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Review

Progress in Research and Development of Potato Staple Food Processing Technology

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Abstract: In 2014, potato production in China amounted to 96 million tons, which was the highest in the world. As one of the most important nutritional foods in the world, potato is rich in starch, dietary fiber, vitamins, minerals, *etc*. Potatoes stand barren environment, drought, saline, and alkaline environment, and cold weather, with a short growing season. These features make them the best rain-fed crops suitable for production even when the annual rainfall is below 400 mm. In 2013, the Chinese Ministry of Agriculture suggested a potato staple food strategy using potatoes to make Chinese traditional staple foods such as steamed bread, noodles, *etc*. Our research group carried out a study on processing technology of potato staple food, especially fermented staple food. Some new processing technologies of potato staple food have been investigated and developed. The aim of this paper is to give an overview of the possible effects of adding potato flour in the dough and of the microstructure characteristics, technological parameters, total polyphenol content, and antioxidant activity of staple foods. We also systematically describe the processing technology of potato staple foods, which may be of great importance in promoting further expansion of the potato-processing industry and increasing the economic benefit of the companies.

Key words: potato staple foods, processing technology, steamed bread, nutrition information, dough rheological properties, industrial production

INTRODUCTION

Potato (*Solanum tuberosum*) is one of the most planted tubers worldwide and the only one used as a major food crop.[1)] In 2014, the total global production of potatoes was 0.39 billion tons. In 2014, China, the leading producer of potatoes, had a production of 96.1 million tons (24.64 % of the world's production).

The nutritional status of crop plants is dependent on their metabolic composition, which is important for human health. Potatoes contain vitamins and minerals as well as an assortment of phytochemicals, including carotenoids and natural phenolic compounds. A medium-size potato (150 g) with skin provides 27 mg of vitamin C, 620 mg of potassium, 0.2 mg of vitamin B_6, and trace amounts of thiamin, riboflavin, folate, niacin, magnesium, phosphorus, iron, and zinc. Potato is known for its carbohydrate content (approximately 26 g in a medium-sized potato) represented by starch. A small but significant portion of this starch is resistant to digestion by enzymes in the stomach and small intestine, and reaches the large intestine intact.[2)] This resistant starch has physiological effects and health benefits similar to those of fiber. It provides bulk, offers protection against colon cancer, improves glucose tolerance and insulin sensitivity, lowers plasma cholesterol and triglyceride concentrations, increases satiety, and possibly reduces fat storage.[2)3)4)] However, because of consumer habits and market demand, the total growth rate of potato production in China is slow, the level of production is low, and the consumption is weak.

China lacks natural agricultural resources, with the area of farmland and water resources per capita less than one-fourth of the world average. Given the steady growth of China's population, the demand for the main agricultural products has increased, but production capacity has not. Thus, food production faces an enormous pressure, and there is an urgent need to adjust the staple food production and reduce the pressure on food security. In areas that mainly produce winter wheat, more than 65 % of the available water is used for agriculture. The use of 200 billion cu-

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Abbreviations: PP, potato protein; PS, potato starch; ΔH, heat of phase transition; HPMC, hydroxypropyl methylcellulose; WS, wheat starch; CS, corn starch; TS, tapioca starch; SS, sweet potato starch; C1, the maximum dough consistency at the initial mixing stage; C2, the minimum torque or minimum value of torque produced by dough passage subjected to mechanical and thermal constraint; C3, the peak torque or maximum torque during the heating stage; C4, the minimum torque during the heating period; C5, the torque obtained after cooling at 50 °C; DDT, dough development time; G', storage modulus; G'', loss modulus; z', the degree of dependence of G' on the frequency sweep; K, the inter- or intramolecular strength of interaction; $J_{\max}$, maximum creep compliance; η_0, zero shear viscosity; J_e, maximum recovery compliance; $J_e/J_{\max}$, relative elastic part of maximum creep compliance; $J_v/J_{\max}$, relative viscous part of maximum creep compliance.

bic meters of groundwater in the agricultural areas of North China creates large groundwater funnel areas where no water is recoverable. The model of predatory exploitation of groundwater for wheat and other staple food grains is unsustainable, and an alternative rain-fed agriculture planting system without irrigation is required. In Northwest, Northeast, and North China, tens of millions of acres of farmland with annual rainfall below 400 mm are not suitable for planting wheat and corn. The existing production method is not conducive to sustainable resource utilization and destroys the environment. In South China, 100 million acres of farmland are vacant during the winter, with sufficient light, water, and good temperature. A new production method for these farmlands is needed. Potato withstands barren conditions, drought, salty, and alkaline conditions, grows in cold climates, and has a short growing season. These characteristics make it the best rain-fed crop for areas with an annual rainfall below 400 mm. Thus, adjusting the planting method and organization in China, and changing the crops to potato would be an unprecedented revolution in planting, achieving sustainable development, and ensuring national food security.

Most of the potatoes in China are consumed fresh, and the production ratio is very low. Besides, the main processing products are starch, starch noodles, etc. The few individual products and large nutrient loss greatly limit potato consumption in China.

Therefore, to increase the proportion of potato in the daily food intake of residents in China, it is necessary to consider the Chinese consumption habits and develop new potato staple foods such as steamed bread, noodles, *etc*., that are suitable for Chinese people. In 2013, the Ministry of Agriculture of the People's Republic of China suggested a new potato staple food strategy. On July 22, 2015, the Prime Minister, Keqiang Li, indicated clearly in an executive meeting of the State Council that China will promote potato staple food processing. The farming working points in 2015 suggested by the Ministry of Agriculture stated the intent of promoting potato staple food production and industrial development. In 2016, the Central First Document stated that China will promote potato staple food development. Implementing a strategy for industrializing the production of potato staple foods in China is inevitable to ensure national food security, ease the pressure on resources and environment, and comply with the growing nutritional and health needs of the population, and is necessary for sustainable development of agricultural production.

To support this strategy, our research group carried out a study on processing technology of potato staple food, especially fermented staple food.

MAIN PROGRESS OF POTATO STAPLE FOOD PROCESSING IN CHINA

Calorimetric, rheological, and structural properties of potato protein (PP) and potato starch (PS) composites and gels.

A good gel structure plays an important role in obtaining the desirable quality of many food products such as bread, pudding, cheese, yoghurt, tofu, and sausage. Gels are formed by hydrocolloid dispersion such as polysaccharide and protein dispersion, transformed from a solution to a three-dimensional gel network under mechanical and thermal treatment.5) Gel matrix exhibits a solid-like behavior and traps a large amount of water and other important food ingredients.6)

Starch and proteins are responsible for the formation of the function and structure in edible systems given their gelling abilities.7) When proteins and starch are used to form gels, the resulting systems are usually described as composites.5) Protein-starch composites form gels after thermal treatments, and the gel structure obtained is based on the interactions between proteins and starch.8) Understanding the interactions between proteins and starch during the thermal-treated gelling process would aid in better designing of the structures and functions of gels and in developing end products of better quality.5)8) Many studies used well characterized proteins (such as soy) and starches (such as potato, corn, and cassava) to investigate protein-starch interactions during thermal treatment in composite gels.5)9)10)

PP and PS, with good nutritional qualities and gelling properties, are widely used in potato food products, and the interactions between these two biopolymers can be utilized to impart some specific and desired textures.11) PP and PS were incorporated into corn starch to make gluten-free bread, and 2 % (w/w) PP caused a diminished density of bread crumbs, reduced porosity, and increased bread volume, but a further increase in PP led to a deterioration of bread quality.12) Therefore, the gelling behaviors and structures of PP-PS gels are dependent on the ratio of PP to PS, which determines the texture of the end products.11) However, limited information is currently available on the influence of different PP-to-PS ratios on the gelling behaviors and structures of PP-PS gels.

In order to provide a better understanding of the structure-function relationship of PP-PS composite gels and formulate better textured potato products, we investigated the calorimetric, rheological, and structural properties of PP and PS composites at different ratios, and their corresponding thermal-induced gels. Data of ΔH (heat of phase transition) were close to $\Delta H_{\text{PP-PS composite}}$, indicating that PP and PS underwent phase transitions independently during thermal treatment of PP-PS composites. The onset of gelation (T_{gel}) increased from 57.9 to 61.9 °C, hard to identify as the PP content increased, indicating that PS formed a gel more easily than PP. The decrease of the degree of dependence of the storage modulus (G') on frequency sweep (z') from 0.20 to 0.08 and the increase of the strength of molecular interactions (K) from 1.49 to 2.22 indicated that the physical interactions in PP-PS gels decreased, but the covalent interactions and the strengths of the gels increased as the PP content increased. PS prevented the thermal-induced secondary structural changes of PP, and a more uniform network structure was generated in the PP-PS gels as the PS content increased. Thus, by adjusting the ratios of PP and PS, the quality of PP-PS gels is enhanced.13)

Comparative study of the effects of starches from 5 different sources on the rheological properties of gluten and gluten-free model doughs.

Dough is a viscoelastic material with a high degree of elasticity, combined with considerable plasticity or viscosity.[14] Rheological properties of the dough influence its mechanical, handling, and technological properties such as extensibility, molding, and shaping capacities, mixing behavior, gas holding capacity as well as the steaming and baking performances, and the quality of the products.[15][16][17] Several studies focused on the rheological properties of doughs, mainly of doughs made with whole flours (*e.g.* wheat flour, rice flour, *etc.*), which contained a variety of ingredients, making it hard to identify the main influencing factors and the role of each ingredient on the rheological properties.[18][19][20][21] Only few studies focused on the key ingredients and their effects on the rheological properties of doughs.[22][23]

Gluten is the main component in wheat protein, playing an important role in controlling the rheological properties of wheat dough.[24] However, gluten is the responsible pathogenic factor of celiac disease.[25] Therefore, the development of gluten-free products is necessary.[26] The replacement of gluten presents a major challenge for food processing because of the poor rheological properties.[27] Hydrocolloids are often used as a substitute for gluten in gluten-free doughs to improve dough rheological properties and the quality of end products.[28] Hydroxypropyl methylcellulose (HPMC) is commonly used in gluten-free doughs because of its promising effects on the rheological properties of the dough and the quality of end products.[20][29] HPMC improves the crumb structure, cohesiveness, and springiness of gluten-free breads.[30] HPMC produces soft gluten-free bread and reduces staling kinetics during storage.[31] HPMC addition also improves the elasticity of chestnut flour doughs.[32]

Starch is the main component of gluten and gluten-free doughs. The dough is commonly mixed with different starches. For instance, partially gelatinized corn starch improves the technological quality and delay bread staling.[33] The addition of 20 or 30 % PS to rice flour improves bread quality and delays starch retrogradation.[34] PS addition increases the overall quality, including appearance, color, odor, hardness, *etc.*, of gluten-free pasta made with sorghum, rice, and corn flours.[35] However, limited information is available on the influence of starch from different sources on the rheological properties of gluten and gluten-free doughs.

We prepared starch-HPMC and starch-gluten model doughs, and the effect of wheat starch (WS), corn starch (CS), tapioca starch (TS), sweet potato starch (SS), and potato starch (PS) on the rheological properties and moisture distribution of doughs was investigated. The methods used were as follows:

Dough preparation: On a moisture-free basis, wheat flour dough contains approximately 14 % gluten proteins.[36] Therefore, 15.0 % gluten was added to the starch (WS, CS, TS, SS, and PS) to prepare gluten model doughs. An appropriate amount of water based on the water absorption obtained from Mixolab (Chopin Technologies, France) results was added and mixed for 15 min. According to pre-experiment results, 2.0 % HPMC was added to WS, CS, TS, SS, and PS to prepare gluten-free model doughs. An appropriate amount of water based on the water absorption obtained from Mixolab results was added and mixed for 15 min. The starch-gluten and starch-HPMC doughs were packaged using a fresh-keeping film and allowed to rest for 25 min for further use.

Thermomechanical properties of model doughs: The mixing and pasting behavior of starch-gluten and starch-HPMC doughs were studied using a Mixolab apparatus, which simultaneously determined dough rheological characteristics during the process of mixing at constant temperature as well as during the period of constant heating and cooling.[37] Measurements were performed using the Mixolab Chopin + protocol for starch-gluten dough, while Chopin + 90 protocol was used for starch-HPMC dough.[38] The setting used in the test was 30 °C for 8 min, an increase by a rate of 4 °C/min until 90 °C, followed by an 8-min holding period at 90 °C, a temperature decrease of 4 °C/min until the mixture reached 55 °C, and then a 6-min holding at 55 °C. The stirring speed during the entire assay was 73 rpm. The process was repeated twice for each sample. Parameters from the Mixolab recorded curve were as follows: the maximum dough consistency at the initial mixing stage, C1 (in N・m); the minimum torque or minimum value of torque produced by dough passage subjected to mechanical and thermal constraint, C2 (in Nm); the peak torque or maximum torque during the heating stage, C3 (in Nm); the minimum torque during the heating period, C4 (in Nm); and the torque obtained after cooling at 50 °C, C5 (in Nm). [19] Derived parameters from the Mixolab recorded curve were calculated as follows: water absorption for the dough to produce a torque for 1.10 ± 0.05 Nm for Chopin + or 1.10 ± 0.07 Nm for Chopin + 90, W_{abs} (%); dough development time (DDT, min); dough strength or the difference between the maximum dough consistency at the initial mixing stage (C1) and the minimum value of torque produced by dough passage subjected to mechanical and thermal constraint (C2), C1-C2; and setback or the difference between the torque obtained after cooling at 50 °C (C5) and the minimum torque during the heating period (C4), C5-C4.

Dynamic rheological characterization of model doughs: Dynamic rheological characteristics of the dough samples were determined in three replicates, using a controlled stress rheometer (Physica MCR 301, Anton Paar, Austria) with a parallel-plate geometry of 25 mm diameter and a gap of 2 mm. Each dough sample was placed between the plates after mixing and left to rest for 25 min. The test started after the dough rested for extra 10 min. The rim of the dough sample was coated with silicone oil to prevent water evaporation during determination. The linear viscoelastic zone was determined by dynamic strain sweep performed over a strain range of 0.01–10 % at an angular frequency of 10 s^{-1} at 25°C. The strain sweep provided information relating the relative strength of junction zones formed within the model dough and their relative resistance to flow. The relative strength of junction zones formed within the model dough and their relative resistance to flow were assessed by the storage modulus (G') and loss modulus (G''). Frequency sweep was performed from 0.1–100 s^{-1} at a strain of 0.1 % at 25 °C to determine G' and G'' as a function of frequency. The degree of dependence of G' on the frequency sweep (z') and the inter- or intramolecular strength of interaction (K) were obtained by fitting the frequency sweep data into power law model: $G' = K' (\omega)^{z'}$, where ω is the angular frequency. Temperature sweep was performed from 25 to 90 °C at a heating rate of 5 °C/min. During temperature sweep the G' and G'' of the mixtures were recorded at constant frequency of 1 Hz and strain of 0.1 %. The complex shear modulus $|G^*|$ and the loss factor tan δ were recorded during temperature sweep. Creep and recovery measurements were carried out as follows: creep phase was recorded at a shear stress of 250 Mpa, which exceeded the linear viscoelasticity region for 300 s, followed by a recovery phase of 300 s at a stress of 0 Pa. Measurements were performed at 25 ± 0.1 °C. Creep and recovery curves were recorded and analyzed by RHEOPLUS/32 version 3.21 software to get parameters.[39)] The parameters obtained were: maximum creep compliance ($J_{\max}$), zero shear viscosity (η_0), maximum recovery compliance (J_e), relative elastic part of maximum creep compliance ($J_e/J_{\max}$), and relative viscous part of maximum creep compliance ($J_v/J_{\max}$). All rheological measurements were performed in triplicate.

Moisture distribution analysis of model doughs: The proton relaxation studies were carried out on a low-resolution MesoMR spectrometer (Niumag, Shanghai, China) operating at a ^1H resonance frequency of 21.3 MHz. Carr-Purcell-Meiboom-Gill (CPMG) pulse sequences were employed to measure spin-spin relaxation time, T_2. Two spin–spin relaxation time constants, the first relaxation time (T_{21}) and the second relaxation time (T_{22}), have been identified from the NMR spectrum using the CPMG sequences. Typical pulse parameters were as follows: dwell time 18 μs, echo time 400 μs, recycle time 1,500 ms, echo count 5,000, and scan repetitions 4. Each measurement was performed in duplicate.

Results showed that, for starch-HPMC model doughs, TS and SS addition resulted in the highest and lowest dough development time, respectively. To form uniform doughs, WS and PS absorbed the most and the least water, respectively. Higher C5-C4 value indicated that CS-HPMC dough retrograded more slowly than other model doughs. According to the rheological properties, PS-HPMC and TS-HPMC dough presented the most and least stable network structure, respectively. Gluten-free model doughs made with WS and PS exhibited minimum and maximum resistance to deformation, respectively. The maximum $J_v/J_{\max}$ value of WS-HPMC dough indicated the highest dough stickiness, while the minimum $J_e/J_{\max}$ value of TS-HPMC dough indicated the highest dough elasticity. According to the ^1H nuclear magnetic resonance results, the lowest T_{21} and highest A_{21} (the amplitude of T_{21}) of WS-HPMC dough suggested the highest content of bonding water. Higher T_{21} and T_{22} values indicated the highest mobility of water in PS-HPMC model dough.

For starch-gluten model doughs, Mixolab studies showed that PS and SS addition resulted in the highest and lowest dough development time, respectively. To form uniform doughs, WS and PS absorbed the most and least water, respectively. Higher C5-C4 value indicated that CS-gluten dough retrograded more slowly than other model doughs. Rheological properties showed that WS-gluten dough presented more stable network structure and less molecular interactions between WS and gluten. On the contrary, PS-gluten dough presented less stable network structure and more molecular interactions between PS and gluten. Model doughs made with WS and PS exhibited minimum and maximum resistance to deformation, respectively. Higher η_0 and $J_v/J_{\max}$ values of PS- and TS-gluten dough indicated higher dough stickiness. The lowest T_{21} and highest A_{21} of WS-gluten dough (2.10 ms and 23.20 %) suggested the highest content of bonding water, while the highest T_{22} and A_{22} (the amplitude of T_{22}) of PS-gluten dough (20.73 ms and 100 %) indicated the highest water mobility in the dough. Thus, by adding starches from different sources, the rheological properties of the doughs may be improved.

According to the abovementioned findings, starches from different sources contributed differently to the rheological properties of doughs. Therefore, different starches should be selected to improve the rheological properties of doughs. Furthermore, starch modification methods (e.g. high hydrostatic pressure, ultrasonic, *etc.*) should also be considered to obtain better rheological properties of doughs.

Influence of potato flour on dough rheological properties and quality of steamed bread.

Potato flour changes dough properties, which are important for the quality of steamed bread. Thermo-mechanical parameters, dynamic rheological properties, and fermentation characteristics remarkably influence the volume, texture, and structure of steamed bread or bread products.[19)40)41)] Therefore, it is important to study these dough properties in order to get high-quality potato steamed bread. In our lab, fresh potatoes (cultivar Shepody) were peeled, washed, steamed for 30 min at 100 °C, and dried in a dryer where the temperature varied between 170 and 200 °C. They were milled into flour by a hammer mill and sieved with a 100-μm screen in order to obtain smooth flour with a uniform particle size. Potato flour at various concentrations (0–35 %) was incorporated into steamed bread. Dough rheological properties, technological qualities, and correlations between them were analyzed. In addition, the nutrition qualities, including proximate components, antioxidant capacity, and *in vitro* starch digestibility of steamed bread were evaluated [42)].

Our results showed that potato flour addition significantly influenced the dough rheological properties and steamed bread quality such as increased water absorption, maximum gaseous release height, total volume of CO_2, and hardness, while decreased dough stability and specific volume of steamed bread.[42)] Moreover, correlation analysis suggested that dough height at maximum development time, dough stability, water absorption, and the phase tangent may be used for predicting the technological quality of steamed bread. Potato-wheat steamed bread had higher dietary fiber, ash content, and antioxidant activity than those of wheat steamed bread. The estimated glycemic index decreased from 73.63 to 60.01. Considering the sensory evaluation, the steamed bread with 20 % potato flour was acceptable. A higher proportion of potato flour negatively affected dough development during the fermentation process and the quality of the products. For example, dough height was reduced, specific volume decreased, and hardness increased.

Research and development of tailored flour for potato staple foods.

The potato staple food strategy has brought new opportunities and challenges to the potato processing industry. On one hand, the limited number of processed potato products, excess potato resources, warehousing difficulties, wasting of resources, and other problems may be solved by making potatoes a part of common staple foods.[43][44] On the other hand, the addition of a large proportion of potatoes into staple foods to achieve the value of potatoes as food crops is a key technical problem.[45] Searching for potato raw materials that are suitable for staple food processing has become the key point to solve this technical problem.

The main potato raw materials of potato staple food products include fresh potato, potato flour, *etc.*, but there are some defects in the different raw materials. Because of the high moisture content, short shelf life, storage and transportation difficulties, and difficult steps during potato staple food processing, fresh potatoes are only suitable for home-style cooking and are not suitable for large-scale industrial production. The components of potato flour match closely with those of fresh potatoes. More than 95 % of commercially available potato flour consists of post-cooked potato flakes or granules. These products can be eaten by adding water and are mainly used as the main raw material for the production of mashed potatoes, French fries, potato chips, and other baked foods.[46] However, high-temperature cooking and drying processes result in high energy consumption and nutrient loss, high costs, and complete gelatinization of the starch in this product, and the complete structure of the original starch is damaged. Therefore, the original processing characteristics of the potato are completely changed, and adding a high volume of potato would increase the viscosity of steamed bread, noodles, and other staple food products, making these products difficult to shape and give them poor sensory quality after steaming or baking. Thus, it is necessary to develop tailored flour for potato staple foods that is inexpensive, with low energy consumption, and high nutritional value. However, there is no relevant research on tailored flour for potato staple foods in China and abroad.

Therefore, fresh potatoes were used as raw materials. Single factor and response surface optimization experiments were carried out, and the processing parameters of tailored flour for potato staple foods were optimized. After pilot-scale production, the nutritional value and the application of tailored flour for potato staple foods in potato steamed breads were investigated to provide technical support and theoretical instruction for the industrialization and application of tailored flour for potato staple foods.

Processing technology of tailored flour for potato staple foods.[47]

Fresh potatoes (cultivar Shepody) were used as raw materials, and the tailored flour for potato staple foods was prepared using the following procedure: fresh potatoes → cleaning → peeling → slicing → blanching → color protecting → drying → smashing → screening (100-mesh sieve; aperture −150 μm).

From a single factor experiment, the polyphenol oxidase activity, total polyphenol content, antioxidant activity, reducing sugar content, color, viscosity, flavor, and taste were affected significantly by the blanching temperature (60, 70, 80, 90, and 100 °C), blanching time (10, 15, 20, 25, and 30 s), drying temperature (50, 60, 70, 80, and 90 °C), drying time (15, 17, 19, 21, and 23 h), slice thickness (2, 4, 6, 8, and 10 mm), vitamin C concentration (0.20, 0.25, 0.30, 0.35, and 0.40 %), citric acid concentration (0.80, 0.90, 1.00, 1.10, and 1.20 %), and $CaCl_2$ concentration (0.05, 0.10, 0.15, 0.20, and 0.25 %) (Fig. 1–4 and Tables 1–2).

Six indices, including polyphenol oxidase activity, total polyphenol content, antioxidant activity, reducing sugar content, color, and viscosity, were screened by principal

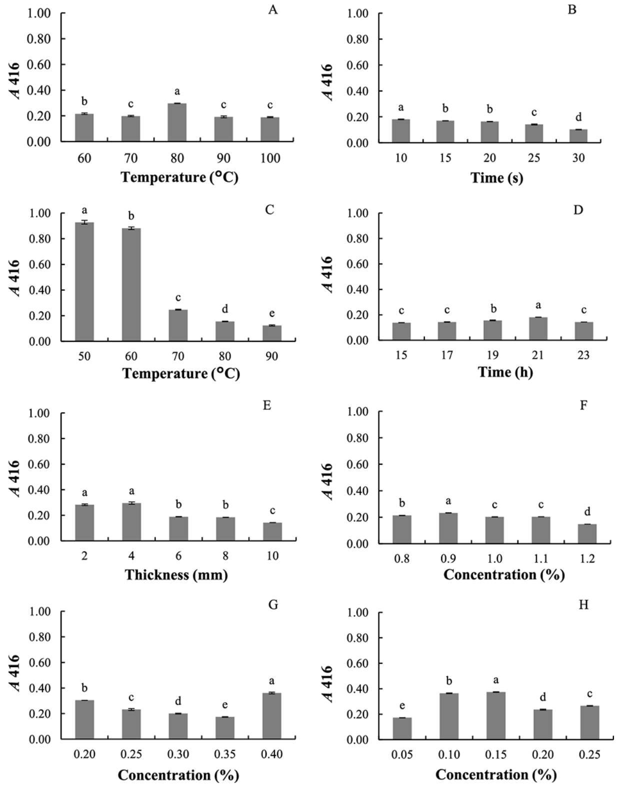

Fig. 1. Polyphenol oxidase activity of tailored flour for potato staple foods under different blanching temperature (A), different blanching time (B), different drying temperature (C), different drying time (D), different slice thickness (E), different ascorbic acid concentration (F), different citric acid concentration (G), and different calcium chloride concentration (H).[46]

Different letters on the same bar chart mean there were significant differences between different treatment conditions ($p < 0.05$).

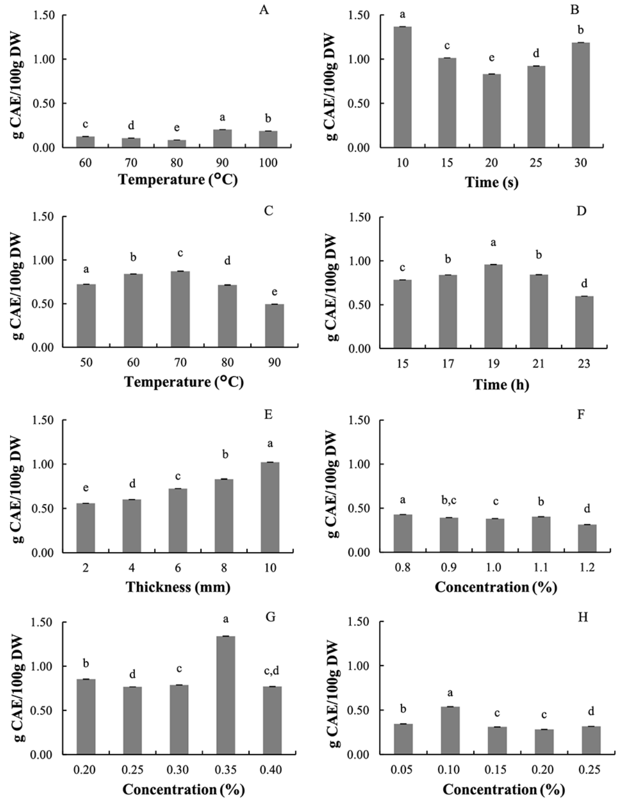

Fig. 2. Total phenolic content of tailored flour for potato staple foods under different blanching temperature (A), different blanching time (B), different drying temperature (C), different drying time (D), different slice thickness (E), different ascorbic acid concentration (F), different citric acid concentration (G), and different calcium chloride concentration (H).[46]

CAE stands for chlorogenic acid equivalent. DW stands for dry weight. Different letters on the same bar chart mean there were significant differences between different treatment conditions ($p < 0.05$).

component analysis, and polyphenol oxidase activity and reducing sugar content were chosen as the quality evaluation indexes of tailored flour for potato staple foods (Tables 3–4). Based on the above results, a Plackett-Burman experiment was carried out and revealed that drying temperature, drying time, and slice thickness had significant effects on polyphenol oxidase activity (Tables 5–6). Therefore, these three factors were further optimized by a response surface optimization experiment (Tables 7–8). The optimal production process parameters of tailored flour for potato staple foods were determined by response surface analysis and comprehensive consideration of the cost and the economic benefits. The pilot production was performed successfully, and the tailored flour for potato staple foods was produced at low cost with low energy consumption.

Nutrition information of tailored flour for potato staple foods.[47]

The proximate composition, vitamins, polyphenol oxidase, polyphenols, antioxidant activity, and minerals of the tailored flour for potato staple foods were analyzed and compared with those of commercial potato flour and wheat flour. Tables 9–12 show that the contents of vitamins B_1, B_2, B_3, and C, and minerals Ca, K, Na, and Se in tailored flour for potato staple foods were higher than those in commercial potato flour. The contents of ash, starch, dietary fiber, vitamins B_1, B_2, B_3, and C, polyphenol oxidase activity, total polyphenol content, antioxidant activity, and minerals Ca, K, P, Mg, Na, Fe, Zn, Cu, and Se in tailored flour for potato staple foods were higher than those in wheat flour. These results indicated that the tailored flour for potato staple foods had a high nutritional value.

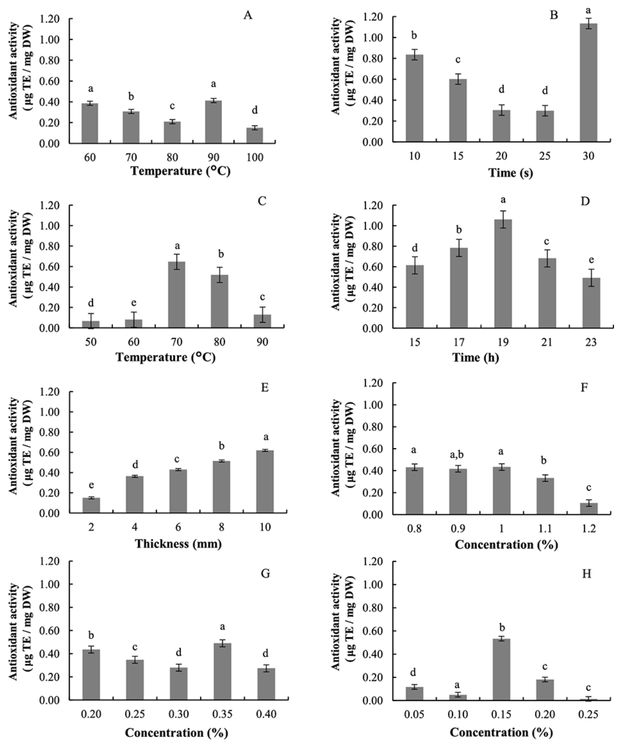

Fig. 3. Antioxidant activity of tailored flour for potato staple foods under different blanching temperature (A), different blanching time (B), different drying temperature (C), different drying time (D), different slice thickness (E), different ascorbic acid concentration (F), different citric acid concentration (G), and different calcium chloride concentration (H).[46]

TE stands for trolox equivalent. DW stands for dry weight. Different letters on the same bar chart mean there were significant differences between different treatment conditions ($p < 0.05$).

Research and development of potato steamed bread containing 30 % of potato flour.[48]

Compared to normal wheat flour, potato flour exhibits a higher degree of gelatinization and viscosity, making fermentation and shaping difficult. Focusing on the above problems, the processing technology of potato steamed bread containing 30 % of potato flour was investigated, and industrial production was achieved.

On June 1, 2015, potato steamed bread containing 30 % potato flour entered the market in Beijing. With the increase of potato steamed bread consumption, Beijing Haileda Food Co., Ltd. has added 4 new potato steamed bread production lines in 2015, with a daily output up to 40 tons, in order to ensure the normal supply. The potato steamed bread containing 30 % potato flour produced by Beijing Haileda Food Co., Ltd. has been sold in more than 690 supermarkets, agricultural markets, and small canteens in

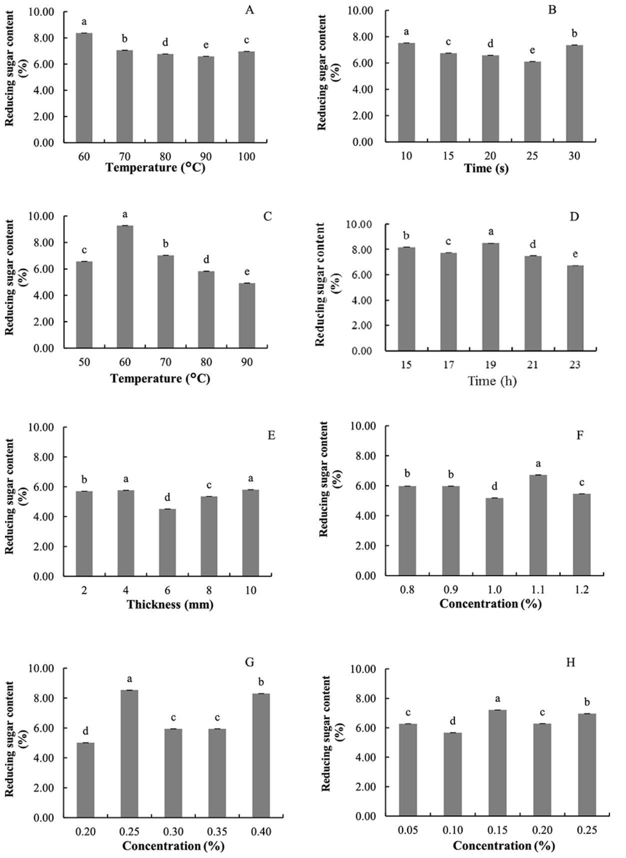

Fig. 4. Reducing sugar content of tailored flour for potato staple foods under different blanching temperature (A), different blanching time (B), different drying temperature (C), different drying time (D), different slice thickness (E), different ascorbic acid concentration (F), different citric acid concentration (G), and different calcium chloride concentration (H).46)

Different letters on the same bar chart mean there were significant differences between different treatment conditions ($p < 0.05$).

Beijing, Tianjin, and Hebei Province, with the market share greater than 90 %. Many domestic and foreign medias, including Xinhua News Agency, People's Daily, Beijing Daily, Economic Daily, Beijing News, the Wall Street Journal, CCTV, Beijing TV, *etc.* have reported potato staple foods produced by Beijing Haileda Food Co., Ltd., improving the understanding of a vast number of consumers of high nutrition potato staple food products and promoting the production and sale of potato staple foods. In the press conference of the Ministry of Agriculture of the People's Republic of China held on May the 5, 2016, Yu Xinrong, the Vice Minister of agriculture, said that potato staple food products have entered thousands of households.

*Research and development of potato steamed bread containing 55 % of potato flour.*48)

Based on a single factor experiment, the added volumes of water, gluten, dietary fiber, and modified dietary fiber were selected, and the formula of potato steamed bread containing 55 % potato flour was optimized by response surface optimization (water 74.93 g/100 g flour, gluten 2.98 g/100 g flour, dietary fiber 2.07 g/100 g flour, and modified dietary fiber 0.81 g/100 g flour). By research and development of the key processing technology and equipment for potato steamed bread containing 55 % potato flour, the existing problems with potato steamed bread containing high potato content such as having high viscosity, being difficult to mold, and breaking easily, were solved. The potato steamed bread product containing 55 % potato flour was developed successfully, and industrial production at Beijing Haileda Food Co., Ltd. was achieved.

Table 1. Color of tailored flour for potato staple foods under different processing parameters.47)

Processing parameters	*L**	*a**	*b**
Blanching 60 °C	84.07 ± 0.10^{b}	0.957 ± 0.1^{d}	14.25 ± 0.10^{u}
Blanching 70 °C	83.90 ± 0.06^{c}	1.680 ± 0.0^{y}	14.29 ± 0.06^{t}
Blanching 80 °C	82.03 ± 0.05^{k}	1.993 ± 0.01^{s}	14.97 ± 0015^{l}
Blanching 90 °C	80.20 ± 0.05^{v}	2.560 ± 0.0^{f}	15.31 ± 0.05^{k}
Blanching 100 °C	80.23 ± 0.07^{t}	2.553 ± 0.0^{g}	16.27 ± 0.07^{d}
Blanching 10 s	83.22 ± 0.22^{f}	1.992 ± 0.2^{t}	13.51 ± 0.22^{y}
Blanching 15 s	82.42 ± 0.03^{g}	2.112 ± 0.0^{r}	13.59 ± 0^{x}
Blanching 20 s	81.48 ± 0.06^{o}	2.438 ± 0.0^{m}	14.16 ± 0.06^{v}
Blanching 25 s	81.92 ± 0.05^{n}	2.432 ± 0.0^{n}	14.40 ± 0.05^{s}
Blanching 30 s	79.41 ± 0.03^{ai}	2.531 ± 0.0^{h}	14.57 ± 0.03^{q}
Drying 50 °C	82.21 ± 0.10^{i}	3.251 ± 0.1^{d}	12.48 ± 0.10^{bi}
Drying 60 °C	84.57 ± 0.25^{a}	1.527 ± 0.2^{ai}	14.16 ± 0.25^{v}
Drying 70 °C	81.04 ± 0.09^{p}	2.424 ± 0.0^{o}	17.29 ± 0.09^{c}
Drying 80 °C	66.33 ± 0.21^{ki}	7.403 ± 0.2^{c}	21.60 ± 0.21^{b}
Drying 90 °C	62.45 ± 0.10^{li}	8.745 ± 0.2^{b}	22.41 ± 0.20^{a}
Drying 15 h	83.83 ± 0.06^{d}	1.783 ± 0.0^{x}	12.69 ± 0.06^{ai}
Drying 17 h	82.34 ± 0.06^{h}	2.494 ± 0.0^{j}	13.67 ± 0.06^{w}
Drying 19 h	83.76 ± 0.06^{e}	1.826 ± 0.0^{v}	13.11 ± 0.06^{z}
Drying 21 h	82.02 ± 0.07^{l}	1.372 ± 0.0^{bi}	14.45 ± 0.07^{r}
Drying 23 h	80.76 ± 0.19^{q}	2.386 ± 0.1^{p}	15.53 ± 0.19^{i}
Slice thickness 2 mm	73.49 ± 0.03^{ji}	9.189 ± 0.0^{a}	15.82 ± 0.03^{h}
Slice thickness 4 mm	81.97 ± 0.06^{m}	1.357 ± 0.0^{ci}	14.95 ± 0.06^{m}
Slice thickness 6 mm	79.52 ± 0.02^{y}	1.962 ± 0.0^{u}	14.76 ± 0.02^{n}
Slice thickness 8 mm	79.91 ± 0.03^{w}	1.821 ± 0.0^{w}	14.71 ± 0.03^{p}
Slice thickness 10 mm	79.53 ± 0.09^{x}	1.593 ± 0.0^{z}	14.73 ± 0.09^{o}
Ascorbic acid 0.8 %	78.44 ± 0.23^{ci}	2.514 ± 0.2^{i}	15.48 ± 0.23^{j}
Ascorbic acid 0.9 %	78.75 ± 0.06^{bi}	2.825 ± 0.03^{e}	15.92 ± 0036^{g}
Ascorbic acid 1.0 %	80.76 ± 0.62^{q}	2.446 ± 0.6^{k}	15.48 ± 0.62^{j}
Ascorbic acid 1.1 %	80.22 ± 0.36^{u}	2.442 ± 0.3^{l}	16.08 ± 0.36^{f}
Ascorbic acid 1.2 %	82.42 ± 0.37^{g}	2.332 ± 0.3^{q}	16.19 ± 0.37^{e}
Citric acid 0.20 %	78.03 ± 0.15^{di}	$-0.02+0.10^{ji}$	$9.90+0.1^{ji}$
Citric acid 0.25 %	79.46 ± 0.33^{z}	0.066 ± 0.3^{fi}	11.46 ± 0.33^{di}
Citric acid 0.30 %	80.28 ± 0.24	0.028 ± 0.2^{gi}	10.80 ± 0.24^{ei}
Citric acid 0.35 %	80.34 ± 0.36^{r}	0.024 ± 0.3^{hi}	10.52 ± 0.36^{gi}
Citric acid 0.40 %	82.16 ± 0.17^{j}	0.016 ± 0.1^{ii}	11.51 ± 0.17^{ci}
Calcium chloride 0.05 %	77.07 ± 0.14^{ei}	$-0.23+0.04^{mi}$	$9.97+0.0^{ii}$
Calcium chloride 0.10 %	76.58 ± 0.06^{gi}	$-0.21+0.04^{mi}$	$10.00+0.04^{hi}$
Calcium chloride 0.15 %	76.60 ± 0.20^{fi}	$-0.146+0.02^{li}$	10.55 ± 0.06^{fi}
Calcium chloride 0.20 %	75.22 ± 0.08^{hi}	$-0.10+0.02^{ki}$	$9.78+0.0^{li}$
Calcium chloride 0.25 %	74.79 ± 0.05^{ii}	0.069 ± 0.0^{ei}	9.80 ± 0.0^{ki}

Values in the same column with different letters are significantly different ($p < 0.05$).

The nutritional information of the potato steamed bread containing 55 % potato flour was analyzed and compared with that of the potato steamed bread containing 30 % potato flour and pure wheat flour steamed bread. Tables 13 and

Table 2. Viscosity of tailored flour for potato staple foods under different processing parameters.47)

Processing parameters	PV (cP)	TV (cP)	FV (cP)	SB (cP)	BD (cP)
Blanching 60 °C	3446.00±0.00^{ci}	1965.33±3.30^{li}	4894.33±3.40^{fi}	2925.67±1.89^{p}	1480.33±0.47^{e}
Blanching 70 °C	3314.00±2.16^{ii}	2282.00±3.56^{hi}	4855.33±0.94^{gi}	2575.67±0.94^{bi}	1034.67±2.49^{w}
Blanching 80 °C	3269.33±2.62^{ji}	2511.00±0.82^{ai}	5046.33±2.87^{bi}	2536.00±0.00^{ei}	755.67±1.89^{gi}
Blanching 90 °C	4739.67±4.11^{c}	2757.33±3.09^{n}	4942.67±4.11^{di}	2183.33±0.47^{hi}	1981.67±1.25^{b}
Blanching 100 °C	5102.67±3.77^{a}	2714.67±1.25^{s}	4644.67±3.68^{ji}	1926.00±2.16^{ii}	2383.33±0.94^{a}
Blanching 10 s	3672.67±1.70^{r}	2421.33±2.87^{ci}	5377.33±2.36^{x}	2597.33±4.92^{z}	1252.00±2.16^{k}
Blanching 15 s	4113.33±2.05^{k}	2640.33±1.89^{w}	5672.33±1.89^{l}	3031.67±1.25^{h}	1476.00±1.63^{f}
Blanching 20 s	3754.33±2.49^{p}	2544.33±4.64^{z}	5667.67±3.40^{m}	3123.00±1.63^{g}	1210.67±1.70^{l}
Blanching 25 s	4131.33±2.62^{j}	3389.00±2.45^{b}	6274.00±2.16^{b}	2884.67±1.70^{s}	739.33±1.25^{hi}
Blanching 30 s	3365.67±1.25^{gi}	2802.67±0.94^{m}	5263.00±1.63^{y}	2463.00±1.63^{fi}	564.00±0.00^{li}
Drying 50 °C	3993.00±1.63^{l}	2921.33±0.47^{i}	5912.33±1.70^{g}	2992.33±2.05^{l}	1070.67±2.05^{t}
Drying 60 °C	3465.67±3.40^{ai}	2377.33±1.70^{ei}	5020.00±0.82^{ci}	2643.33±1.25^{y}	1086.67±1.25^{r}
Drying 70 °C	4138.00±2.16^{i}	3105.33±2.62^{f}	5886.67±2.62^{h}	2784.00±0.82^{u}	1035.67±1.25^{v}
Drying 80 °C	3202.67±1.25^{li}	2754.00±0.00^{o}	4556.00±2.16^{ki}	1803.33±0.94^{ji}	450.67±1.70^{mi}
Drying 90 °C	2840.33±0.94^{pi}	2603.33±1.70^{x}	4012.00±0.82^{li}	1407.33±1.89^{ki}	237.67±1.70^{ni}
Drying 15 h	4383.00±1.41^{e}	3200.33±3.40^{e}	6195.67±1.25^{d}	2995.67±1.89^{k}	1182.67±2.05^{n}
Drying 17 h	4304.00±1.41^{h}	3008.33±2.87^{h}	5918.67±0.94^{f}	2911.67±1.25^{q}	1297.67±2.49^{i}
Drying 19 h	4324.33±2.49^{g}	3224.00±2.45^{d}	5871.00±0.82^{i}	2648.00±0.00^{x}	1103.33±3.30^{p}
Drying 21 h	3571.67±1.25^{u}	2879.00±3.27^{k}	5424.67±1.70^{v}	2545.00±2.16^{di}	692.00±1.41^{ii}
Drying 23 h	4340.33±1.70^{f}	3238.33±2.49^{c}	6151.00±1.41^{e}	2911.33±1.25^{q}	1098.33±0.94^{q}
Slice thickness 2 mm	4839.67±0.47^{b}	3633.67±2.49^{a}	7082.67±2.05^{a}	3446.67±1.25^{b}	1205.00±1.63^{m}
Slice thickness 4 mm	3886.33±2.05^{m}	2374.67±1.25^{fi}	5672.00±2.16^{l}	3294.00±0.82^{d}	1512.00±2.16^{d}
Slice thickness 6 mm	3484.67±1.25^{z}	1941.00±2.16^{mi}	5493.00±1.63^{s}	3548.67±0.47^{a}	1542.67±0.47^{c}
Slice thickness 8 mm	3152.33±2.05^{mi}	1980.00±0.82^{ki}	4922.00±1.41^{ei}	2940.00±2.16^{o}	1122.67±1.89^{o}
Slice thickness 10 mm	2955.33±1.70^{ni}	2182.67±1.70^{ii}	4765.33±2.62^{ii}	2585.33±1.70^{ai}	776.33±2.62^{fi}
Ascorbic acid 0. 8%	3510.00±2.94^{y}	2432.00±2.16^{bi}	5378.00±0^{w}	2945.00±1.63^{n}	1080.00±2.45^{s}
Ascorbic acid 0.9 %	3623.67±2.05^{t}	2700.33±1.25^{t}	5721.67±0.94^{j}	3017.67±1.89^{j}	920.67±1.25^{bi}
Ascorbic acid 1.0 %	3782.67±1.70^{n}	2726.67±1.25^{q}	5715.67±2.05^{k}	2992.00±1.41^{l}	1055.33±1.25^{u}
Ascorbic acid 1.1 %	3755.67±3.40^{o}	2753.33±2.05^{p}	5593.67±1.70^{q}	2840.33±1.25^{t}	1002.67±2.05^{z}
Ascorbic acid 1.2 %	4401.33±2.62^{d}	3097.00±1.41^{g}	6247.00±2.83^{c}	3151.67±1.70^{f}	1300.00±2.16^{h}
Citric acid 0.20 %	3320.33±2.05^{hi}	1852.00±1.63^{ni}	5130.00±0^{ai}	3282.33±2.62^{e}	1466.67±1.25^{g}
Citric acid 0.25 %	3396.00±0^{fi}	2593.67±2.05^{y}	5165.33±1.70^{z}	2568.67±2.62^{ci}	801.00±0.82^{di}
Citric acid 0.30 %	3464.00±2.94^{bi}	2809.33±3.09^{l}	5462.33±1.70^{t}	2653.33±0.47^{w}	647.00±1.63^{ji}
Citric acid 0.35 %	3421.67±1.70^{di}	2404.00±2.16^{di}	5435.00±1.63^{u}	3028.33±2.49^{i}	1016.67±1.25^{x}
Citric acid 0.40 %	3522.33±2.62^{v}	2718.67±0.47^{r}	5666.00±2.45^{n}	2946.33±0.94^{n}	805.33±1.25^{di}
Calcium chloride 0.05 %	3414.00±1.63^{ei}	2115.33±0.94^{ji}	5502.00±1.41^{r}	3385.67±1.25^{c}	1296.00±0.82^{j}
Calcium chloride 0.10 %	3643.00±1.63^{s}	2662.00±1.63^{v}	5613.67±0.47^{o}	2951.67±1.25^{m}	978.00±2.16^{ai}
Calcium chloride 0.15 %	3696.00±2.94^{q}	2903.33±1.70^{j}	5609.00±0.82^{p}	2708.00±4.97^{v}	793.00±1.63^{ei}
Calcium chloride 0.20 %	3514.00±1.63^{w}	2689.00±2.83^{u}	5593.00±0.82^{q}	2900.67±2.62^{r}	822.00±2.16^{ci}
Calcium chloride 0.25 %	2895.67±3.40^{oi}	2322.00±1.41^{gi}	4775.00±2.45^{hi}	2447.00±2.83^{gi}	575.33±0.94^{ki}

PV, peak viscosity; TV, trough viscosity; BD, break down viscosity; FV, final viscosity; SB, Setback. Values in the same column with different letters are significantly different ($p < 0.05$).

Table 3. Principal component analysis of quality of tailored flour for potato staple foods.47)

Principal components	Characteristic root	Rate of contribution/%	Accumulative contribution rate/%
1	2.2280	37.13	37.13
2	1.3676	22.79	59.93
3	0.8884	14.81	74.73
4	0.7933	13.22	87.96
5	0.5234	8.72	96.68
6	0.1993	3.32	100

Table 4. Contribution rate of six quality indices. [47)]

Quality indexes	First principal component	Second principal component	Third principal component	Fourth principal component	Fifth principal component	Sixth principal component
Polyphenol oxidase activity	−0.317591	0.668722	0.008163	0.346802	0.081375	0.570076
Reducing sugar content	0.483132	−0.171440	−0.623642	−0.004245	−0.276642	0.521261
Antioxidant activity	0.440208	−0.298205	0.384378	0.388594	0.588292	0.269170
Total polyphenol content	0.425223	0.214373	0.597067	0.030994	−0.642885	0.049787
Luminance value (L*)	0.429828	0.466094	−0.321519	0.402923	0.116827	−0.564476
Viscosity	0.326144	0.413876	0.058254	−0.751929	0.379223	0.098667

Table 5. ANOVA of Placket-Burman design experiment for reducing sugar content.[47)]

	Level		F-value	P-value
	−1	1		
Model			3.61	0.1594
Blanching temperature (°C)	90	100	8.80	0.0592
Blanching time (s)	25	30	0.27	0.6410
Drying temperature (°C)	70	80	2.88	0.1880
Drying time (h)	17	19	2.07	0.2462
Slice thickness (mm)	6	8	10.46	0.0480
Ascorbic acid concentration (g/L)	1.10	1.00	0.18	0.6983
Citric acid concentration (g/L)	0.30	0.35	3.20	0.1718
Calcium chloride concentration (g/L)	0.10	0.15	1.02	0.3859

Table 6. ANOVA of Placket-Burman design experiment for polyphenol oxidase activity.[47)]

	Level		F-value	P-value
	−1	1		
Model			16.04	0.0217
Blanching temperature (°C)	90	100	0.19	0.6929
Blanching time (s)	25	30	8.13	0.0651
Drying temperature (°C)	70	80	76.82	0.0031
Drying time (h)	17	19	13.17	0.0342
Slice thickness (mm)	6	8	14.38	0.0322
Ascorbic acid concentration (g/L)	1.0	1.1	1.52	0.3049
Citric acid concentration (g/L)	0.30	0.35	13.32	0.0355
Calcium chloride concentration (g/L)	0.10	0.15	0.26	0.6476

Table 7. Design approach and experimental result of response surface methodology.[47)]

No.	Factor			Y
	X_1	X_2	X_3	
1	80	18	8	0.515
2	75	18	7	0.253
3	75	18	7	0.270
4	80	19	7	0.595
5	80	17	7	0.435
6	75	19	6	0.288
7	75	17	6	0.241
8	75	17	8	0.245
9	70	18	8	0.199
10	75	19	8	0.361
11	75	18	7	0.275
12	75	18	7	0.257
13	70	17	7	0.218
14	80	18	6	0.435
15	70	19	7	0.150
16	75	18	7	0.251
17	70	18	6	0.176

X_1, drying temperature; X_2, drying time; X_3, slice thickness; Y = polyphenol oxidase activity.

Table 8. ANOVA of the result of response surface methodology. [47)]

Source of variation	Sum of squares	Degree of freedom	Mean square	F-value	p-value
Model	0.24	9	0.027	88.33	< 0.0001
X_1	0.19	1	0.19	632.29	< 0.0001
X_2	0.008128	1	0.008128	26.87	0.0013
X_3	0.004050	1	0.004050	13.39	0.0081
X_1X_2	0.013	1	0.013	42.96	0.0003
X_1X_3	0.0008123	1	0.0008123	2.69	0.1453
X_2X_3	0.001190	1	0.001190	3.93	0.0877
X_1^2	0.019	1	0.019	64.17	< 0.0001
X_2^2	0.001752	1	0.001752	5.79	0.0470
X_3^2	0.00001946	1	0.00001946	0.064	0.8071
Residual	0.002118	7	0.0003025		
Mismatch error	0.001661	3	0.0005536	4.85	0.0807
Pure error	0.0004568	4	0.0001142		
Sum	0.24	16			
		r^2=0.9913			

14 showed that potato steamed bread containing 55 % potato flour had a high nutritional value, which made it healthier for humans. Briefly, the protein content of the potato steamed bread containing 55 % potato flour was a higher than that of potato steamed bread containing 30% potato flour and wheat flour steamed bread. All essential amino acid scores were higher than 90 %, and there was almost no limiting amino acid. In addition, there was a greater abundance of dietary fiber, vitamins, and minerals in potato steamed bread containing 55 % potato flour. The dietary fiber content was 1.5 times that of wheat flour steamed bread. The vitamin B_1 content was 1.4 times that of the potato steamed bread containing 30% potato flour and 1.8 times that of wheat flour steamed bread. The vitamin B_2 content was 1.2 times that of the potato steamed bread containing 30 % potato flour and 2.3 times that of wheat flour steamed bread. The vitamin B_3 content was 2.4 times that of the potato steamed bread containing 30 % potato flour and 5.1 times that of wheat flour steamed bread. The vita-

Table 9. Proximate composition of tailored flour for potato staple foods (g/100 g).47)

The name of ingredients	Tailored flour	Market flour	Wheat flour
Moisture	11.20±0.15	6.01±0.00	11.98±0.02
Ash	2.60±0.05	2.60±0.05	0.48±0.01
Starch	73.60±0.05	74.50±0.04	60.96±1.22
Protein	9.31±0.06	9.46±0.01	11.39±0.01
Fat	0.56±0.01	1.05±0.01	0.68±0.02
Dietary fiber	2.31±0.04	5.59±0.04	0.64±0.00
Energy*	1458.00±0.00	1525.00±0.00	1481.50±0.00
Carbohydrate	74.10±0.00	75.20±0.00	73.73±0.06

* The unit of energy is kJ/100 g.

Table 10. Vitamin content of tailored flour for potato staple foods (mg/100 g).47)

Samples	Vitamin B_1	Vitamin B_2	Vitamin B_3	Vitamin C	Vitamin E*
Tailored flour	0.60±0.00	0.16±0.00	7.65±0.05	87.00±0.05	<0.01
Market flour	0.01±0.01	0.10±0.00	5.01±0.15	13.0±0.00	86.30±0.05
Wheat flour	0.26±0.01	0.04±0.00	0.91±0.01	ND	689.97±3.17

* The unit of vitamin E is µg/100 g.

Table 11. Activity of polyphenol oxidase, total polyphenol content, and antioxidant activity of tailored flour for potato staple foods. 47)

Samples	PPO (A416)	Total polyphenol content (g chlorogenic acid equivalent/100 g)	Antioxidant activity (µg Trolox equivalent/mg)
Tailored flour	0.158±0.00	0.850±0.00	2.464±0.04
Market flour	0.075±0.01	0.323±0.00	2.503±0.04
Wheat flour	0.097±0.01	0.004±0.00	1.420±0.01

Table 12. Mineral element composition of tailored flour for potato staple foods (mg/100 g).47)

The name of mineral elements	Tailored flour	Market flour	Wheat flour
Ca	32.60±0.00	25.30±0.05	20.12±0.10
K	941.50±0.01	386.00±0.00	173.04 ±2.00
P	233.50±0.00	173.40±0.25	36.12 ±0.24
Mg	56.90±0.20	61.10±0.00	20.64 ±1.02
Na	4.35±0.09	2.66±0.08	2.02 ±0.33
Fe	1.42±0.00	2.98±0.14	1.14 ±0.01
Mn	0.27±0.00	3.93±0.00	0.43 ±0.00
Zn	1.22±0.00	6.50±0.03	0.20 ±0.00
Cu	0.52±0.17	2.46±0.00	0.01 ±0.00
Se*	1.39±0.05	0.33±0.00	0.60 ±0.03

* The unit of Se is µg/100 g.

Table 13. Nutrition information of steamed breads containing 55 % potato flour, 30 % potato flour, and 100 % wheat flour.48)

Items	Potato steamed bread containing 55 % potato flour		Potato steamed bread containing 30 % potato flour		Steamed bread containing 100 % of wheat flour	
	100 g	Nutrient reference values %	100 g	Nutrient reference values %	100 g	Nutrient reference values %
Energy (kJ)	907.81	10.81	962.00	11.45	986.67	11.75
Protein (g)	8.41	14.02	7.54	12.57	7.59	12.65
Fat (g)	0.39	0.65	0.81	1.35	0.45	0.75
Carbohydrate (g)	47.90	15.97	45.92	15.31	49.15	16.38
Dietary fiber (g)	2.71	10.84	3.03	12.12	1.66	6.64
Vitamin B_1 (mg)	0.30	21.43	0.22	15.71	0.17	12.14
Vitamin B_2 (mg)	0.07	5.00	0.06	4.29	0.03	2.14
Vitamin B_3 (mg)	3.11	22.21	1.31	9.36	0.61	4.36
Vitamin C (mg)	32.66	32.66	14.59	14.59	ND	—
Ca (mg)	17.72	2.22	25.28	3.16	13.41	1.68
P (mg)	97.49	13.93	53.55	7.65	24.08	3.44
K (mg)	400.55	20.03	194.50	9.73	115.36	5.77
Na (mg)	3.40	0.17	35.98	1.80	13.47	0.67
Mg (mg)	26.98	8.99	30.34	10.11	13.76	4.59
Fe (mg)	0.84	5.60	0.92	6.13	0.76	5.07
Zn (mg)	1.00	6.67	0.23	1.53	0.13	0.87
Se (µg)	4.81	9.62	4.87	9.74	3.98	7.96
Cu (mg)	0.20	13.33	0.05	3.33	0.01	0.67
Mn (mg)	0.22	7.33	0.26	8.67	0.29	9.67

Table 14. Effect of potato flour content on essential amino acid scores.[48)]

Potato flour content (%)	Ile	Leu	Lys	Met+Cys	Phe+Try	Thr	Trp	Val
0	85.00	95.00	52.00	166.00	145.00	62.00	93.00	101.00
5	86.49	97.64	56.17	162.19	146.47	65.53	92.75	101.90
15	89.47	102.91	64.50	154.56	149.40	72.58	92.25	103.70
25	92.45	108.18	72.83	146.93	152.33	79.63	91.75	105.50
35	95.43	113.45	81.16	139.30	155.26	86.68	91.25	107.30
45	98.41	118.72	89.49	131.67	158.19	93.73	90.75	109.10
55	101.39	123.99	97.82	124.04	161.12	100.78	90.25	110.90
65	104.37	129.26	106.15	116.41	164.05	107.83	89.75	112.70
75	107.35	134.53	114.48	108.78	166.98	114.88	89.25	114.50
85	110.33	139.80	122.81	101.15	169.91	121.93	88.75	116.30
95	113.31	145.07	131.14	93.52	172.84	128.98	88.25	118.10
100	114.80	147.70	135.30	89.70	174.30	132.50	88.00	119.00

Table 15. Nutrient analysis of gluten-free potato steamed bread.[48)]

Items	Gluten-free potato steamed bread	Recommended nutrient value %	Potato steamed bread containing 55 % potato flour	Recommended nutrient value %
Energy (kJ/100 g)	955.00	11.37	907.81	10.81
Protein (g/100 g)	8.40	14.00	8.41	14.02
Fat (g/100 g)	0.37	0.62	0.39	0.65
Carbohydrate (g/100 g)	46.55	15.52	47.90	15.97
Dietary fiber (g/100 g)	2.74	10.96	2.71	10.84
Vitamin B_1 (mg/100 g)	0.38	27.14	0.30	21.43
Vitamin B_2 (mg/100 g)	0.16	11.43	0.07	5.00
Vitamin B_3 (mg/100 g)	4.79	34.21	3.11	22.21
Vitamin C (mg/100 g)	54.02	54.02	32.66	32.66
Ca (mg/100 g)	22.01	2.75	17.72	2.22
P (mg/100 g)	148.84	21.26	97.49	13.93
K (mg/100 g)	612.04	30.60	400.55	20.03
Na (mg/100 g)	18.32	0.92	3.40	0.17
Mg (mg/100 g)	35.33	11.78	26.98	8.99
Fe (mg/100 g)	1.20	8.00	0.84	5.60
Zn (mg/100 g)	0.76	5.07	1.00	6.67
Se (μg/100 g)	2.24	4.48	4.81	9.62
Cu (mg/100 g)	0.33	22.00	0.20	13.33
Mn (mg/100 g)	0.17	5.67	0.22	7.33

min C content was 2.2 times that of the potato steamed bread containing 30 % potato flour and not detected in wheat flour steamed bread. The Ca content was 1.3 times that of wheat flour steamed bread. The P content was 1.82 times that of the potato steamed bread containing 30% potato flour and 4.1 times that of wheat flour steamed bread. The K content was 2.1 times that of the potato steamed bread containing 30 % potato flour and 3.5 times that of wheat flour steamed bread. The Mg content was 2.0 times that of wheat flour steamed bread. The Fe content was 1.1 times that of wheat flour steamed bread. The Se content was 1.2 times that of wheat flour steamed bread. The Zn content was 4.4 times that of the potato steamed bread containing 30 % potato flour and 7.7 times that of wheat flour steamed bread. The Cu content was 4.0 times that of the potato steamed bread containing 30 % potato flour and 19.9 times that of wheat flour steamed bread.

On June 1, 2016, the potato steamed bread products containing 55 % potato flour developed by our research group and produced by Beijing Haileda Food Co., Ltd. began to be sold in the supermarkets in Beijing and received unanimous praise by a vast number of consumers.

Research and development of gluten free pure potato steamed bread.

Nowadays, celiac disease, an immune-mediated enteropathy in genetically susceptible individuals caused by the ingestion of gluten, is one of the most common lifelong disorders.[49)] The estimated prevalence of this disease is about 1 % in the general population, and it affects people of any age, race, and ethnic group.[50)] The only acceptable treatment currently is strictly lifetime gluten-free diet.[51)] Therefore, interest for gluten-free products has increased in the market trend.[52)]

A diet based on gluten-free products mainly contains starch, rice flour, and/or corn flour, and is characterized by low content of some nutritional components such as protein and essential fatty acids as well as physiologically important components like dietary fiber.[53] Therefore, supplements of gluten-free products to increase the nutritional and physiologically important contents are important.[54] Potato flour may be a good supplement to gluten-free products as it is a rich source of essential fatty acids, dietary fiber, and protein, and contains several phytochemicals such as phenolics, flavonoids, and carotenoids. The incorporation of potato flour into gluten-free products would enhance their nutritional and functional qualities.

We researched and developed gluten-free potato steamed bread (Liu *et al*., unpublished results), analyzing:

(1) Effect of proteins from different sources on rheological properties and protein structure of gluten-free potato dough;

(2) Effect of dietary fiber from different sources on thermal characteristics, farinograph property, dynamic rheology, thixotropy, microstructure, rheological properties, and protein structure of gluten-free potato dough;

(3) Effect of proteins from different sources on specific volume, height-to-diameter ratio, color, and texture characteristics of gluten-free potato steamed bread.

Gluten-free potato steamed bread was developed successfully (tailored flour for potato staple foods 86.61 g/100 g flour, pregelatinized potato flour 4.84 g/100 g flour, modified dietary fiber 1.68 g/100 g flour, egg white protein 5.87 g/100 g flour, and water 69.69 g/100 g flour) and dietary fiber, vitamins B_1, B_2, B_3, C, and minerals such as Ca, P, K, Na, Mg, Fe, and Cu were more abundant in gluten-free potato steamed bread compared to potato steamed bread containing 55 % potato flour (Table 15) (Liu *et al*., unpublished results).

Research and development trend in the future.

In order to achieve potato staple food industrialization in China, there are still a lot of research and development works to perform. Studies on the influencing factors and mechanisms of potato steamed bread quality characteristics are required as well as studies on the changes of nutritional components during the processing of potato staple foods. Analyses of the effect of potato, wheat, maize, millet, rice varieties, mixed flour formula, and processing parameters on the quality of potato steamed bread, bread, and other potato staple food products are needed in order to determine the best formula of product, optimize the process parameters, and establish quality control system. The modification and design of critical components based on the processing demands of potato steamed breads in home kitchens and small canteens need to be studied, and small and medium size potato steamed bread processing equipment needs to be developed.

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