which can preserve the freshness for more than 6 months. Meanwhile, the 4M1E (man, machine, material, method, and environment) and hazard analysis critical control point (HACCP)-based industry chain of clean eggs' safety control system and the industry chain of clean eggs' traceability platform, which uses the "cloud + management + end" logic, offer new approaches to clean egg safety control that can lower costs for clean egg safety management and achieve accurate traceability[14]. Some studies have shown that the concentration of $H_2S$, a characteristic spoilage gas produced in the storage process of clean eggs, can effectively characterize the freshness of poultry eggs. This technology can be used to check the quality of poultry eggs during the processing of egg products at any time[15]. In poultry egg classification, China's domestic poultry egg processing plant classification equipment is mostly based on the mechanical balance to measure the quality. According to the quality of the egg to classify eggs, which can meet the quality classification standard requirements, but the classification efficiency is low, ranging from 5 400 to 30 000 pieces per hour. At present, there are studies through LabVIEW to establish the corresponding human-computer interface. Its primary features include a user or expert login interface, a database verification interface, and an inference machine inference interface. The system can effectively determine the egg's quality level, although the technology is not yet widely used in factories[16].

#### 3.5.2 High technology for non-destructive testing of egg quality

Machine vision inspection technique is the most used way for non-destructive verification of chicken egg quality. It has some characteristics, including low detection error, rapid grading speed, strong stability, and repeatability, as well as the capacity to complete multiple quality indicators at once. Especially in the need to repeat, monotonous rely on vision to collect information occasions, such as huge amounts of product quality testing, grading, it can receive rapid, accurate, non-destructive, and other artificial incomparable effect. Machine vision technology is useful for designing and manufacturing automatic grading assembly lines, and it has a promising future in identifying agricultural product quality[17]. In addition, non-destructive testing based on spectral analysis, including visible-near-infrared spectroscopy, hyperspectral diffuse reflectance, transmission spectroscopy, near-infrared spectroscopy, and hyperspectral imaging technology, can be used to detect internal quality indexes, including blood spots, meat spots, breeder egg sex, fertilization information, and embryonic egg activity[18–23]. Another type of acoustic detection is primarily used to identify and classify surface cracks on eggs[24]. Machine vision technology is mainly applied to the detection of appearance parameters such as size and color of eggs[25]. Optical detection is mainly used for the detection of internal quality such as freshness of eggs[26–27]. There are also means of detecting the quality of poultry eggs by using the kinetic properties or electrical and mechanical properties of the egg, chemical, biological, and integrated detection methods[28–29].

#### 3.5.3 A variety of new materials to improve the quality of fresh egg preservation

The traditional refrigeration method of preservation is too much investment and the breakage rate is high[30]. Researchers tested up to 30 materials to investigate the egg vacuum sterilization preservation technology (EVSPT) at room temperature, which includes coating, spraying, impregnation, hand rubbing, and mechanical methods. This gives a solid theoretical foundation for fresh egg preservation[31]. The inhibition of cold nitrogen plasma (CNP) on *Salmonella typhi* biofilm and its application in poultry egg preservation can effectively reduce the risk of contamination[32]. The latest film coating technology is used to prepare a coating material with natural essential oil and lead acetate, which can react with the $H_2S$ produced in the process of egg spoilage that has an antimicrobial effect while also intuitively reflecting the degree of egg freshness[33]. For instance, the use of chitosan coating on poultry eggs increased freshness and shelf life[34].

#### 3.5.4 New developments in traditional egg product processing technologies

Traditional Chinese egg products are mainly preserved eggs and salted eggs. Some studies have shown that the technique of enzymatic hydrolysis combined with medium temperature treatment is used for preserved egg pickling. Under the premise of quality assurance, pickled preserved eggs produced using this technology can reduce the production cycle to around one-third of the typical pickling process, significantly enhancing the efficiency of industrialized production[35]. A few conclusions have also been obtained in the research of liquid formula, processing technique, storage, and quality of non-heavy metal preserved eggs[36–39]. Now many manufacturers processing preserved eggs gradually are using food-grade NaOH, reducing production costs by 40% and shortening the cycle time by 20%[31]. Wang[40] developed the clear material method of processing yellow preserved eggs. Their products had better gel characteristics, color and flavor than traditional preserved eggs. In terms of salted egg processing technology, China’s rapid curing salted duck egg technology currently includes ultrasonic-assisted curing technology, pulsation pressure technology, ultrasonic-pulsation pressure coupling-assisted curing technology, magneto-electricity-assisted rapid curing process, vacuum decompression method of curing technology, and circulating water curing process[41–46]. Another study showed that by boiling, filtering, and salt replenishment process of pickling solution, three times recycling of salted egg pickling solution can be realized under the condition of ensuring the quality of salted egg, which not only saves salt, but also reduces the discharge of high salt wastewater[47].

#### 3.5.5 Egg powder and egg liquid processing technology to a new level

As the earliest processed product of new egg products, the processing technology of egg powder and egg liquid has matured and realized from basic research to factory mass production and wide application.

Egg powder has high protein content, rich variety of minerals and vitamins, and has significant functional properties, such as gelation, emulsification, fat and water retention. It is an ideal substitute for fresh eggs. When compared to fresh eggs, egg powder has a longer storage life of up to a year, is easy to use, pack, and transport, and has been widely utilized in the food industry, animal and poultry production, cosmetics, and medical care[48]. At the same time, after a series of processing and treatment, egg powder is safer and more hygienic, easier to use, and may be changed to meet specific application needs, resulting in a specialized egg powder with stronger processing properties. Studies have shown that the processing features of egg white powder, such as gelation, foaming property, and emulsification, can be improved to various degrees under the three treatment methods of physical, chemical, and enzyme[5]. After microwave treatment, the structure of egg white protein altered dramatically, improving the gelation and foaming capabilities of egg white powder[49]. Following glycosylation, egg white powder’s gelation and water holding capacity have improvement in different degree[50]. He[51] treated the egg white powder with glutamine transaminase, which could cause some of the protein molecules in the egg white to cross link both inside and between themselves. The protein molecules formed had a larger relative molecular weight, a compact structure, and a significant increase in water absorption capacity and gel hardness. In addition, studies have shown that neutral protease and papain can significantly improve the immunomodulatory biological activity of egg white protein powder[52].

Egg white liquid is widely used in food processing due to its superior nutritional and functional preservation, excellent cleanliness and safety, simplicity of operation, and ease of storage and transportation. Furthermore, it has become an essential food ingredient in the production of bakery goods, meat products, surimi products, and other food products. In the manufacturing of egg liquid, the standard pasteurization technique is commonly used. However, due to the limitations of the heat transfer mechanism, it would result in excessive thermal processing of egg liquid, causing protein denaturation, product quality deterioration, and other issues. Supplemented with microwave physical field processing method of pasteurization will help to solve the problem of the pain point of the traditional pasteurization method and provide direction for industrial production[53]. Furthermore, the storage cycle and supply radius of egg liquid are shorter than those of egg powder, typically lasting no more than 24 h. Due to the high moisture content of egg liquid and the lack of the innate antimicrobial resistance of eggshell, it has a higher chance of microbial contamination, and some psychrophiles can still proliferate even at its storage temperature (4 °C). Nonetheless, egg liquid products remain more popular in the food industry than egg powder due to their superior functional and nutritional properties[54]. In China, computer control technology and integrated production of light, power, and machine are currently being implemented in the egg liquid processing production process.

#### *3.5.6 Automated production of poultry egg packaging*

In order to improve the efficiency and cost of poultry egg packaging and processing, relevant researchers designed a parallel robot-based poultry egg pick and place packaging production line, the results showed that the robot completed the pick and place of each whole tray of 30 eggs, with the success rate of 99.3% and the fastest speed of up to 2.4 s[55]. Another study showed that the machine vision-based Delta parallel robot found the dynamic individual egg by vision, planed the intelligent handling paths' trajectories, created the robot control program for the intelligent pickup. The test results of the intelligent pickup of chicken eggs showed that the vision-based Delta parallel robot could be used to achieve the goal of intelligent poultry egg pickup and tray loading work[56].

## 4 Problems and challenges in egg processing industry development in China

In recent years, China's provinces have experienced tremendous growth in poultry egg production, resulting in supply and demand imbalances that have hampered the development of animal agriculture. Hence, in order to resolve the contradiction between egg production and marketing, as well as to improve poultry efficiency, the egg market must be changed to address the "three more than three less" problem: ordinary eggs more and brand eggs less, shell eggs more and deeply processed eggs less, and more fresh eggs edible and less deep processing product development and utilization. Although the Chinese egg processing industry is currently experiencing rapid development and has a very positive market outlook, one of the biggest challenges it faces is how to improve the deep processing technology of egg products. Another major issue is the production of high-value-added products. Focusing on market-oriented science and technology, research and development of high-value-added natural products in poultry and egg products is essential. This will help to improve the utilization of poultry and egg value, encourage the growth of poultry and egg production, create more job opportunities, and support the prosperity of both urban and rural economies. It will also supply the essential raw materials, main agents, additives, and functional factors for the third generation of functional foods.

### 4.1 Further improvement of processing technology

#### *4.1.1 Processing technology of fresh eggs*

Although fresh eggs are produced and consumed in vast quantities annually in China, there hasn't been much of an export of fresh eggs. This is mostly because unclean eggs have long dominated China's fresh egg consumption, and exports are severely hampered by "green barriers". At present, North America, some European countries, Japan, and other developed countries, poultry eggs on the market must be clean eggs, and the cleaning and disinfection rate of poultry eggs has reached 100%. In Asia, including Singapore, Malaysia, Korea, and Taiwan, China, more than 70% of poultry eggs are cleaned and disinfected[57]. Due to the low penetration of clean egg processing and the lack of clean egg technology, it is not conducive to the stable development of the poultry egg market and export trade. Interestingly, "raw egg" refers to aseptic eggs produced following rigorous sterilization and inspection. "Tamago kake gohan" has its origins in Japan and is made simply by adding some seasonings after pouring aseptic raw eggs into well-boiled rice and mixing thoroughly. Now that "Tamago kake gohan" has gained popularity in China, it can be found in many restaurants and residences, but acceptability is low. The most pressing worry for customers is the hygiene of raw eggs, where the risk of *Salmonella* and *Staphylococcus aureus* is unclear. The key to whether eggs can be eaten raw is if they are produced using standardized agricultural and processing procedures and are subjected to stringent distribution control before reaching customers. Furthermore, some research has demonstrated that aseptic eggs have nutritional value equivalent to that of regular eggs and are not entirely devoid of bacteria[58]. There isn't currently a recommended daily intake for raw eggs in China, therefore more research is needed to determine whether eating "Tamago kake gohan" is safe.

#### *4.1.2 Processing technology of processed egg products*

Finished egg products are classified into two categories: egg powder and egg liquid.

Egg powder is an important product form that can significantly increase the shelf life of egg. Drying, being the primary procedure for egg powder, is especially crucial. China now processes egg powder mostly using hot air spray drying and vacuum freeze drying, with a limited amount of freeze drying, shallow tray drying, drum drying, and other methods being used. Spray drying is frequently utilized as a drying technology in more modern ways in food production and processing industries[59]. Egg powder belongs to the category of dry egg products, China mostly applies egg powder as a food additive in the food industry, but China's egg powder processing starts late and the technology is weak. There are still many problems in the processing and production, resulting in poor quality of egg powder processed products, which cannot meet the needs of the consumers. The development of functional egg powder will be a key orientation of new Chinese egg product innovations[60]. For example, the conventional vacuum drying technique for making protein powder produces is primarily inconsistent in terms of production, efficiency, and product rehydration[61]. To prevent *Salmonella* contamination of egg products, the eggshells must be completely cleansed and sterilized prior to the beating and stirring process. Cracked eggs cannot be utilized as raw materials[62]. There has been more research into egg powder physical and chemical index detection, but the technology is not mature enough. Chromatography, mass spectrometry, graphite furnace atomic absorption spectrometry, and other physicochemical methods are specific and sensitive, but the majority of them require complex pre-treatment operations that are time-consuming and expensive, and cannot meet the requirements of large-scale online detection[48].

Liquid egg not only maintains almost the same nutritional value of whole egg, but also solves a major disadvantage of shell eggs that are easy to break. Hence, it is necessary to improve the processing technology of liquid egg products to broaden the market space. In the process of liquid egg production and processing, any physical and chemical treatment may have a bad impact on the quality of egg liquid. Furthermore, due to the viscosity of the egg liquid itself and the characteristics of the egg liquid such as extremely easy denaturation, there are really some difficulties in ensuring the microbiological safety of the egg liquid on the basis of minimizing the loss of its nutritional and functional properties[54]. At the moment, China's egg liquid processing system is insufficient. A lack of study on the relationship between the functional qualities of egg liquid and processing and storage conditions has hampered egg liquid growth to some extent.

#### 4.1.3 Non-destructive testing quality control technology

When non-destructive testing is used on egg products, the idea is that the eggs won't be damaged and their nutritional value won't be compromised. Besides, physical or chemical methods are used as a way to use equipment and modern technology to create test indicators that indirectly represent the quality of poultry eggs. The majority of the world's salted egg grading currently takes place in China using artificial light inspection methods. These methods have a low inspection efficiency and are influenced by a variety of subjective factors, making them unsuitable for modern production needs. The internal quality and crack detection of poultry eggs are only roughly classified, and there are fewer automatic non-destructive testing machinery and equipment for poultry egg quality on the market. Developed countries produce a more efficient egg grading and packaging production line. This is achieved through the use of zero-speed electronic weighing of eggs for weighing and grading, with quality accuracy down to 0.1 kg. This production line features a high grading efficiency and a quick weighing speed. Besides, it can be automated non-destructive testing of eggs and poultry eggs joint operations, with an efficiency of up to 180 000 pieces per hour[28]. Enhancing the applicability of non-destructive testing in the real production process and improving its integrity and systematization for the detection of egg products provide a significant challenge to the egg product industry.

#### 4.1.4 Processing technology for component extraction and application

Poultry eggs contain a variety of nutrients required by the human body, and the human body's absorption and utilization rate is very high. Hence, for getting a specific active ingredient, extraction, separation, and purification, as well as the study of its characteristics and mechanism, are conducive to the development of high-value-added products and the broadening of its application. At the moment, egg white protein separation and purification methods include ion exchange, affinity chromatography, ultrafiltration, salinity, isoelectric point method, and other separation and purification techniques. Laboratory research has a complete set of continuous separation of proteins in poultry eggs in the process of operation, but there are still problems such as insufficient purity of the separated substances, cumbersome operation steps, time-consuming, and so on[63–72]. Furthermore, supercritical fluid extraction, membrane separation, chromatographic separation, ultrafine pulverization, enzyme treatment, and other processing technologies have been used to extract and prepare high-value-added natural products such as egg yolk lecithin[73], high *F* value oligopeptides[74–75], egg yolk immunoglobulin[76–77], and eggshell calcium preparations[78], as well as egg yolk product development. However, the majority of these are laboratory investigations, and product manufacture and application have only recently begun[79].

### 4.2 Poor use of by-products

#### 4.2.1 Eggshells

In the processing and utilization of poultry eggs, a large number of eggshells are thrown away, polluting the environment and wasting resources. If they are utilized comprehensively, they can increase the utilization rate of the resources, as well as avoid polluting the environment. Eggshells contain many substances that can be extracted and used in the production of animal feed to supplement animal growth and enhance immunity. At present, the application of more is the collection of discarded eggshells, made of eggshell powder directly added to animal feed, to supplement the calcium required for animal growth and development. Adding eggshell powder to pig feed is conducive to the adjustment of the ratio of calcium and phosphorus in the pig organism and access to the necessary micronutrients[80]. Another study proposed a new way of efficiently utilizing eggshell waste as a green dephosphorizing agent and accelerator for reduction roasting of high-phosphorus oolitic iron ore[81].

#### 4.2.2 Eggshell membrane

Studies have shown that eggshell membrane can be used as a multifunctional and sustainable biomaterial for translational biomedical applications[82]. It has demonstrated good restorative effects such as accelerating epithelial formation, anti-inflammatory, and promoting skin growth in the field of medicine[83–84]. Due to its adsorbent nature of the membrane, it can also be applied in the recycling of precious metals[85–86]. There have been laboratory personnel in the research on the extraction and application of soluble eggshell membrane protein, collagen, keratin, salivary acid, hyaluronic acid, novel antimicrobial proteins, lysozyme, chondroitin sulfate, and other components of eggshell membrane[87–90]. Through years of research and development, the utilization of eggshell membranes has now shifted from simple direct utilization to the extraction of important biomolecules from them, and there are many high-value-added products that can be applied to food, cosmetic, and biopharmaceutical industries[91]. Recently, Kim et al.[92] found that eggshell membrane-supported forward osmosis films can be used for seawater desalination, which is a valuable new discovery to carry out new research directions. However, China is still a certain distance away from the true industrialization of eggshell membrane resources. There are still many connected problems hindering the ongoing development of eggshell membrane development, which need to be improved and handled by taking specific actions[93].

### 4.3 Lack of brands in the egg-processing industry

The egg processing industry in China is quite huge, with fewer brands and a more decentralized company structure. Since a brand represents an enterprise's essential values, it is difficult to build new egg brands and capitalize on them. At present, most of the poultry egg products are still in the stage of unbranded consumption. Consumer awareness of poultry eggs stays in the difference between foreign eggs and soil eggs. There are some domestic egg brands that are more common. Red Sun is famous for its double-yolked eggs from Gaoyou Lake Beach. For hundreds of years, Gaoyou duck eggs have been revered both domestically and internationally as gifts to the imperial court, with a strong following both north and south of the Yangtze River. On the basis of traditional processing technology, Red Sun is the first to introduce an assembly line integrating egg cleaning, counting, testing and grading, from

Taiwan, China, ending the history of manual processing of eggs that has lasted for thousands of years. Its products are a true local specialty and industry brand, having received the green food certification, earned the China Famous Brand Agricultural Products, Jiangsu Province Famous Trademark, and other honors. The "egg ID system" established by Deqingyuan puts an end to the "no standard, no brand, no production date" of Chinese eggs, and the brand actively pushed and participated in the development of China's first egg standard, which set a pattern for Chinese egg brands. Shendan is a national key leading enterprise in agricultural industrialization, which mainly focuses on processing and selling egg products, and integrates feed processing, egg-breeding poultry rearing and service. Shendan is the first company to introduce the world's most advanced production line for clean eggs, which leads to the first appearance of "clean eggs" in China.

### 4.4 Lack of innovation in new egg products

With the arrival of the era of science and technology innovation, the combination of the internet and egg processing can reduce intermediate links and provide cost-effective services for users. The main consumer of the egg processing industry is gradually getting younger. The development of new egg products is an inevitable trend to adapt to the market development. New egg products, including the third generation of functional health food and high-value-added products, primarily involve the extraction of beneficial substances from poultry eggs, separation and purification, application in a variety of industries, and the development of new products. The new products already available in the Chinese market are fermented protein powder, instant egg powder, egg concentrate, lactic acid fermented egg drink, egg yogurt, and lead-free loose-coiled eggs. Supplementing with high-quality proteins will become the norm, particularly in the post-epidemic era, and protein beverages are predicted to become a daily drink, similar to milk or other liquids. Hence, it is necessary to break the traditional concept of egg products processing, introduce the new concept of science and technology, and explore the new egg processing technology.

### 4.5 Strengthen the transformation of egg industrialization

At home and abroad, there are many laboratory studies on the physicochemical properties, functional properties and biological activities of egg products. However, few of them can really be transformed into consumer-oriented and widely circulated products, resulting in a serious disconnect between the research and actual production of egg products. The results of scientific research are not efficiently transformed[94]. The link between research results and products is economic accessibility. Due to numerous external limitations, some of the research mechanisms identified by fundamental theory research cannot really be used to increase the quality of products. In the implementation of industrialization, cost plays a crucial role together with time, labor, physics, and management. It is challenging to accurately reflect the positioning of a raw material used in egg processing products, so the realization of industrialization of the product is not simply equal to the magnification of the process. This leads to the input of products into the market before the product is profitable, discouraging many companies and preventing the possibility of industrialization of egg products from being realized. In order to accelerate the transformation of China's egg processing industry, scientific research and basic research should associate enterprises, close to the actual production, practical solutions to practical problems and carry out relevant research work. Enterprises may finish product transformation work on schedule, provide timely feedback findings to guide scientific study, and create a comprehensive benign work cycle chain for industrialization transformation. Most importantly, the factory must improve the quality stability of processed eggs and ensure the safety of processed eggs.

### 4.6 Industry standards to be improved

The traditional egg products business has a low market barrier, and the lack of unified industry standards and professional supervision in the service process has hampered its development. China's egg industry food safety system is not perfect. Many traditional egg products processing and finished product standards are still not sound, and there is a lack of testing methods. The lack of quality and safety standards for the egg processing industry has hindered the development of China's egg industrialization to a certain extent. The fragmentation of production has led to difficulties in forming a system for the management of safety and protection of egg products. The market's requirements for the standards of egg products are rather ambiguous. There are only 13 current and valid national standards for the egg processing industry in China (Table 2).

**Table 2** Current and valid national standards for the egg processing industry and implementation dates in China.

| Standard name | Implementation date |
|---|---|
| GB/T 19050–2008 Product of geographical indication-Gaoyou salted duck eggs | 2008-10-01 |
| GB/T 25009–2010 Criterion of producing management for egg products | 2010-12-01 |
| GB/T 9694–2014 Preserved egg | 2015-12-01 |
| GB 2749–2015 National standards for food safety, eggs and egg products | 2016-11-13 |
| GB 21710–2016 National standards for food safety, egg and egg products production hygiene standards | 2017-12-23 |
| GB/T 34262–2017 Terms and classification of egg and egg products | 2018-04-01 |
| GB/T 34238–2017 Requirement for cleaning eggs in prosess and circulating | 2018-04-01 |
| GB/T 37108–2018 Basic information description of agricultural products-eggs | 2019-07-01 |
| GB/T 39438–2020 Packed eggs | 2021-06-01 |
| GB/T 42237–2022 General quality for egg powder | 2023-07-01 |
| GB/T 42235–2022 General quality for liquid egg | 2023-07-01 |
| GB/T 23970–2022 General quality for pot-roast eggs | 2024-07-01 |
| GB 4789.19–2024 National standards for food safety, microbiological examination of food hygiene, sampling and handling of eggs and egg products | 2024-08-08 |

## 5 Egg processing industry development trend outlook in China

From a worldwide perspective, the development of the egg processing industry has shown the development trend of scale, automation, greening and deep processing. Semi-finished products, re-products and refined products after primary processing or deep processing are constantly flooding into the market. Despite decreased sales of fresh eggs on the international market, egg consumption in major developed countries throughout the world is increasing. It can be seen that the consumption of egg processing goods has become the primary driver of egg industry growth. In China, the egg processing industry has been maintaining a steady upward trend in recent years. It will develop in the direction of technological maturity, industrial intelligence, product diversification, extensive application and conceptual unification in the future.

### 5.1 Processing technology for egg products gradually advanced, incorporating scientific and technological innovation into a new approach

The traditional method of preparing eggs is the wisdom crystallization of Chinese laborers. The foundation of egg processing is a historical gem worth preserving. The times' current topic is scientific and technological innovation, which offers fresh perspectives on egg processing techniques and constructs a bridge to support the industry's growth. The maturation of egg product processing technology will come from the fusion of new and ancient ideas. With the gradual use of mechanized processing and new technologies, the processing technology of egg products has been further enhanced in the direction of lead-free, mud-free, and tiny packaging.

### 5.2 Intelligent egg industry to create a digital platform for intelligent production

The advent of the internet era has brought great convenience for the egg processing industry. Big data is quickly integrated to improve the efficiency of the egg industry chain, from production and processing to sales and consumption, from the local to the national level. This includes the integration of quantitative data to provide direct feedback on the status of each step in real time, to provide data support for the prediction of market changes, and to quickly clarify the relationship between supply and demand in order to adjust the industrial strategy. In the industrial equipment, it has accomplished the automatic production line of various egg products processing, including automatic egg basket cleaning machine, automatic multi-functional salted egg yolk dryer, and automatic cooked egg stripping machine. Intelligent automated equipment not only ensures product quality under the premise of greatly improving production efficiency, but also greatly reduces the manpower, material and financial resources. It can be predicted that the next period of time will be the golden period of rapid development of China's poultry and egg industry. Poultry and egg enterprises must seize development opportunities, adhere to scientific and technological innovation, increase investment in scientific research, and then improve product diversity and competitiveness, all while forming their own brand advantages and promoting the healthy and rapid development of China's poultry and egg industry.

### 5.3 Diversification of egg products to meet the development trend of the times

The main body of egg products gradually shifts to the post-1990s and 2000s. As people's consumption habits shift, the consumption of fresh eggs gradually diminishes, and the diversification of egg products is an unavoidable tendency. The goal of product diversification is not only to suit customer requirements, but also to create a new approach to fully utilize egg resources, open up market competition patterns, and improve the industry's competitiveness.

### 5.4 Egg and their components are widely used in many different industries

Eggs are a highly nutritious food item. Certain components found in eggs can also be utilized as additives or auxiliary materials for study in several domains, and it is worthwhile to investigate their significance in this regard. A variety of high-value-added bioactive substances extracted from poultry eggs have been used in medicine, cosmetology, health care products and many other areas. In medical research, the hydrogel prepared from egg white is used as an *in vitro* simulated scaffold for human tissue cells[95], and the preparation of novel wound healing excipients[96–97]. Cosmetics companies have used eggshell membrane extracts to create skin care products with both beauty and health benefits. These extracts contain a range of effective ingredients that promote both beauty and health, such as hyaluronic acid, collagen, and small-molecule peptides[98].

### 5.5 Egg source functional food steps market with deeply developing

There are many functional ingredients in egg products that are beneficial for human health, most of which have not yet been put into use. Because China's egg output is so large, studying egg source efficacy components for the development of nutritional and functional modernization of egg products will help to extend the egg processing industry market and better fulfill consumer demand.

### 5.6 Egg processing industry standards gradually improved, production and consumer market concepts unified

Egg processing industry products are gradually diversified. The World Egg Association predicted that in 2025 China's processed egg products accounted for 30%. The future of China's poultry egg deep processing products market has a larger space. Food safety regulations will be further enhanced in order to harmonize ideas about production and consumption, foster a positive environment within the sector, and hasten the growth of the egg processing market.

## Conflict of interest

No conflict of interest exits in the submission of this manuscript.

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## References


[1] Z. C. You, Abundant nutritional substances in egg and human health, Global Food Ind. 2 (2006) 56–57.

[2] N. S. Shou, Egg nutrition and human health, Food Drug 4 (2004) 22. https://doi.org/10.3969/j.issn.1672-979X.2004.04.013.

[3] J. R. Yang, J. H. Liu, Y. M. Wang, et al., Research progress on the effects of different treatments on the microstructure and properties of egg yolk and its components, Food Sci. 44(15) (2023) 368–378. https://doi.org/10.7506/spkx1002-6630-20220613-122.

[4] Z. W. Li, Z. Ruan, B. S. Li, et al., Comparison of egg white foams in different whipping states and their gel properties, Mod. Food Sci. Technol. 40(3) (2024) 219–228. https://doi.org/10.13982/j.mfst.1673-9078.2024.3.0320.

[5] S. C. Liu, S. Y. Zhang, Research progress on processing properties and modification of egg white powder, China Poult. 44(6) (2022) 100–106. https://doi.org/10.16372/j.issn.1004-6364.2022.06.018.

[6] J. J. Wang, Y. Zhao, Y. G. Tu, et al., Research progress on antimicrobial peptides derived from egg protein, Food Sci. 34(9) (2013) 399–403. https://doi.org/10.7506/spkx1002-6630-201309076.

[7] J. J. Wang, Y. Zhao, Y. G. Tu, et al., Research progress in the antioxidant peptides derived from egg protein, Sci. Technol. Food Ind. 35(2) (2014) 358–363. https://doi.org/10.13386/j.issn1002-0306.2014.02.064.

[8] C. Chen, Advance in the antihypertensive peptides derived from egg protein, Sci. Technol. Food Ind. 32(3) (2011) 429–431; 428. https://doi.org/10.13386/j.issn1002-0306.2011.03.047.

[9] Y. P. Jiao (Ed.), Poultry and eggs, China Financial and Economic Publishing House, Beijing, 1964.

[10] S. X. Jia, Qi Min Yao Shu, China Commercial Publishing House, Beijing, 1984.

[11] Y. H. Wang, Y. C. Zheng, Z. X. Li, et al., Comparative analysis of external quality and nutritional components of poultry eggs, Anim. Husb. Vet. Med. 54(5) (2022) 40–44.

[12] H. Y. Li, J. W. Zhang, H. Y. Ren, et al., EMQ-based poultry egg monitoring system, Internet Things Technol. 11(12) (2021) 47–49. https://doi.org/10.16667/j.issn.2095-1302.2021.12.012.

[13] Q. G. Tong, Liquid egg processing technology perspectives, Farm Prod. Process. 1 (2014) 16–17. https://doi.org/10.3969/j.issn.1671-9646.2014.01.009.

[14] R. W. Sun, S. M. Zhao, J. You, et al., The design and implementation of the safety control system for the entire industrial chain of clean eggs based on 4M1E and HACCP, J. Chin. Inst. Food Sci. Technol. 22(10) (2022) 438–449. https://doi.org/10.16429/j.1009-7848.2022.10.044.

[15] Y. F. Hu, Y. N. Chen, L. P. Zhang, et al., The correlation between characteristic spoilage gas and freshness of clean eggs during storage, Chin. Agr. Sci. Bull. 37(30) (2021) 128–132. https://doi.org/10.11924/j.issn.1000-6850.casb2020-0437.

[16] L. L. Yang, Y. P. Yu, L. A. Li, et al., Design of egg quality grading system based on LabVIEW, Agr. Technol. Equip. 8 (2021) 26–28. https://doi.org/10.3969/j.issn.1673-887X.2021.08.010.

[17] C. Zhang, W. Lu, T. H. Ding, et al., Research status and prospect of the nondestructive detection of eggs quality, Sci. Technol. Food Ind. 36(18) (2015) 381–384. https://doi.org/10.13386/j.issn1002-0306.2015.18.069.

[18] D. J. Cui, Y. Y. Liu, Y. T. Xia, et al., Non-destructive detection of egg fertilization status based on hyperspectra diffuse reflectance, Spectrosc. Spectr. Anal. 42(12) (2022) 3685–3691. https://doi.org/10.3964/j.issn.1000-0593(2022)12-3685-07.

[19] Study on nondestructive detection of the fertile information for chicken eggs prior to the incubation based on hyperspectral image technology, Huazhong Agricultural University, Wuhan, 2015, pp. 1–11. https://doi.org/10.7666/d.Y2803190.

[20] K. Song, C. L. Yang, Y. H. Shi, et al., Research on sex identification of chicken eggs based on visible-near infrared hyperspectral technology, J. Food Saf. Qual. 13(17) (2022) 5518–5525. https://doi.org/10.19812/j.cnki.jfsq11-5956/ts.2022.17.009.

[21] Q. H. Wang, Y. X. Ma, D. D. Fu, Progress of non-destructive detection of poultry egg internal quality based on spectroscopy, J. Huazhong Agr. Univ. 40(6) (2021) 220–230. https://doi.org/10.13300/j.cnki.hnlkxb.2021.06.027.

[22] X. Y. Zhang, Y. Ji, J. Z. Xi, et al., Study on early fertilization detection of breeding eggs based on spectroscopic technology, China Poult. 45(3) (2023) 106–112. https://doi.org/10.16372/j.issn.1004-6364.2023.03.016.

[23] Z. H. Zhu, Q. H. Wang, S. C. Wang, et al., The detection of hatching eggs prior to incubation by the near infrare spectrum, Spectrosc. Spectr. Anal. 32(4) (2012) 962–965. https://doi.org/10.3964/j.issn.1000-0593(2012)04-0962-04.

[24] H. K. Cho, W. K. Choi, J. H. Paek, Detection of surface cracks in shell eggs by acoustic impulse method, Trans. ASAE 43(6) (2000) 1921–1926. https://doi.org/10.13031/2013.3097.

[25] Q. H. Wang, Y. X. Wen, X. D. Lin, et al., Correlation between egg freshness and morphological characteristics of light transmission image of eggs, Trans. Chin. Soc. Agr. Eng. 24(3) (2008) 5. https://doi.org/10.3321/j.issn:1002-6819.2008.03.036.

[26] R. M. Wu, L. Y. Yan, Z. X. Qiao, Correlation between freshness and optical property of different kinds of eggs, Acta Agr. Univ. Jiangxiensis 26(5) (2004) 4. https://doi.org/10.3969/j.issn.1000-2286.2004.05.028.

[27] H. Lin, J. W. Zhao, L. Sun, et al., Freshness measurement of eggs using near infrared (NIR) spectroscopy and multivariate data analysis, Innov. Food Sci. Emerg. Technol. 12(2) (2011) 182–186. https://doi.org/10.1016/j.ifset.2011.01.008.

[28] J. Gao, Z. J. Yu, B. Jiang, et al., Research status of testing and grading mechanization technology of poultry egg, Agr. Eng. 11(3) (2021) 74–77. https://doi.org/10.3969/j.issn.2095-1795.2021.03.015.

[29] Y. Yu, S. L. Zhang, Z. M. Li, Research progress on nondestructive testing and grading technology of egg quality, J. Food Saf. Qual. 11(23) (2020) 8740–8745. https://doi.org/10.19812/j.cnki.jfsq11-5956/ts.2020.23.033.

[30] L. M. Liu, Refrigerated preservation of fresh eggs, Farm Prod. Process. 2 (2009) 28–29. https://doi.org/10.3969/j.issn.1671-9646-C.2009.02.018.

[31] C. X. Huang, Q. X. Yue, H. Z. Sun, et al., Research progress of egg products and their processing technology, Graz. Vet. Sci. (7) (2021) 4–7.

[32] L. Lin, X. Liao, C. Li, et al., Inhibitory effect of cold nitrogen plasma on *Salmonella Typhimurium* biofilm and its application on poultry egg preservation, LWT-Food Sci. Technol. 126 (2020) 109340. https://doi.org/10.1016/j.lwt.2020.109340.

[33] M. Q. Luo, Overview of research and patent application direction of coating preservation on eggs, Mod. Food 15 (2020) 32–34. https://doi.org/10.16736/j.cnki.cn41-1434/ts.2020.15.009.

[34] J. H. Han, Y. W. Yu, Research development of chitosan coating in animal product preservation, Acad. Period. Farm Prod. Process. (15) (2013) 50–51; 55. https://doi.org/10.3969/jissn.1671-9646(X).2013.08.017.

[35] H. X. Xu, M. Lin, Z. X. Xia, et al., Study on the technology of rapid pickling preserved egg by enzymatic hydrolysis combined with medium temperature treatment, Storage Process 21(5) (2021) 109–116. https://doi.org/10.3969/j.issn.1009-6221.2021.05.017.

[36] Y. Sun, L. P. Fan, Z. Ma, et al., Development of lead-free quail eggs, China Food Saf. Mag. 3 (2021) 132–134. https://doi.org/10.16043/j.cnki.cfs.2021.03.075.

[37] D. C. Zhang, Y. Wang, L. Lei, et al., Effect of curing agent and recombination on quality of salted preserved eggs without heavy metal, Sci. Technol. Food Ind. 42(6) (2021) 43–49. https://doi.org/10.13386/j.issn1002-0306.2020050325.

[38] J. Sun, Q. F. Zhu, H. B. Jiao, et al., Effects of different protein source feeds on the quality of duck eggs and their processing eggs, China Poult. 42(9) (2020) 62–67. https://doi.org/10.16372/j.issn.1004-6364.2020.09.010.

[39] Y. T. Wang, Preparation and characterization of sodium alginate-based composite film and study on storage of heavy metals-free preserved eggs, Nanchang University, Nanchang, 2021, pp. 3–5. https://doi.org/10.27232/d.cnki.gnchu.2021.001472.

[40] P. Wang, Study on physicochemical properties and gel quality of yellow preserved egg prepared by feed liquid processing technology, Nanchang University, Nanchang, 2021, pp. 4–6. https://doi.org/10.27232/d.cnki.gnchu.2021.002506.

[41] D. H. Li, Analysis of the process of quick curing salted duck egg the magnetoelectric auxiliary, Electron. Test 17 (2016) 175; 172. https://doi.org/10.16520/j.cnki.1000-8519.2016.17.092.

[42] Y. Chen, P. Zheng, H. P. Liu, et al., Changes in physiochemical properties of egg white during vacuum curing of salted eggs, Food Res. Dev. 43(3) (2022) 6–13. https://doi.org/10.12161/j.issn.1005-6521.2022.03.002.

[43] S. Q. Wang, S. C. Wang, Y. P. Zhang, et al., Parameter optimization for quickly salted egg by using ultrasonic-pulsed pressure technology, Trans. Chin. Soc. Agr. Eng. 29(23) (2013) 286–292. https://doi.org/10.3969/j.issn.1002-6819.2013.23.039.

[44] P. Q. Zan, Y. D. Cheng, Y. Z. Jin, Research progress on rapid pickling process of salted duck eggs and comprehensive utilization of salted duck eggs white, Food Mach. 36(10) (2020) 210–214. https://doi.org/10.13652/j.issn.1003-5788.2020.10.039.

[45] L. Wu, Study on new technology of salted egg preserved with mixed low-sodium and pulse pressure, Huazhong Agricultural University, Wuhan, 2011, pp. 10–14.

[46] Y. J. Pu, J. P. Du, Z. H. Liang, et al., Study on processing of salted egg with circulating water, China Poult. 32(16) (2010) 25–27. https://doi.org/10.16372/j.issn.1004-6364.2010.16.002.

[47] X. L. Fu, L. G. Zou, L. P. Ma, Recycling process of brine solution of salted duck eggs, J. Zhejiang Agr. Sci. 61(9) (2020) 1869–1871. https://doi.org/10.16178/j.issn.0528-9017.20200947.

[48] Z. H. Zhu, K. Yang, Y. C. Wang, et al., Research progress on egg powder quality detection technology, China Poult. 45(6) (2023) 76–81. https://doi.org/10.16372/j.issn.1004-6364.2023.06.012.

[49] Z. Y. Xiong, M. H. Ma, Z. X. Cai, et al., Research advance on the influence of modification on functional activity of ovalbumin, Hubei Agr. Sci. 52(15) (2013) 3473–3477. https://doi.org/10.14088/j.cnki.issn0439-8114.2013.15.007.

[50] Y. J. Chi, W. Xu, Y. M. Hong, Effect of glycosylation on gelling and physicochemical properties of egg white powder, Food Sci. 34(7) (2013) 82–85. http://doi.org/cnki:sun:spkx.0.2013-07-019.

[51] W. M. He, Effects of transglutaminase and spray drying conditions on gelling and emulsifying properties of egg white powder, Sichuan Agricultural University, Ya'an, 2019, pp. 1–8. https://doi.org/10.27345/d.cnki.gsnyu.2019.000436.

[52] Q. Peng, M. H. Ma, Y. G. Jin, Optimization of enzymolysis parameters of highly soluble egg white protein powder and its application in immunoregulation *in vitro*, Mod. Food Sci. Technol. 34(4) (2018) 129–136; 226. https://doi.org/10.13982/j.mfst.1673-9078.2018.04.021.

[53] M. Q. Sun, H. Y. Yang, B. W. Yan, et al., Study on microwave inactivation kinetics and protein variation of liquidwhole egg, Food Ferment. Ind. 50(5) (2024) 82–87. https://doi.org/10.13995/j.cnki.11-1802/ts.035845.

[54] J. Wang, Study on the spoilage deterioration of refrigerated liquid whole egg and its quality control, Jiangnan University, Wuxi, 2022, pp. 1–4. https://doi.org/10.27169/d.cnki.gwqgu.2022.000109.

[55] S. Kou, Y. H. Wang, Research and experiment of egg packaging production line based on parallel robot, Packag. Eng. 44(1) (2023) 169–174. https://doi.org/10.19554/j.cnki.1001-3563.2023.01.019.

[56] L. Zhang, S. C. Wang, Studies on experimental device of egg intelligent handling based on parallel, J. Huazhong Agr. Univ. 37(3) (2018) 117–124. https://doi.org/10.13300/j.cnki.hnlkxb.2018.03.017.

[57] J. Sun, J. P. Du, L. Z. Lu, et al., Duck egg colony and egg processing, China Food Saf. Mag. (31) (2018) 28–29. https://doi.org/10.16043/j.cnki.cfs.2018.31.006.

[58] X. Chen, Aseptic eggs are not totally sterile, China Food Ind. (12) (2022) 86–87.

[59] X. R. Zhao, L. Zhao, H. Ye, Research on centrifugal spray drying of the duck egg powder, Food Mach. 25(4) (2009) 144–148. https://doi.org/10.13652/j.issn.1003-5788.2009.04.037.

[60] M. Li, Study on preparation technology andfunctional characteristics of fermentedwhole egg powder, Wuhan Polytechnic University, Wuhan, 2020, pp. 2–9. https://doi.org/10.27776/d.cnki.gwhgy.2020.000181.

[61] W. Q. Tang, S. W. Guo, Influence of technological parameters on the quality of centrifuge spray dried protein powder, Sci. Technol. Food Ind. 2 (2006) 53–55. https://doi.org/10.3969/j.issn.1002-0306.2006.02.014.

[62] Q. J. Yang, X. X. Wang, Egg food and its hygiene requirements, Chin. Livest. Poult. Breed. 9(1) (2013) 125. https://doi.org/10.3969/j.issn.1673-4556.2013.01.095.

[63] T. Croguennec, F. O. Nau, S. Pezennec, et al., Two-step chromatographic procedure for the preparation of hen egg white ovotransferrin, Eur. Food Res. Technol. 212(3) (2001) 296–301. https://doi.org/10.1007/s002170000242.

[64] X. J. Ma, B. R. Xi, H. B. Chen, et al., Simultaneous separation of three major allergens in hen' s egg white, Food Sci. 30(22) (2009) 40–43. https://doi.org/10.3321/j.issn:1002-6630.2009.22.005.

[65] Q. Huang, M. H. Ma, X. Huang, et al., Separation of ovalbumin and lysozyme from chicken egg white using two-stage ultrafiltration technique, Trans. Chin. Soc. Agr. Mach. 43(3) (2012) 6. https://doi.org/10.6041/j.issn.1000-1298.2012.03.027.

[66] L. Q. Sun, H. X. Lu, J. Y. Wang, Separation of lysozyme from egg white by electrodialysis with ultrafiltration membrane (EDUF) process, Chem. Ind. Eng. Prog. 42(5) (2023) 2262–2271. https://doi.org/10.16085/j.issn.1000-6613.2022-1293.

[67] M. Yilmaz, G. Bayramoglu, M. Y. Arica, Separation and purification of lysozyme by Reactive Green 19 immobilised membrane affinity chromatography, Food Chem. 89(1) (2005) 11–18. https://doi.org/10.1016/j.foodchem.2004.01.072.

[68] Q. H. You, X. L. Yin, Optimum extraction technology of egg white lysozyme, Food Sci. Technol. 35(2) (2010) 259–261; 267. https://doi.org/10.13684/j.cnki.spkj.2010.02.018.

[69] L. L. Liu, Q. Ma, T. L. Yang, Measuring productivity of ovalbumin by egg white salting-out method with smart phone sensor, Exp. Technol. Manage. 33(12) (2016) 60–62. https://doi.org/10.16791/j.cnki.sjg.2016.12.016.

[70] L. L. Zhang, M. L. Ma, C. X. Li, et al., Isolation, purification and antibacterial activity of lysozyme from egg white, Biol. Chem. Eng. 3(1) (2017) 13–16. https://doi.org/10.3969/j.issn.2096-0387.2017.01.004.

[71] I. Roy, M. V. S. Rao, M. N. Gupta, An integrated process for purification of lysozyme, ovalbumin, and ovomucoid from hen egg white, Appl. Biochem. Biotechnol. 111(1) (2003) 55–63. https://doi.org/10.1385/ABAB:111:1:55.

[72] C. Guérin-Dubiard, M. Pasco, A. Hietanen, et al., Hen egg white fractionation by ion-exchange chromatography, J. Chromatogr. A 1090(1/2) (2005) 58–67. https://doi.org/10.1016/j.chroma.2005.06.083.

[73] J. Gao, L. B. Qi, S. Y. Lin, et al., Effect of ethanol on extraction purity of egg yolk phospholipids and solubility of egg yolk powder, Food Ferment. Ind. 49(7) (2023) 212–217. https://doi.org/10.13995/j.cnki.11-1802/ts.031386.

[74] F. L. Zhao, Research on the controllable enzyme disassemble conditions of high *F* value oligopeptides from eggwhite, Jilin University, Changchun, 2007, pp. 2–8.

[75] H. Wan, Research on preparation of high *F* value oligopeptides from egg white, Wuhan Polytechnic University, Wuhan, 2011, pp. 7–11.

[76] C. Liu, Study of graded purification of yolk immunoglobulin based on membrane separation technology and production line design, Huazhong Agricultural University, Wuhan, 2022, pp. 1–11. https://doi.org/10.27158/d.cnki.ghznu.2022.001466.

[77] J. L. Gao, L. P. Gu, C. H. Chang, et al., Comprehensive utilization of by-products from immunoglobulin extraction in egg yolk, J. Food Sci. Biotechnol. 42(10) (2023) 73–82. https://doi.org/10.12441/spyswjs.20220317001.

[78] B. Y. Li, Optimization of the process to produce calcium acetate, calcium citrate and calcium propionate from eggshells by response surface method, Jilin University, Changchun, 2020, pp. 1–3. https://doi.org/10.27162/d.cnki.gjlin.2020.004667.

[79] Y. J. Chi, Review of the high effective extraction technologies and the bioactive products' exploitation techniques in eggs, Food Sci. 23(8) (2002) 303–306. https://doi.org/10.3321/j.issn:1002-6630.2002.08.096.

[80] E. O. Ajala, O. A. A. Eletta, M. A. Ajala, et al., Characterization and evaluation of chicken eggshell for use as a bio-resource, Arid Zone J. Eng. Technol. Environ. 14 (2018) 26–40.

[81] S. C. Wu, T. C. Sun, H. D. Xu, A new way to efficient utilization of eggshell waste: as green dephosphorization agent and accelerator for reduction roasting of high-phosphorus oolitic iron ore, Process Saf. Environ. Prot. 173 (2023) 702–714. https://doi.org/10.1016/j.psep.2023.03.058.

[82] R. A. Mensah, K. Salim, K. Peszko, et al., The chicken eggshell membrane: a versatile, sustainable, biological material for translational biomedical applications, Biomed. Mater. 18(4) (2023) 042001. https://doi.org/10.1088/1748-605X/acd316.

[83] T. A. E. Ahmed, H. P. Suso, A. Maqbool, et al., Processed eggshell membrane powder: bioinspiration for an innovative wound healing product, Mater. Sci. Eng. C: Mater. Biol. Appl. 95 (2019) 192–203. https://doi.org/10.1016/j.msec.2018.10.054.

[84] G. D. Mogoşanu, A. M. Grumezescu, Natural and synthetic polymers for wounds and burns dressing, Int. J. Pharm. 463(2) (2014) 127–136. https://doi.org/10.1016/j.ijpharm.2013.12.015.

[85] R. G. Saratale, Q. Sun, V. S. Munagapati, et al., The use of eggshell membrane for the treatment of dye-containing wastewater: batch, kinetics and reusability studies, Chemosphere 281 (2021) 130777. https://doi.org/10.1016/j.chemosphere.2021.130777.

[86] W. Bessashia, Y. Berredjem, Z. Hattab, et al., Removal of basic fuchsin from water by using mussel powdered eggshell membrane as novel bioadsorbent: equilibrium, kinetics, and thermodynamic studies, Environ. Res. 186 (2020) 109484. https://doi.org/10.1016/j.envres.2020.109484.

[87] T. Liu, T. P. Zhang, X. Y. Luan, et al., Use of response surface analysis for optimization of extraction process of chondroitin sulfate from egg shell membrane, Packag. Eng. 40(17) (2019) 48–55. https://doi.org/10.19554/j.cnki.1001-3563.2019.17.008.

[88] Y. Liu, H. Y. Hao, Y. M. Bao, et al., Study on the technology for the extraction of soluble eggshell membrane protein, Food Res. Dev. 42(14) (2021) 87–92. https://doi.org/10.12161/j.issn.1005-6521.2021.14.014.

[89] W. T. Zhu, S. J. Wu, H. Yang, et al., Optimization of the process of extracting hyaluronic acid from egg shell membrane by enzymatic method, Food Sci. Technol. 41(1) (2016) 204–209. https://doi.org/10.13684/j.cnki.spkj.2016.01.041.

[90] X. Y. Luan, Extraction and application of eggshell membrane polysaccharide, Harbin University of Commerce, Harbin, 2016, pp. 2–3.

[91] G. P. Zhang, M. F. Niu, J. He, Research progress on application of eggshell membrane, Food Mach. 38(12) (2022) 205–211. https://doi.org/10.13652/j.spjx.1003.5788.2022.80319.

[92] T. Kim, S. Park, Y. Lee, et al., Thin film biocomposite membrane for forward osmosis supported by eggshell membrane, Membranes 12(2) (2022) 166. https://doi.org/10.3390/membranes12020166.

[93] Y. R. An, M. Y. Xia, Y. P. Huang, et al., Exploitation and utilization of the eggshell membrane, Sci. Technol. Food Ind. 34(3) (2013) 375–378; 382. https://doi.org/10.13386/j.issn1002-0306.2013.03.057.

[94] N. Zhu, F. Qin, Thoughts and suggestions on the transformation and upgrading of layer industry in China, China Poult. 41(16) (2019) 1–4. https://doi.org/10.16372/j.issn.1004-6364.2019.16.001.

[95] B. C. Duan, M. H. Yang, Q. C. Chao, et al., Preparation and properties of egg white dual cross-linked hydrogel with potential application for bone tissue engineering, Polymers 14(23) (2022) 5116. https://doi.org/10.3390/polym14235116.

[96] Y. Zhao, Y. L. Zhao, Y. G. Chu, et al., Facile synthesis of hydroxypropyl chitosan-egg white hydrogel dressing with antibacterial and antioxidative activities for accelerating the healing of burn wounds, J. Mater. Chem. B 11(19) (2023) 4330–4345. https://doi.org/10.1039/D3TB00210A.

[97] L. L. Guo, The experiments and mechanisms of the 3D printed bioactive egg white hydrogel on promoting wound healing and skin regeneration, Southern Medical University, Guangzhou, 2022, pp. 1–5. https://doi.org/10.27003/d.cnki.gojyu.2022.000091.

[98] L. J. Zhu, Y. Zhang, C. F. Xu, Science and technology innovation to promote the healthy development of China's egg industry, Anim. Breed. Feed 1 (2019) 23–27. https://doi.org/10.13300/j.cnki.cn42-1648/s.2019.01.008.