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# Potato Processing Industry in China: Current Scenario, Future Trends and Global Impact

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## Abstract

Potatoes play an important role in ensuring food security. During the COVID-19 epidemic, consumption of processed potato products decreased, and consumption of fresh potatoes increased. China is the world's largest potato producer with more than 4.81 million hectares of area under potato production and 90.32 million metric tonnes of potatoes produced in 2018. This accounts for 27.36% of the world's planting area and 24.53% of the world's potato production. The proportion of potatoes processed in China was about 12% in 2017, mostly dominated by starch production. However, the recent policy of the Chinese government to popularise potato as a staple food has created new markets for processed potato products other than starch. A very few reports have analysed these future trends of the rapidly growing Chinese potato processing industry and its impact within and outside China. This paper provides an overview of the latest developments with a focus on processed potato products such as potato chips, French fries and dehydrated potatoes, and also, due to the unique Chinese diet culture, it highlights the need for more scientific research dedicated towards the development of novel potato-based healthy foods.

**Keywords** China · Development · Potato · Potato industry · Potato processing

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## Introduction

The cultivated potato originated in South America where it has been used for food for over 10,000 years, while it was domesticated during pre-Columbian times over 8000 years ago [Camire et al. 2009; Brown 1993]. In the literature [Awuah et al. 2007] it is claimed that potatoes were purchased by a hospital for feeding patients in Seville (Spain) in 1573 and were used as cattle feed in Italy in 1588. In the eighteenth and nineteenth centuries, potatoes became a major food source in much of Europe. At this point, people began to use potatoes similar to vegetables, grains, and feed. At present, the potato is the third most important food crop in the world after rice and wheat in terms of human consumption, with more than a billion people consuming potatoes worldwide [Hermansen and Forbes, 2012]. The global total potato production in 2018 exceeded 368 million metric tonnes (FAOSTAT, 2020).

Today, the potato has a major role to play in feeding the increasing population worldwide [Armelagos 2012]. Potatoes can grow in all kinds of environments and have high nutritional value [Woolfe, 1987], are an excellent source of carbohydrate, protein, vitamins, minerals and dietary fibre and are also one of the richest sources of antioxidants [Buono et al., 2009; Chung et al. 2012]. The potato produces more nutritious food and grows more quickly, using less land, and in harsher climates than any other major food crop [Liu et al. 2017], which are the reasons why it can become the third staple food in the world.

Fresh potatoes are available only for a few months because they are only single-cropped during one year in most countries [Kaur et al. 2009] and in two seasons per year at most in the central double-cropping early and southwest mixed cropping zone of China. Due to the large-scale production, they cannot be consumed in time and are likely to become spoiled. Stored potatoes are exposed to potential risks (e.g., excessive weight loss, spoilage by pathogens and sprout growth), even under good storage conditions, resulting in a decline in their yield and quality [Sinha et al. 2017]. To solve the problems associated with post-harvest storage and to expand the use of potatoes in the food industry, a large proportion of potatoes are processed using methods such as freezing, frying/freezing, dehydration, and canning.

Potato products at an industrial scale mainly include potato chips, French fries, dehydrated potato powder and starch [Hao 2017]. The potato industry is highly industrial, technologically advanced, and very market-driven; however, it relies heavily on available potato raw materials [Jansky et al. 2009]. The potato industry is very mature in the west, but it still needs further development and progress in China. However, with the development of the economy and the state's policy on potatoes as a staple food, the potato industry has developed quickly in recent years.

Potato is an important crop in China. In the early 1990s, China became the largest potato producer in the world, and the sown area and total output of potatoes increased steadily [Sinha et al. 2017; Keijbets 2008]. According to FAOSTAT, the area harvested and production of potatoes in China in 2017 are 5.77 million hectares and 99.21 million metric tonnes, respectively, accounting for 29.88% of the world's planting area and 25.56% of the world's production. In the USA, for example, per capita consumption of processed potato products

in 2010 was estimated to be about 2.1 times that of fresh potatoes [Wang and Zhang 2004]. Table 1 shows potato-food availability in the USA in recent years. The consumption of potatoes in the USA was mainly fresh potatoes, potatoes for freezing, canning, chips and shoestrings and dehydration. Amongst them, the amount of dehydrated potatoes increased rapidly, whilst other increases were gentle, with little change. At present, most of China's (45%) potato crops are used for foodstuffs, 14% for export and feed and 21% for starch and other processed products. Approximately 10% of the production is used for seeds, and loss accounts for 10% of the total production [Wang and Zhang 2010]. With the increase in the potato planting area, the amount of potato seeds increased every year.

This report compiles data from different sources and analyses the current status of China's potato processing industry and also discusses its impacts on Chinese agriculture, and the diet of the Chinese population. Graphical analysis provides a visual summary of the changes that have occurred over time and forecast the development trends of the Chinese potato processing industry for the future. The COVID-19 situation has influenced all industry sectors, and some information on its impact on the potato industry has been gathered and included in this report.

## Potato Production in China—the Largest Producer in the World

China covers a large geographic area, with potatoes produced throughout the country [Wang and Zhang 2010]. According to the potato cultivation system, planting type, variety type and distribution in China, combined with the biological characteristics of potato, according to geographical, climatic conditions and meteorological indicators, China is divided into four major agroecological zones [Alva et al. 2011].

**Table 1** Potato food availability in the USA, 2014–2019 (10,000 tonnes)

| Items | | | Year | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| Fresh | Total food availability | | 486 | 497 | 494 | 514 | 490 | 510 |
| Freezing | | | 680 | 723 | 695 | 764 | 764 | 767 |
| Canning | | | 5 | 6 | 6 | 7 | 6 | 6 |
| Chips and shoestrings | | | 288 | 285 | 243 | 262 | 268 | 290 |
| Dehydration | | | 175 | 168 | 176 | 190 | 193 | 203 |
| All uses | Supply | Production | 1712 | 1772 | 1705 | 1805 | 1754 | 1844 |
| | | Imports | 237 | 234 | 255 | 282 | 295 | 279 |
| | | Beginning stocks | 99 | 93 | 91 | 102 | 107 | 107 |
| | | Total supply | 2049 | 2100 | 2051 | 2188 | 2157 | 2229 |
| | Nonfood use | Exports | 321 | 329 | 334 | 344 | 329 | 351 |
| | | Ending stocks | 93 | 91 | 102 | 107 | 107 | 104 |
| | Total food availability | | 1634 | 1679 | 1615 | 1737 | 1722 | 1774 |

Source: USDA, Economic Research Service-based on data from various sources as documented on the Food Availability Data System home page. Data last updated April 1, 2020

The North Single-cropping zone includes the Heilongjiang and Jilin provinces in the northeast of China and most of Liaoning Province except the Liaodong Peninsula, Northern China (e.g., northern Hebei, northern Shanxi, Inner Mongolia), Northwestern China (e.g., Ningxia Hui Autonomous Region, Gansu, northern Shaanxi), eastern Qinghai, and northern Tianshan of Xinjiang Uygur Autonomous Region are all included. The climate in the region is cool, and the sunshine is sufficient, which is suitable for potato growth and development. Therefore, its planting area is relatively large, accounting for more than 50% of the total potato planting area in China. This zone includes the main potato-producing areas in China, such as Gansu (Dingxi) and Inner Mongolia (Ulanqab). The potato tuber seeds produced are of good quality and have become an important potato seed production base in China.

The Central Double-cropping zone is located in the south of the southern boundary of the North Single-cropping zone, including Daba Mountain, eastern Miaoling, Nanling and northern provinces of Wuyi Mountain such as the south of four provinces (Liaoning, Hebei, Shanxi, Shaanxi), the east of two provinces (Hubei, Hunan) and other provinces (Henan, Shandong, Jiangsu, Zhejiang, Anhui, Jiangxi, and others). This zone experiences a summer with high temperatures, which is not conducive to the growth of potatoes. To avoid high temperatures in summer, the potato is cultivated in spring and autumn. In the spring, it is mainly used to produce potatoes for commercial applications. In the fall, it is mainly used to produce seed potatoes and often intercropped with other crops. The total area cultivated in this zone is less than 5% of the country's area used for potato production. However, in recent years, with the increase in the level of potato cultivation and the improvement of cultivation techniques, the planting area has been expanded, particularly in the "Traditional Chinese Potato Township" in Tengzhou City (Shandong Province).

The South Winter-Cropping zone is located in the provinces (districts) south of Nanling and Wuyi Mountain, including Guangdong, Guangxi Zhuang Autonomous Region, Hainan, Fujian and Taiwan (autonomous regions). The grain production in this area is mainly rice cultivation. After rice harvest, the winter fallow fields are usually used for the cultivation of potatoes. Because the two cultivation seasons are mainly between autumn and winter or between winter and spring, it is different from the two cultivation seasons of spring and autumn in the Central Double-cropping zone. At present, the South Winter-Cropping zone is an important export base of commodity potato in China, and it is also the area with the most rapid development of potato.

The Southwest Mixed-cropping zone is a single- and double-cropping mixed area, which includes Yunnan, Guizhou, Sichuan, Tibet Autonomous Region and the western mountainous areas of Hunan and Hubei. Most of these areas are mountainous and plateaus, with a vast area, complex terrain, and the altitude varies greatly. In these areas, potatoes are cultivated once or twice annually. Weining County of Guizhou Province is known as the "Hometown of Chinese Potatoes."

According to the data in Table 2, from 2014 to 2017, China's potato planting area and production were stable, the cultivated area exceeds 5500 ha, and the production is maintained at about 9.5 million tonnes, making China the largest potato producer in the world. The total potato production in China increased slightly in 2017, whilst the imports decreased, and the total demand increased slightly. In general, the total output of the potato has increased steadily. Due to the adaptability and tolerance of

**Table 2** Summary of China's potato production and processing data. Balance of China's potato production and consumption, 2014–2017 (10,000 ha or 10,000 tonnes)

| Items | Year | | | |
|---|---|---|---|---|
| | 2014 | 2015 | 2016 | 2017 |
| Cultivated area (10,000 ha) | 557 | 551 | 568 | 579 |
| Total production | 9552 | 9486 | 9201 | 9682 |
| Import | 36 | 48 | 33 | 30 |
| Surplus at the beginning of this campaign | 2095 | 1928 | 1936 | 2103 |
| Total supply | 11,682 | 11,462 | 11,171 | 11,815 |
| Total demand | 11,682 | 11,462 | 11,171 | 11,815 |
| Edible consumption | 5842 | 5695 | 5534 | 5895 |
| Processing consumption | 865 | 854 | 736 | 823 |
| Seed consumption | 373 | 379 | 396 | 431 |
| Feed consumption | 2110 | 2068 | 1905 | 1838 |
| Loss | 478 | 455 | 427 | 445 |
| Other uses | 22 | 22 | 21 | 24 |
| Export | 65 | 52 | 50 | 60 |
| Surplus at the end of this campaign | 1928 | 1936 | 2103 | 2299 |

Source: Potato Food Professional Committee of China National Food Industry Association

potato plants to arid, cold climates and poor soils, they can grow in most parts of China and are widely grown in almost all provinces. According to a recent report, in 2016, provinces, autonomous regions and municipalities with an area of more than 370,000 ha of potato cultivation include Inner Mongolia, Guizhou, Gansu, Sichuan, Yunnan and Chongqing. The area planted in these areas was 3.69 million ha, accounting for 67% of the total potato area in China [Li 2017].

## Growth of Potato Processing Industry in China

In recent years, North America and the European Union are the leaders in the global potato processing industry. The global rate of potato conversion from raw to processed products is 60–70% [Birch et al. 2012], whereas the Chinese potato processing conversion is around 12% [Jin et al. 2018]. Frozen French fries and other pre-frozen products accounted for 62% of the total processing (18.8 million tonnes) in North America and the European Union. In Europe, the Netherlands, Germany, Belgium, France and the UK have the largest potato processing capacity, whilst potato processing in Poland is growing very fast, the potato starch processing capacity in the EU and other countries is 1.5–1.8 million tonnes/year. Oceania is the third largest potato processing region in the world, but it lags far behind North America and Europe. However, the potato industry in Asia, especially China, is now growing rapidly [Yang et al. 2017].

Due to the increasing population and more demand for grain production, the commercial potato processing started quite late in China, with the modern potato

processing industry beginning to develop in the early 1990s. According to the statistical results of the Lanzhou Institute of Chemical Physics (Chinese Academy of Sciences, 2018), there are 294 large and medium-sized potato processing enterprises in China, including 194 starch production enterprises, 13 modified starch, 38 dehydrated potato flour, 35 French fries, and 38 potato chip production enterprises. China's potato processing enterprises are mainly concentrated in Inner Mongolia (61), Gansu (46), Ningxia (21), Shaanxi (21) and Heilongjiang (19). The form of processed potato products in some provinces and regions is monotonous. For example, Xinjiang Uygur Autonomous Region has 9 potato processing enterprises, 8 of which produce starch, and only one produces dehydrated potato flour. There are 11 potato processing enterprises in Sichuan Province, 10 of which produce starch, and only one produces dehydrated potato flour.

The production and processing capacity of the main potato-producing areas are inconsistent. In some areas, potato production is large, but the processing capacity is low. The potato production of Sichuan, Yunnan, and Guizhou exceeded 12 million tonnes, but the processing capacities were 276,200, 138,900 and 144,200 tonnes/year. The annual potato output of Chongqing is 6.085 million tonnes, but the processing capacity is only 26,000 tonnes/year, and only three potato processing companies produce starch and starch-related products. Starch is the main potato processing product in China, and there are 194 potato starch enterprises with a total annual production capacity of 33.921 million tonnes. With 50 potato starch enterprises, Inner Mongolia is the predominant province for potato starch production. But Gansu has the largest production capacity, which is 788,600 tonnes/year and more than the 605,600 tonnes/year in Inner Mongolia. Inner Mongolia Nailun Agricultural Science and Technology Co., Ltd., is the largest potato starch producer in China, with a production capacity of 100,000 tonnes/year. The production capacity of modified potato starch in China is 458,000 tonnes/year. Gansu, with four enterprises and a total production capacity of 133,000 tonnes/year, is the predominant province.

Due to the Chinese dietary culture, the potato processing industry has its obvious characteristics. The demand for starch-based products promotes the development of the potato starch processing industry. Chongqing is an important potato production area in China, with three potato starch processing enterprises, and two of them continue to process potato starch into vermicelli, which solves the problem of labour force employment caused by the strong seasonality of starch processing. At present, there are only 8 enterprises that produce both potato starch and modified starch in China, if potato starch and modified starch processing are combined, using wet starch (before drying) to produce modified starch, it can reduce the costs associated with the drying process energy.

## French Fries—the Fastest Growing Processed Industry in China

Modern potato processing and consumption in China are closely related to those of other industrialised countries. Production is highly industrial and technologically advanced and relies heavily on a continuous and guaranteed supply of potatoes [Ngobese and Workneh 2017]. As can be seen from Fig. 1, the processing

capacity and actual production of Chinese frozen French fries began at 63,000 tonnes in 2006 and continued to grow to 318,000 metric tonnes in 2015. The average annual growth rate continues to maintain encouraging growth, and the highest average annual growth rate was 64.36% in 2010. In 2016, due to partial adjustments of wholly foreign-owned enterprises, the production capacity of French fries in China went down slightly. In 2017, the annual production capacity was 281,500 tonnes, with an increased rate of 6.23%. The sales revenue of several key enterprises exceeded ¥ 2.9 billion.

According to the China Food Industry Association's professional committee on potato food, it is expected that the processing capacity and actual production of frozen French fries in China will be greatly improved in the future due to a number of new French fry production lines expecting to start production, e.g., Farm Frites cooperates with Inner Mongolia Linkage Potato Co. Ltd., and is setting up a French fry factory with an annual capacity of 70,000 tonnes frozen French fries in Wudan Town, Chifeng City in Inner Mongolia. Landun Xumei Food Co., Ltd., is planning to build a French fry production line with an annual capacity of 100,000 tonnes, and Aviko Snowvalley, a new potato processing facility, located at Zhangjiakou (Hebei Province), will have an annual production capacity of 100,000 tonnes of French fries and 50,000 tonnes of freshly cut potato products. Inner Mongolia Minfeng Potato Industry Co., Ltd., located at the Ulanqab French fry factory will have an annual capacity of 50,000 tonnes in 2020.

## Growth of the Potato Chips Industry

The supply of potato and potato-based raw materials is critical to the continuity of the modern potato processing industry and its supply chain. It is influenced by the right variety, good agricultural practices, harvesting and refrigeration facilities and continuous control of processing quality at the processing plant [Morrow and Jecha-Beard 2003].

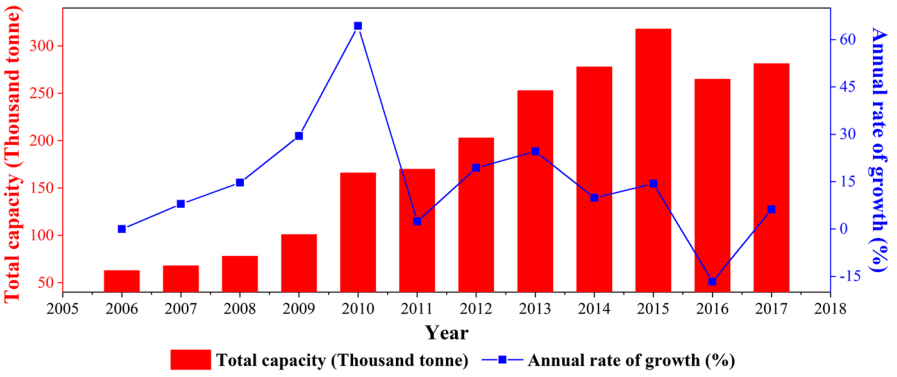


**Fig. 1** Processing capacity of French fries in China, 2006–2017. Source: Potato Food Professional Committee of China National Food Industry Association

According to the statistical results of the Lanzhou Institute of Chemical Physics (Chinese Academy of Sciences, 2018), there are 38 potato chips producers in China. The potato chips factories are mainly concentrated in Fujian (Dali Garden, Panpan, Qinqin (including "Pringles"), etc. Shanghai (Lay's and Oishi) and Beijing (Orion) are also the main potato chips processing bases in China, which account for 22.59% and 12.91% of the total factory sales at the national level, respectively.

Dali Group is the largest potato chips processing enterprise in China, with annual sales of 16 billion RMB, accounting for 34.42% of the total sales nationwide. As a comprehensive modern food enterprise group, Dali Group has established 18 subsidiaries in 16 provinces and regions across the country; the potato chips brand is called "Copico," which is produced in 10 Dali's subsidiaries located in Quanzhou, Chengdu, Jinan, Hubei, Jilin, Gansu, Maanshan, Shanxi and Yunnan.

## Growth of Dehydrated Potato Flour Industry

Dehydrated potato flour is an important raw material for "potato as a staple food," as it is nutritionally more comprehensive than pure starch. The pure starch-based vermicelli or similar products can only provide glucose to the human body whereas whole potato products such as mashed potatoes made from dehydrated potato flour retain the nutrition value of whole potato tuber, e.g. starch, protein, vitamins, dietary fibre and minerals [Camire et al. 2009]. The industrial production of dehydrated potato flour is very important for the development of ready-to-eat type healthy and nutritious mashed potato products suitable for the Chinese population [Mu et al. 2017].

As shown in Fig. 2, the production capacity of dehydrated potato flour in China increased steadily from 2010 to 2013, then decreased slightly in 2014, and continued to grow in 2015–2016 and retained the same level in 2017 and 2018 (Potato Food Professional Committee of China Food Industry Association). Based on ensuring the supply of raw materials for snack food processing, the major enterprises of dehydrated potato flour in China have actively developed new products and made initial progress.

## Growth of the Potato Starch Industry

The processing of starch is currently the most important component of the Chinese potato processing industry. The country's ability to process starch is greater than all other processed potato products [Hermansen and Forbes, 2012]. Different reviews [Kaur et al. 2002] have discussed the unique physicochemical properties of potato starch, especially in terms of extensive phosphorylation of its amylopectin molecules. Potato starch also contributes greatly to the textural properties of many foods and has various industrial applications in the area of food, medicine, petrochemical industry, papermaking, textile, feed, fermentation, casting, building materials and so on. Potato starch is widely used as an emulsifier, thickener, water retention agent, wrapped slurry agent, softener, disintegrating agent, coating agent, sizing agent and adhesive [Kaur et al. 2007].

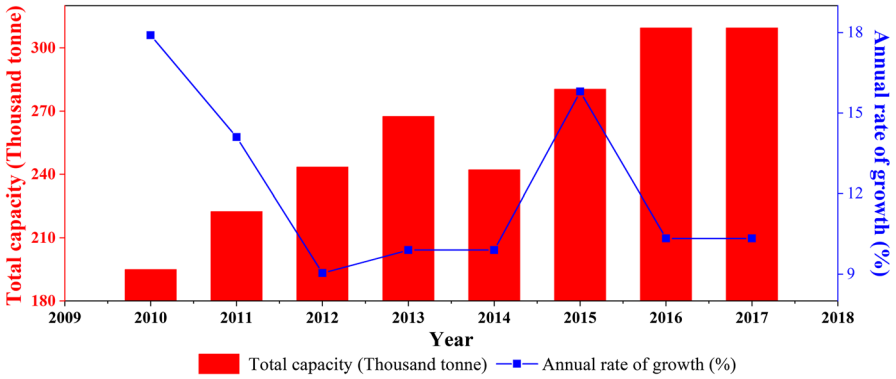


**Fig. 2** Processing capacity of dehydrated potato flour in China, 2010–2017. Source: Potato Food Professional Committee of China National Food Industry Association

The continuous development of the Chinese potato starch industry is closely related to two main reasons. Firstly, Chinese people like to eat vermicelli made from potato starch, especially Hot pot and Malatang, which are must-have dishes during meals. Secondly, starch processing is the main way to utilise defective potato tubers in China. Potato tubers of high quality in China are usually used for fresh consumption, French fries, potato chips and whole flour processing. Defective potato tubers such as small size potatoes, green-skinned potatoes, rotten potatoes and sprouted potatoes can often be used as raw materials for starch production.

At present, the processing capacity of potato starch in China is more than 2 million tonnes. However, the current market demand is around 700,000 tonnes per year. The purchase price of raw materials for potato starch processing is from 600 RMB/ton to 900 RMB/ton, far below the price of commodity potato 2000 RMB/ton. In 2017, the total potato starch production was estimated to be 1.18 million tonnes in China, of which about 540,000 tonnes included high-quality starch.

The main potato starch processing areas in China are concentrated in the Northwest, Northeast, North China and southwest (Fig. 3a); Northwest include Gansu, Ningxia, Qinghai, Xinjiang and Shaanxi; and Northeast includes Heilongjiang, Jilin and Liaoning. North China includes Inner Mongolia, Shanxi, and Hebei, and Southwest includes Yunnan, Guizhou, Sichuan and Hubei. According to the Potato Starch Specialty Council of China Starch Industry Association (2017), the potato starch production in Heilongjiang, Ningxia, Gansu and Inner Mongolia was 128,000, 96,500, 91,200 and 81,300 tonnes, respectively, accounting for 23.83%, 17.79%, 16.98% and 15.14% of the national total output, respectively (Fig. 3b). The total output of starch of the abovementioned four provinces is about 400,000 tonnes, accounting for 74% of China's total potato starch output.

Figure 4 shows the potato starch production in China from 2005 to 2017, and the total output of potato starch in 2017 was 537,000 tonnes (138 companies counted by the China Starch Industry Association), with an increased rate of 36% when compared to 2016. China's annual potato starch production is variable, mainly due to

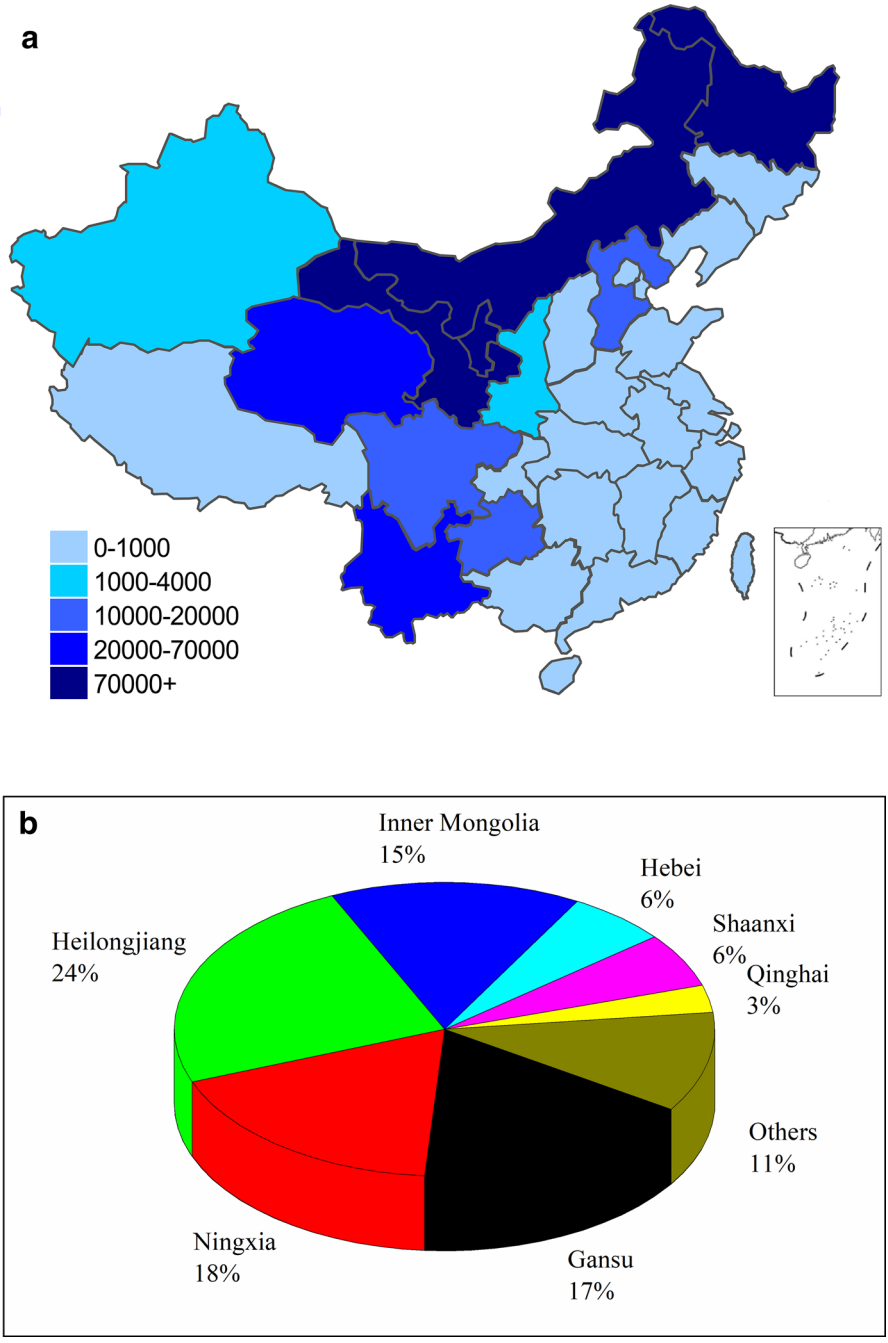


**Fig. 3** Distribution of potato starch production in China by the province in 2017 (unit: tonnes). **a** statistical map. **b** The proportion of the main producing provinces. Source: China Starch Industry Association

China's vast territory, unstable climate, environmental pressures and natural calamities, including droughts, floods and frosts [Hermansen and Forbes, 2012].

In addition, the development of modified starch in China began in the 1980s, mainly through the physical, chemical, enzymatic or mixed use of various methods to change the properties of natural starch. At present, more than 2000 kinds of modified starch products have been developed and marketed in China, including oxidised starch, acid-modified starch, cationic starch, cyclodextrin and dialdehyde starch (China Starch Industry Association).

In 2019, the output of modified starch in China was 1,757,800 tonnes. The varieties of modified starch with an output of more than 100,000 tonnes include compound modified starch, oxidised starch, cationic starch, acetate starch, phosphate starch and pre-gelatinized starch, with an output of 319,200 tonnes, 279,600 tonnes, 219,900 tonnes, 216,100 tonnes, 155,900 tonnes and 119,100 tonnes, respectively. The output of these six products accounts for about 75.79% of the total output of modified starch. China's modified starch production is mainly concentrated in Shandong, Guangxi, Zhejiang, Guangdong, Jiangsu and Jiangxi Province, which account for more than 85% of the total output. In 2019, the output of modified starch in Shandong Province was 656,600 tonnes. From the perspective of production enterprises, there are four enterprises with an annual output of more than 100,000 tonnes, accounting for 40.96% of the total modified starch. Amongst them, the output of Guangxi Nongken Mingyang Biochemical Group Co., Ltd., is 196,000 tonnes, accounting for 11.15% of the total output of the country. The papermaking industry is the largest demand field for modified starch in China, accounting for 58% of the total consumption of modified starch. As the second largest consumption field of modified starch, the food industry accounts for 18% of the total consumption of modified starch in China, and it is mainly used in instant noodles, ham sausage, yoghurt and various sauces. China is a net importer of modified starch, mainly in the form of dextrin and other modified starch. In 2019, China's net import of modified starch was 369,100 tonnes, a year-on-year increase of 13.46% (China Starch Industry Association).

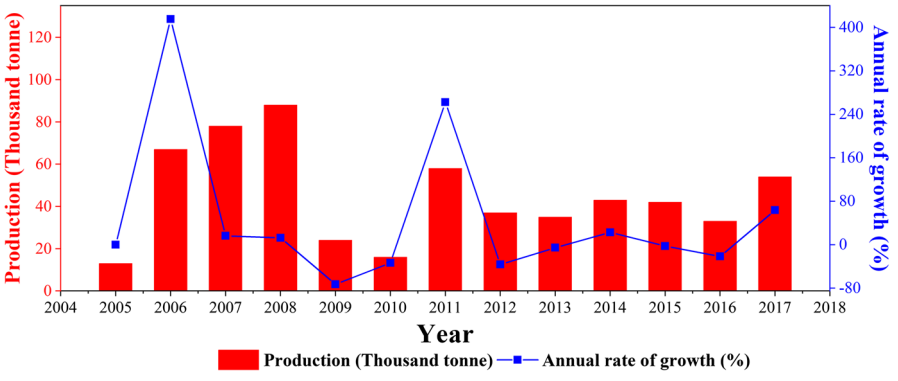


**Fig. 4** Changes in potato starch production in China, 2005–2017. Source: China Starch Industry Association (100 companies in 2016, 138 companies in 2017)

The main problems associated with the potato starch processing industry in China include firstly, potato starch enterprises with an annual capacity of less than 10,000 tonnes should be integrated, as not only they are at a disadvantage in the international potato starch industry due to their small scale, but also a vicious domestic competition of raw material for starch processing can be avoided. Secondly, the ability of technology, research and development and risk resistance should be enhanced, especially for the modified starch industry. Thirdly, private enterprises have corporate financing difficulties. Finally, due to environmental policy and tax policy impact, there is an urgent need for capital to integrate the industry and enlarge the production scale.

## Other Processed Potato Products in China

With the steady development of the economy, the continuous advancement of technology and industry, the gradual improvement of people's lives and the rise of e-commerce and mobile Internet, the consumer confidence index continues to rise in China [Huang and Tian 2016]. Consumers' consumption opinions are more optimistic, and consumer demand for snack foods is expanding day by day. In recent years, the variety of potato-related foods has diversified and consumption has grown moderately, such as potato-steamed bread, potato bread, potato noodles, potato steamed corn cake and potato cakes [Zeng et al. 2019].

According to the data in Table 3, the sales of major potato food enterprises in China in 2018 (the data is only the expected delivery, the market sales revenue is higher than these): the sales revenue of freshly cut potato chips is 9.5 billion RMB, and the output is 475,000 tonnes, with a year-on-year growth of 5.5%. The sales revenue of compound fried potato chips was 7 billion RMB, and the output was 350,000 tonnes, with zero growth. The sales revenue of compound baked potato chips reached 3.8 billion yuan, and the output was 190,000 tonnes, an increase of 8.5% annually, showing acceleration. The sales revenue of hard and crisp potato chips was 800 million RMB, and the output was 40,000 tonnes, with a negative growth of 11.1%. The sales revenue of biscuits and potato chips/strips was 1.7 billion yuan, the output of 85,000 tonnes and the sales revenue of puffed potato chips was 1.3 billion RMB, and the output of 65,000 tonnes showed zero growth. The sales revenue of puffed potato chips was 2.5 billion RMB and the output was 135,000 tonnes, up 13.6% year on year. The sales revenue of freshly cut French fries was 860 million yuan, and the output was 43,000 tonnes, an increase of 43.3% year-on-year. The sales revenue of Miguo (made from potato flour) reached 1.9 billion yuan, and the output reached 335,000 tonnes, up by 6.3% annually. The sales revenue of Little steamed buns (made from potato flour) was 1.9 billion yuan, and the output was 95,000 tonnes, up by 5.6% year-on-year. The total sales revenue of potato food was 36.06 billion RMB, with a total output of 180.3 million tonnes, with an annual increase of 5.1%.

As can be seen from Table 3, there are many types of processed potato products, of which freshly cut potato chips have the highest production, followed by Miguo and compound potato chips. The production of other potato products is relatively

**Table 3** Summary of China's potato production and processing data: summary of China's major potato processing products market data for 2014–2018

| Items | Year | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2014 | | 2015 | | | 2016 | | | 2017 | | | 2018 | | |
| | Sales (Billion RMB) | Yield (Thousand tonnes) | Sales (Billion RMB) | Yield (Thousand tonnes) | Growth rate (%) | Sales (Billion RMB) | Yield (Thousand tonnes) | Growth rate (%) | Sales (Billion RMB) | Yield (Thousand tonnes) | Growth rate (%) | Sales (Billion RMB) | Yield (Thousand tonnes) | Growth rate (%) |
| Fresh cut chips | 6.9 | 345 | 7.9 | 395 | 14.5 | 8.6 | 430 | 8.9 | 9.0 | 450 | 4.6 | 95 | 475 | 5.5 |
| Compound fried potato chips | 5.0 | 250 | 5.5 | 275 | 10 | 6.49 | 325 | 18 | 7.0 | 350 | 7.8 | 7.0 | 350 | 0 |
| Compound baked potato chips | 1.8 | 90 | 2.0 | 100 | 11.1 | 2.52 | 126 | 26 | 3.5 | 175 | 3.9 | 3.8 | 190 | 8.5 |
| Hard crisp potato chips | 1.0 | 50 | 0.9 | 45 | − 10 | 0.9 | 45 | 0 | 0.9 | 45 | 0 | 0.8 | 40 | − 11.1 |
| Biscuit chips / strips | 1.8 | 90 | 1.66 | 83 | − 7.8 | 1.65 | 82.5 | − 0.6 | 1.7 | 85 | 3.03 | 1.7 | 85 | 0 |
| Puffed potato chips | 1.5 | 75 | 1.5 | 75 | 0 | 1.5 | 75 | 0 | 1.3 | 65 | − 1.3 | 1.3 | 65 | 0 |
| Puffed French fries | 2.5 | 125 | 28.8 | 144 | 15.2 | 3.3 | 165 | 14.6 | 2.2 | 110 | 3.4 | 2.5 | 125 | 13.6 |
| Fresh cut fries | 0.1 | 5 | 0.15 | 7.5 | 50 | 0.32 | 16 | 113.3 | 0.6 | 30 | 87.5 | 0.86 | 43 | 43.3 |
| Rice cracker (potato flour) | 5.8 | 290 | 6 | 300 | 3.4 | 6.12 | 306 | 2 | 6.3 | 315 | 2.9 | 6.7 | 335 | 6.3 |
| Little steamed bun (potato flour) | 1.5 | 75 | 1.5 | 75 | 0 | 1.8 | 90 | 20 | 1.8 | 90 | 0 | 1.9 | 95 | 5.6 |
| Total | 27.9 | 1395 | 29.99 | 1435.5 | 7.5 | 33.2 | 1660.5 | 10.2 | 34.3 | 1715 | 3.3 | 36.06 | 1803 | 5.1 |

Source: Potato Food Professional Committee of China National Food Industry Association

low, especially the yield of freshly cut potato fries. From 2014 to 2017, the growth rate of freshly cut potato chips has been declining, rising slightly in 2018. The output of freshly cut French fries is increasing year by year, and in 2016, the maximum growth rate emerged as high as 113.3%.

Between 2014 and 2018, the total sale of potato products has been growing, but the annual growth rate has increased or decreased. At the same time, some potato snack processing enterprises in China are being developed, and it is expected that the operating value will increase once their operation begins. More and more unique snack foods made of potatoes will emerge along with China's new strategy, new mechanisms, new technologies, new equipment, new materials, new economic models and new platform, all of these advantages will promote the company's development of manufacturing, then the consumer and market satisfaction will also be improved.

## "Potato as a Staple Food" Policy in China

In 2013, the Ministry of Agriculture and Rural Affairs (MARA) of the People's Republic of China (MARA of PRC) proposed the idea of a "potato staple food" strategy. In 2015, Prime Minister Keqiang Li indicated clearly in an executive meeting of the State Council that China will promote potato staple food processing. The MARA indicated in "Farming working points in 2015" that China will promote potato staple food products and industrial development actively, which indicates that China's potato staple food strategy has been fully implemented. In 2016, the Central First Document stated that China will promote potato staple food development.

In China, potato staple food products include potato steamed bread, potato bread, potato noodles, potato steamed corn cake, mashed potatoes, potato chips, potato cakes, and so on [Zhang et al. 2017]. Besides original wheat flavours, special potato flavours are also maintained in these products [Mu et al. 2017]. Some studies have shown that the incorporation of potato flour into steamed and baked bread would enhance their nutritional and functional qualities [Blades et al. 2008]. For the same potato cultivar, the comprehensive nutritional value of steamed bread was higher than that of baked potato bread. Moreover, Hongmei was the optimal potato cultivar for bread making, followed by Blue Congo, Shepody, and Atlantic [Liu et al., 2017]. At the same time, adding various proportions of potato flour to wheat flour also helps to reduce gluten levels and prevent complications associated with celiac disease [Ijah et al. 2015]. However, adding too much amount of potato granules may hurt the rheological properties of dough systems. Noodles added with 20% potato granules could preserve the overall quality of noodles during storage and it was suggested as the most appropriate recipe for potato noodles [Xu et al. 2017]. Another study showed that the incorporation of food additives (such as xanthan gum, and curdlan) improved the peak viscosity and breakdown of fresh potato instant noodles [Javaid et al. 2018; Wang et al. 2010]. In many cases, this implies the partial substitution of wheat flour in the staple diet with potato flour derived from tuber as a means of diversifying and upgrading staple food in China.

At present, China has developed more than 200 kinds of potato staple food products, and several of these products have been successfully commercialised. Due to

the particularity of the physicochemical properties of potato, the technologies and equipment used for processing common rice, noodles, stream bread, rice noodles and other staple food products may not be suitable for processing potato staple food products. Currently, the technologies and facilities for processing potato products are merely limited to starch, potato granules, French fries and chips, new technologies are required to process locally processed potato formats or new equipment may be imported from abroad [Du and Li, 2016]. Therefore, there is a need to undertake independent research for the development of processing technologies and equipment, suitable to process potato staple products and suitable for Chinese consumers. An optimistic attitude should be held about the industrialisation of traditional Chinese potato processing products, a successful example is that the industrial production line of vermicelli (with starch from potatoes, sweet potatoes or other sources as raw material) has been developed by Chinese food scientists and engineers, which meets the needs of combining traditional Chinese diet culture and modern potato processing industry [Chen et al. 2017]. The industrial and technologically advanced vermicelli production line is comparable to the production lines for French fries, dehydrated potatoes, starch, etc.

In Southwestern China such as Chongqing, Sichuan and Guizhou, there is a kind of traditional semi-finished potato product that is well worth industrial production. Potatoes are steamed and then cut into thick slices and dehydrated, and finally, a kind of transparent and very chewy potato product is obtained, which is similar to dehydrated abalone, commonly referred to as "Plant Abalone." This kind of semi-finished potato product not only solves the problem of potato storage, but also, based on the dietary habits of the southwest China population, can be processed into a very delicious dish together with chicken. People even prefer to eat "Plant Abalone" to chicken in this dish. There is a need to develop specialised drying equipment to process this kind of semi-finished high-quality potato products, to avoid longer dehydration "solar drying" times.

## Status of Potato as a Healthy Food in China

Unlike Western countries, which have higher per capita consumption of processed potato products such as French fries etc., Chinese people like to eat sour and hot potato shreds (SHPS), which remains a national dish all year round, no matter if it is in a cheap country restaurant or in a most expensive luxury restaurant in the big cities like Shanghai or Beijing. Our conservative estimate is that more than half of all the potatoes harvested in China are consumed as fresh table stock in the form of SHPS [Pan 2018]. Freshly harvested potatoes are most suitable for processing SHPS; otherwise, they will lack the typical crispness or brittleness due to sweetening during cold storage [Singh and Kaur 2009]. With advantaged climate conditions, Yunnan province provides the best raw material for kitchen processing of SHPS during the spring season, when the price of Yunan's potato (a well-known variety) is normally 3 to 4 times higher than the other varieties available in the North part of China. Therefore, Yunnan province is the region with the best economic benefits for potato growth in China.

The calories in French fries and potato chips are 312 and 545/100 g (USDA Food Composition Databases), whilst the SHPS has only 120 cal/100 g, which is slightly higher than the boiled potato (87 cal/100 g) and lower than the roast potato (149 cal/100 g). SHPS is a very healthy way of potato consumption, in addition to low-fat content, and short time of high-temperature processing, starch may not be completely gelatinized, such a potato product is less likely to cause obesity due to high-resistant starch content, but it still needs further scientific confirmation. Considering that potato tubers contain high-quality protein (especially lysine is absent in rice and wheat), and are rich in minerals such as potassium, magnesium and iron, the Ministry of Agriculture and Rural Affairs of the People's Republic of China has listed potatoes as the fourth staple food after rice, wheat and corn for domestic food security [Su and Wang, 2019].

## Research and Development on Potato Processing

The research and development activities on potato processing in the Chinese research institutes and universities have increased significantly. Several research papers in the areas of potato starch [Wu et al. 2009; Zhang et al. 2011; Zhou et al. 2014], potato starch modification [Ruan et al. 2009], the composition of potatoes [Xu et al. 2018] and processed potato products [Liu et al. 2019], sensory analysis to nutritional properties of potatoes [Zeng et al. 2019; Xu et al. 2020] and their glycaemic properties during starch digestion [Liu et al., 2018] have been published in the international journals. A typical search on the Web of Science using keywords like "Potato processing, potato starch, French fries, potato composition, potato starch digestibility" results in more than 280 papers published in the last 10 years with most of them published in reputed international journals [Wu et al. 2009; Zhou et al. 2014; Liu et al. 2019; Zhu et al. 2012].

## The Outlook of the Chinese Potato Industry and its Global Impact

In 2016, the Ministry of Agriculture and Rural Affairs of the People's Republic of China proposed guidance for the development of the potato industry [Pan 2018]. Based on the new situation of the national food security strategy in China, the potato industry should guide potato consumption through its nutrition, guide processing through consumption, select and breed a batch of potato varieties suitable for staple food processing, build a batch of high-quality raw material production base, and leading enterprises of staple food processing. The basic principles for potato industry development are not to compete with the three major grain crops (rice, wheat, and corn) for water and land, production development should be unified with overall promotion, industrial development should be combined with comprehensive utilisation, government guidance should be combined with market regulation, and overall planning should be coordinated with step-by-step implementation. According to the plan, in 2020, the potato planting area was expanded to over 5.60 million hectares in China, and the average yield was increased to

21.97 metric tonnes/hectare, with a total production of about 122.94 million metric tonnes. The popularising rate of detoxified seed potatoes reached about 45%, which was significantly higher than that in 2010 [Wang and Zhang 2010], the proportion of potato varieties suitable for staple food processing will reach 30%, and the consumption of potatoes as a staple food will account for 30% of the total potato consumption.

Presently, the fundamental assignments for the potato industry optimise the distribution of raw materials for staple food products on the premise of resource endowment, develop diversified staple food products led by consumer demand, strengthen the technological support for raw material production of staple food products driven by variety selection and breeding, develop processing technology and equipment for staple food driven by scientific and technological innovation, and guide residents to consume staple food products with nutritional functions as the focus. The Chinese government has also put forward some special measures, such as strengthening coordination, guidance and policy support, increasing investment in scientific research, linking up production and marketing, improving the standard system, and strengthening the publicity and guidance of potato consumption.

In the past 20 years, China's potato industry has expanded and developed extensively. It has experienced three stages rapid growth, volatility and slow growth. It is expected that the potato planting area will grow in China before the third stage in 2020. The trend will stabilise and slowly grow to a level of 6.67 million ha. In the future, the growth of China's potato industry will be slowed down by the expansion of scale and gradually enter the stage of intensive growth brought about by the simultaneous changes in total output and total consumption and structural optimization. The potato processing industry is welcoming new development opportunities.

The humble potato (*Solanum tuberosum* L.) always has had a profound impact on society. During the COVID-19 pandemic, the potato has been observed to be a promising food due to its long storage and shelf stability. According to a recent analysis by the International Potato Center [Mohanty 2020], the demand for fresh potatoes (as opposed to processed potato products) in developed countries has skyrocketed during the COVID-19 pandemic. The processed potato products constitute the bulk of potato consumption in western countries. Based on the analysis of 690 network questionnaire surveys in February 2020, the National Potato Industry Technology System of the Ministry of Agriculture and Rural Affairs of the PRC concluded that the COVID-19 pandemic had harmful effects on the potato industry in China, but the degree is low. The impact of the COVID-19 pandemic on the potato industry is mainly reflected in the circulation, but in short term, the COVID-19 pandemic has a positive effect on potato consumption, because potatoes have a longer shelf life and stability during storage and transportation when compared with other vegetables.

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## Declarations

**Conflict of Interest** The authors declare no competing interests.

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