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Research Article

Effect of Microwave Precooking and Freeze-Drying on the Quality of the Germinated Brown Rice

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In this paper, microwave precooking and freeze-drying were used to improve the quality of germinated brown rice. The results suggested that the ideal microwave precooking conditions for germinated brown rice were 1 : 1 (m/V) followed by a 9 min heating time at 600 W. Brown rice with microwave precooking and freeze-drying treatment (TBR) had a better nutritional value than untreated brown rice (UBR). The edible quality of TBR was improved, and its hardness was reduced by 54.78%. TBR, in contrast to UBR, has a rough and porous surface, a loose internal structure, and facilitates the contact between starch and water during cooking, hence enhancing gelatinization. In germinated brown rice, microwave precooking and freeze-drying significantly increased the synthesis of the majority of volatile compounds. The aforementioned data imply that microwave precooking-freeze-drying may greatly improve the nutritional value and palatability of brown rice after germination.

1. Introduction

Rice is a vital staple food for billions of people worldwide. Currently, rice is processed and consumed in two forms, polished rice and brown rice. Brown rice is a type of rice that has the outer layer of skin, aleurone, and germ retained after the rice has been shelled. Brown rice can be utilized as the primary source of carbohydrates for most people [1, 2]. Brown rice is higher in dietary fiber and a range of physiologically active components than polished rice, making it a nutritious and high-quality staple food.

The degree to which the rice is prepared distinguishes brown rice from polished rice. And, most rice consumed today is the result of refined rice processing, which removes all of the seed coverings from the rice and polishes a fraction of the grains [3]. While the taste and appearance are extremely pleasant, considerable nutritional value is lost during processing [4]. The outer tissue of brown rice is predominantly composed of cellulose, resulting in a thick and compact bran layer structure [5, 6]. Water has a tough time penetrating through the bran layer and into the center of the rice grains to reach the starch during regular cooking [7]. As a result, the inherent starch in brown rice is difficult to gelate when cooked. Brown rice has a lower edible quality when cooked for the same period of time as polished rice, which is most visible in the hardness and flavor of brown rice [8–10]. This is one of the reasons why only a small proportion of the population consumes brown rice on a daily basis.

In order to improve the edible quality and nutritional content of brown rice, it is common practice to germinate the grain before processing it. Brown rice has the ability to germinate due to the fact that it is a whole grain. In the soaking and sprouting phases, water penetrates the bran layer and penetrates into the grain's core in a gradual manner, triggering a variety of enzyme activities [11]. Because of the action of enzymes, the concentration of nutrients increases during the germination period, which is the most noticeable. The effectiveness of several active substances, such as GABA, has been greatly enhanced. GABA is a neurotransmitter that has a number of physiological functions in the body [12]. During the germination process, several enzymes are active, and the polysaccharides in the seeds are digested into smaller molecules that are easier for the human body to absorb, resulting in a pleasant flavor [13]. Because brown rice respiration consumes a substantial amount of energy during germination, the overall sugar content of germinated brown rice will be significantly reduced, but the concentration of reducing sugars will rapidly increase as the germination period is prolonged [14]. At the same time, compared to brown rice, germinated brown rice is a more nutritious food that has a nice flavor and is easy to digest.

Microwave heating is frequently used in a variety of food processing equipment because to its uniform heating, quick heating, high penetration, and low energy consumption. It works mostly via its own electric heating and electromagnetic polarization effects [15]. Under microwave radiation, a large number of internal polar macromolecules generate heat in the sample owing to friction, which elevates their own temperature, resulting in changes in their physical and chemical characteristics. By contrast, microwave radiation reorganizes the electron cloud of polymers or groups inside the sample, resulting in a change in molecular conformation [16]. Brown rice's water content rose after microwave precooking. Dehydration is a popular method of food preservation because it decreases microbial deterioration and avoids physical and chemical interactions between food elements during storage. Heat and mass are transmitted simultaneously during the drying process, creating significant changes in the physical and chemical composition, as well as the structure of food products, depending on the transport mechanisms used. As a result, the drying process and selected circumstances affect the microstructure and morphology of meals, as well as the quality of the final product [17]. Freeze-drying is one of the most advanced drying technologies used in the food processing industry, as it minimizes unwanted shrinkage and creates materials with high porosity, unchanged nutrition quality, superior taste, aroma, flavors, and color retention, as well as greater rehydration capabilities. The porous and spongy structure allows for excellent rehydration, making freeze-dried rice useful as instant noodles that are simple to prepare. Furthermore, lowering the water content aids in the long-term preservation of meals after packaging and reduces the material's weight for easier transport [17].

Brown rice's shortcomings were addressed in this research, including its lengthy boiling time, gritty taste, and difficulty to be kept for extended periods of time. Brown rice was germinated simultaneously with microwave precooking to maximize its gelatinization degree and cooking quality. Finally, using vacuum freeze-drying, the nutritional quality, texture characteristics, gelatinization characteristics, microstructure changes, and flavor substance changes of brown rice were analyzed, and quick-food products with a high rehydration rate and sensory evaluation were obtained. This research reveals a novel method for producing nutritious and healthy staple food products from brown rice. Precooked brown rice is high in nutrients and has a positive impact on human health, laying the theoretical groundwork for the processing and production of quick-food germinated brown rice.

2. Materials and Methods

2.1. Raw Materials. Brown rice was purchased from Harbin Jin-He Rice Inc. (Harbin, China) in 2021 and stored at 20°C for use. All the chemicals were analytically pure. All the chemicals and reagents were obtained from Hengxing Chemical Reagent Co., Ltd., Tianjin, China and Bodi Chemical Co., Ltd., Tianjin, China.

2.2. Preparation of Germinated Brown Rice. After removing impurities, rinse the brown rice three times with tap water before adding 0.1% sodium hypochlorite solution for disinfection for 15 s. After disinfection, rinse the brown rice several times with clean water before putting it in a beaker and adding 1.5 times the volume of brown rice to soak in water, changing the water every 1-2 h during the soaking period. After soaking, place it in a 28°C constant temperature incubator to germinate for 13 h.

2.3. Microwave Precooking Process Optimization for Germinated Brown Rice. Investigated the influence of three factors on the microwave precooking process, including solid-liquid ratio (2 : 1, 1.5 : 1, 1 : 1, 1 : 1.5, and 1 : 2), microwave power (300, 400, 500, 600, and 700 W), and heating time (1, 3, 5, 7, and 9 min), and precooking germinated brown rice was prepared under the optimal conditions.

2.4. Freeze-Drying Process Optimization. After a microwave precooking treatment, the germinated brown rice (5, 10, 15, 20, and 25 g) was placed in a 60 mm petri dish, frozen at 18°C (9, 12, 15, 18, and 21 h), and dried in a vacuum freeze drier (10, 15, 20, 25, and 30 h). The rehydration rate and sensory score of brown rice were assessed after drying, and three tests were conducted.

2.5. Index Determine

2.5.1. Degree of Gelatinization. The degree of gelatinization was determined by modifying a method described by Birch and Priestley [18]. Brown rice is broken and sorted through a 60-mesh sieve, both untreated and treated. 0.2 g of untreated brown rice flour was distributed and mixed in 95 mL of clean water, followed by the addition of 5 mL of a 10 mol/L potassium hydroxide solution. The suspension was swirled at a speed of 10 rpm for 5 min in a magnetic stirrer, and the resulting suspension was centrifuged at 4500 g for 10 min. 0.2 mL supernatant was diluted to 10 mL with 0.2 mL hydrochloric acid (0.5 mol/L). Finally, 0.2 mL iodine solution was added and the mixture's absorbance A_1 at 600 nm was evaluated after thorough mixing. 2 mL KOH was substituted for the 1 mL KOH in the preceding stages, and 0.5 mol/L hydrochloric acid was substituted for 0.2 mol/L. The remaining samples were identical, and the absorbance A_2 was determined. Brown rice's degree of gelatinization was determined using the following formula:

$$\text{Degree of gelatinization/\%} = \frac{A_2}{A_1} \times 100. \quad (1)$$

2.5.2. Rehydration Rate. The moisture on the dried surface after reheating in boiled water for 10 min was weighed as m_2, and the brown rice after precooking and freeze-drying treatment was weighed as m_1. The following is

Table 1: Sensory evaluation criteria.

	Poor (0~7 points)	Medium (8~14 points)	Optimal (15~20 points)
Color	Dark yellow, dullness	Light yellow, general burnish	Light yellow, good gloss
Form of organization	Incomplete particles, many cracks	More complete particles, fewer cracks	Complete particles with few cracks
Smell	Rice bran tastes strong	There is no rice bran, but no rice fragrance	There is no rice bran, and the rice is fragrant
Hardness	Very hard	Little hard	Soft
Elastic	No chewiness	Little chewiness	Good chewiness

the formula for estimating the rehydration rate of brown rice:

$$\text{Rehydration rate}/\% = \frac{m_2}{m_1} \times 100. \quad (2)$$

2.5.3. Sensory Evaluation Criteria. A sensory evaluation was carried out with the help of 20 main assessors (8 men and 12 women). The sensory evaluation criteria for brown rice were developed using the method described by Li et al. [19]. The comprehensive score (100 points) was used to reflect the total sensory quality of brown rice in these parameters, and it was reviewed by each assessor (Table 1).

2.6. Nutritional Quality of Brown Rice

2.6.1. Basic Nutrients. The moisture content and crude protein content of the rice samples was determined using the standard method of AACC 44-15A (AACC, 2000) and AOAC 981.10 (AOAC, 2010), respectively. The nitrogen content (N) was converted into the protein content using a conversion factor of $N \times 5.95$. The crude fat content was measured using the methods of AACC 30-20 (AACC, 2000). The starch content of the rice samples was determined using the standard method of AACC 76-11 (AACC, 2010). The total sugar content is determined by the total sugar content detection kit (BC 2710, Beijing Solarbio Science & Technology Co., Ltd, China). Except for moisture content, the results were given on a dry basis. All of the experiments were repeated three times, and the results were provided as mean values.

2.6.2. Main Biologically Active Ingredients. The GABA content of brown rice was determined using the method described by Zhang et al. [20]. Briefly, each sample was crushed to 10 g and then screened through a 0.25 mm hole sizer. It was then dissolved in 0.02 mol/L hydrochloric acid solution and added to a 6% sulfosalicylic acid solution. In a boiling water bath, the heating reflux was turned on for 5 min. After 30 min of oscillation, the solution was transferred to a 50 mL volumetric flask and diluted with pH 2.2 citrate buffer solution to the calibration. It was centrifuged for 15 min at 1000 r/min after standing for 1 h at room temperature. Finally, an amino acid analyzer was used to determine the GABA content. The content of total phenols and flavonoids is determined by the kit (BC1330 and BC1340, Beijing Solarbio Science & Technology Co., Ltd, China).

2.7. Textural Properties. The Texture Analyzer (TMs-Pro, USA) was used to measure the texture of the cooked rice samples. UBR and TBR were boiled in boiling water for 15 min, then simmered for 5 min, and the change of texture characteristics was measured. Three grains of cooked rice were put symmetrically on the target table and crushed using a probe with a 35 mm diameter. The speeds for the pretest, test, and posttest were 2, 0.5, and 0.5 mm/sec, respectively. Seventy percent of the distance was compressed. Rice grains were tested for hardness, adhesiveness, chewiness, and elasticity. The final findings were the average of the test results, minus the highest and lowest numbers.

2.8. Pasting Properties of Brown Rice Flour. A Rapid Visco Analyzer (RVA) was used to determine the pasting properties of rice flour samples (RVA-tech, China). 3 g of rice flour was combined with 25 mL 160 distilled water in an aluminum container. The following are the preset heating and cooling cycles. Each sample was maintained at 50°C for one minute before being heated to 95°C in three minutes and held there for 2.5 minutes. It was then cooled to 50°C in four minutes and maintained there for two minutes.

2.9. Scanning Electron Microscopic (SEM) Observation. After drying, they were mounted on a silver plate and coated with a thin gold film (10 nm) in a vacuum evaporator. The resulting specimens were examined and photographed using a scanning electron microscope (SEM, SU8010, Hitachi, Japan) operating at a 5.0 kV accelerating voltage. SEM measurements were performed on freeze-dried brown rice flour samples using a scanning electron microscope. Each sample was distributed with care using double-sided sticky tape and gold-palladium coated on a copper stub. The micrographs were seen at a 20.0 kV accelerating voltage and a magnification of 1000.

2.10. Analysis of Brown Rice Flavor Compounds. Pretreatment of the sample was as follows: 2.0 g of brown rice was weighed into a clean extraction flask, which was rapidly sealed and put in a 60°C water bath with magnetic stirring at 500 rpm for 20 min, before inserting the extraction head for 30 min extraction. Following that, the extraction head was put into a GC-MS (Agilent 7890A-5975C GC-MS, USA) for 10 min before to initiating the analysis.

Utilizing an HP-5MS elastic capillary column (60 mm × 250 μm × 0.25 μm) with the following column temperatures. After maintaining the initial temperature of 50°C for 3

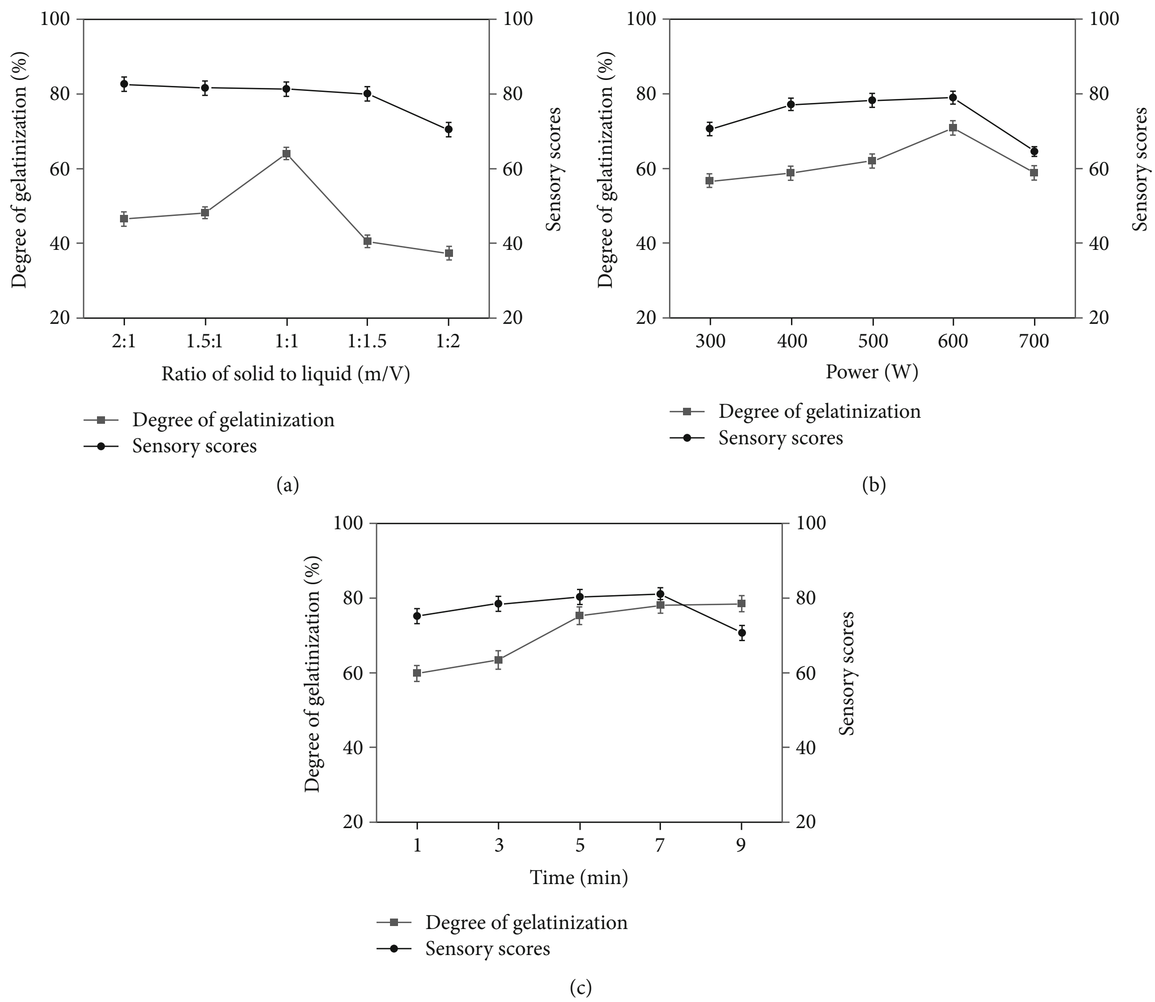

Figure 1: Optimization of brown rice precooking process ((a) ratio of solid to liquid; (b) power; (c) time).

minutes, the temperature was increased to 250°C at a rate of 5°C/min and then maintained for 5 minutes. Other working settings for the GC-MS included 230°C for the ion source, 150°C for the quadrupole, and 70 eV for EI ionization.

2.11. Statistical Analysis. The data was presented as means and standard deviations, and the statistics were analyzed using Excel 2013. The SPSS 16.0 program was used to determine the significant difference. At a confidence level of $P < 0.05$, the difference (mean values with different letters) was regarded as significant.

3. Results and Discussion

3.1. Effect of Microwave Heating Conditions on Germinated Brown Rice. As seen in Figure 1(a), when the ratio of solid to liquid is low, the degree of gelatinization is fairly low. This is because brown rice has a coating of aleurone. Due to the primary membrane's thickness, water absorption is problematic [21]. Unhydrated starch granules are difficult to gelatinize at high temperatures and quickly cause brown rice to cook [22]. When the material-to-liquid ratio is 1 : 1 (m/V), the waist bursting phenomenon does not occur, and the sensory score continues to climb. As a consequence, the recommended microwave precooked liquid ratio is 1 : 1 (m/V), and this result is applied to the experiment of the next influencing factor.

As indicated in Figure 1(b), microwave power has a significant effect on the degree of gelatinization and sensory quality of brown rice. The gelatinization of brown rice increases as the power increases from 300 to 600 W. The degree of gelatinization reaches its maximum at 600 W. The starch is not totally gelatinized. Increased microwave power causes brown rice to become less gelatinous. This is due to the fact that microwave heating power increases proportionally with heating rate. When brown rice starch is exposed to water, the gelatinization process is accelerated and the starch is gelatinized to a greater extent [23]. However, the power consumption is exorbitant, as is the heating time. Rice's sensory quality would be impacted when water is gradually removed from the starch gelatinization process [24]. As a result, the ideal microwave power is chosen to be 600 W in order to preserve the sensory quality of brown rice while increasing the degree of gelatinization, and this result is applied to the experiment of the next influencing factor.

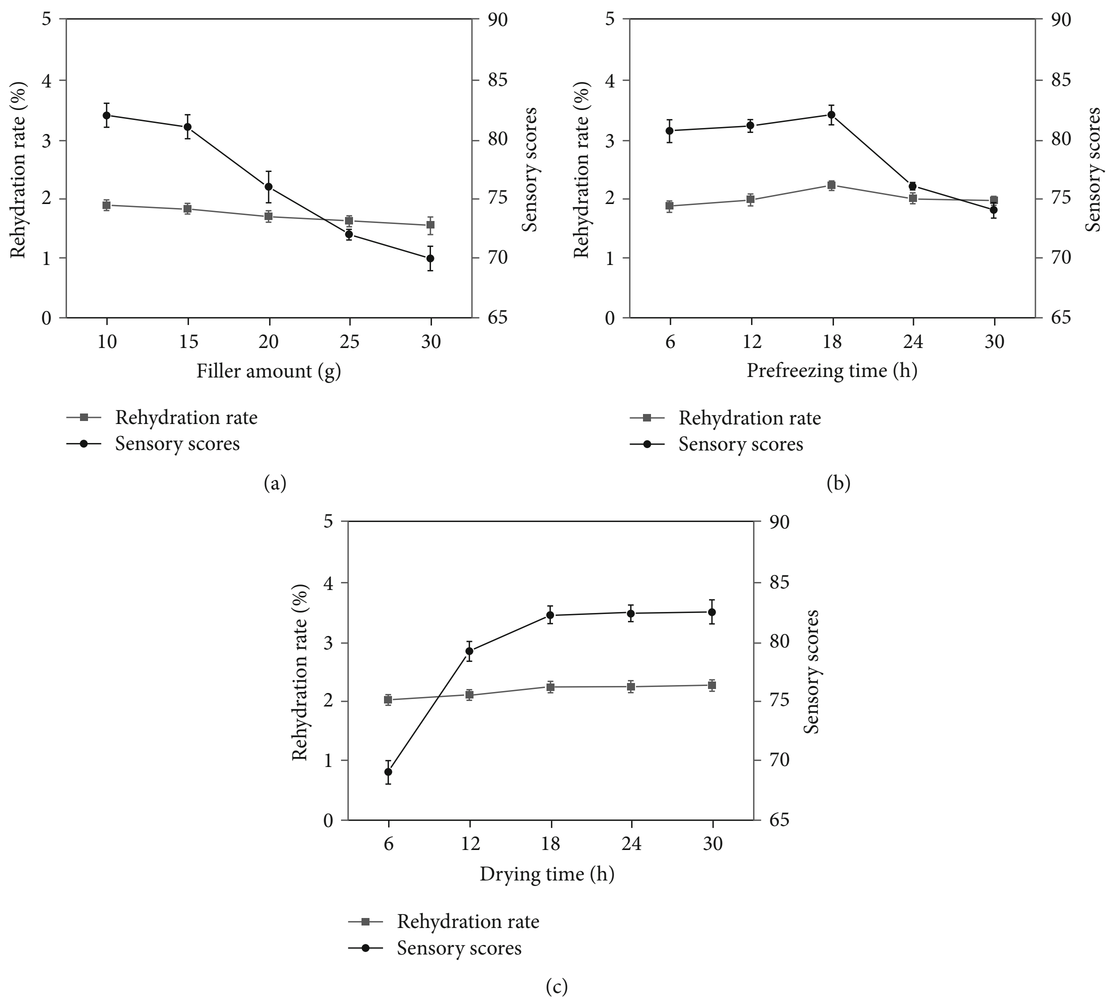

Figure 2: Optimization of brown rice freeze-drying process ((a) filler amount; (b) prefreezing time; (c) drying time).

Figure 1(c) demonstrates that when the material-to-liquid ratio and microwave power remain constant, brown rice's degree of gelatinization continues to rise when microwave-cooking time is increased and increased slowly after 7 min. This is because the water concentration in the system declines gradually throughout gelatinization, and the decrease in brown rice's water absorption capacity after 7 min delay the growth in gelatinization degree [25]. If the microwave time is extended, the brown rice color will darken and the brown rice will get burnt; as the microwave heating time increases, the brown rice's senses will become irritated. After seven minutes, the score continues to deteriorate and is much lower. Brown rice should be microwaved for 7 min to get a greater degree of gelatinization and keep a higher sensory score. Brown rice has reached a degree of gelatinization of (82.76 ± 2.20)% at this time.

3.2. Effects of Vacuum Freeze-Drying Conditions on Brown Rice. Due to water absorption, the moisture content of germinated brown rice increases during microwave precooking, which is unfavorable for immediate preservation after precooking. Brown rice, as a consequence, must be dried. Rather than conventional hot air drying, vacuum freeze drying is used to retain the nutritional value and taste of germinated brown rice while also simplifying long-term storage and transportation [26]. The filled volume of brown rice used in the freeze-drying process has an effect on the pace of rehydration and sensory quality of brown rice after drying. Both the rate of rehydration and sensory quality of brown rice after drying decrease as the amount of filler in brown rice rises, as seen in Figure 2(a). This is due to the fact that the amount of brown rice utilized affects the rate at which it dries. Increased filling thickness prevents water from escaping to the exterior, hence prolonging the drying process and altering the drying impact of brown rice. As a result, it is decided that 15 g of filler is the best quantity, and this result is applied to the experiment of the next influencing factor.

Prefreezing may freeze the moisture inside brown rice, avoiding unwanted changes such as surface cracking or solute transfer produced by the suction environment during the vacuum drying process, and guaranteeing that the rice retains its original shape before and after drying. The size of the ice crystals formed has a direct effect on the rehydration of the product after drying. Figure 2(b) demonstrates that increasing the prefreezing period first boosted the rate

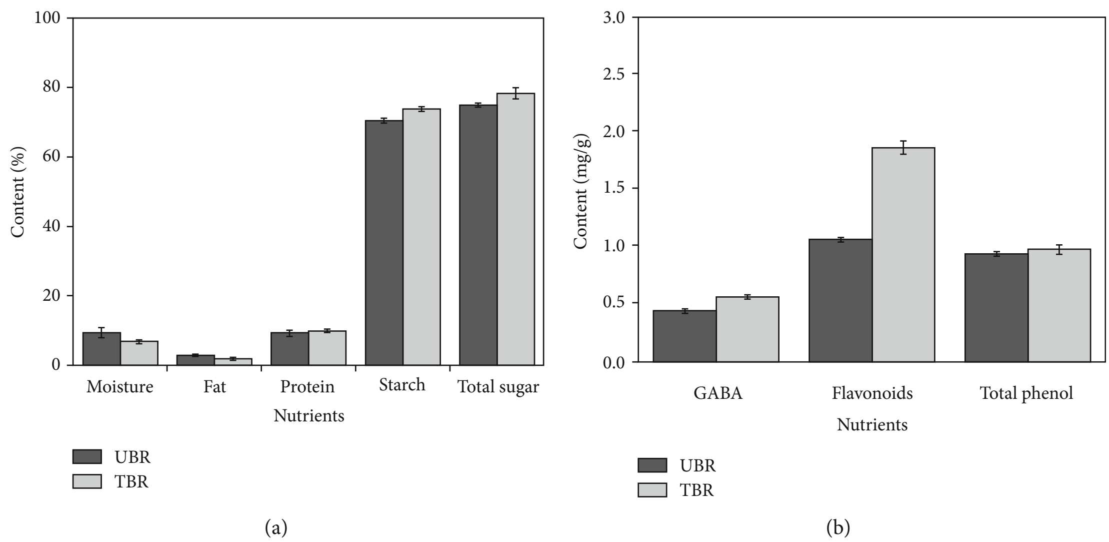

Figure 3: Changes of nutrients in brown rice during processing ((a) basic nutrients; (b) active components).

of rehydration of dry brown rice, but later reduced due to the production of ice crystals within the brown rice during the prefreezing process, which gradually got bigger. The routes produced by the sublimation of small ice crystals in the intermediate and outer layers foster the growth of inner ice crystals, therefore strengthening the drying effect. Large ice crystals generated within the cell wall structure of brown rice will cause the core structure to dry, resulting in a decrease in rehydration rate and a change in sensory quality [27]. According to the aforementioned, the best prefreezing period is 18 hours and this result is applied to the experiment of the next influencing factor.

To accomplish the drying process, the ice crystals formed in brown rice are sublimated into water vapor. As shown in Figure 2(c), as the drying time increases, the brown rice becomes more fully dried, and the more porous structures formed on the surface are more conducive to water absorption, resulting in a gradual increase in the rehydration rate of brown rice, but the rate and the sensory quality changed slowly after 18 h, and the drying time was 18 h considering the economic benefits.

3.3. Effect of Processing on Nutritional Quality of Brown Rice

3.3.1. Nutrients. After precooking and freeze-drying, the moisture content of germinated brown rice is significantly decreased, as seen in Figure 3(a). The starch content was raised by around 2.10%; the increase in starch content is a result of the precooking procedure. Gelatinization disrupts the sequence of starch molecules, destroying the starch's integrity and aggregation structure, enabling the starch to be completely freed [4]. The fat content has decreased by 31.71%. Precooking, which disrupts the structure of the brown rice bran layer and causes fat loss in the rice bran layer, as well as fat hydrolysis at high temperatures, may account for the drop in fat content. The protein content was enhanced by roughly 8.60%. Leaching of soluble chemicals normally found in the peel, aleurone layer, and starch endosperm of brown rice during the precooking process may have changed the ratio of brown rice nutrients in the caryopsis, resulting in an increase in protein content. Precooked brown rice's total sugar content rises when starch is totally freed and cellulose is half digested.

3.3.2. Main Biologically Active Ingredients. During brown rice germination, the natural protease, glutamate decarboxylase, and other enzymes were activated to create GABA and other helpful bioactive components. During brown rice germination, the activity of GABA synthase glutamate decarboxylase was activated, and the amount of glutamic acid, the precursor of proteolytic GABA, increased, resulting in a considerable increase in the GABA content of brown rice [28]. However, due to the fact that GABA is a heat sensitive substance, some GABA was lost in germinated brown rice during microwave precooking, so the increase in GABA content in TBR was not obvious as seen in Figure 3(b). The flavonoid content of the TBR was significantly increased, as seen in Figure 3(b), with a rise of around 76.24%. This could be because the microwave procedure weakens the original compact structure of the cell membrane, increasing permeability, and facilitating the flow of particular flavonoids out of the cell, making them easier to extract from the brown rice [20]. Additionally, it was determined that the treated brown rice's total phenol content had not risen much. This might be because brown rice has a substantially larger amount of total phenol. Following microwave-heating treatment, however, the phenolic chemicals are eliminated or a desugarization event occurs, leading in sprouting. The total phenol content of brown rice did not significantly increase.

3.4. Texture Properties. To some degree, the textural characteristics of brown rice indicate its eating quality. The difference of texture between UBR and TBR is due to the fact that the sample from TBR obtained from freezing drying had more porous structure and this cause the weakness of cooked rice structure after rehydration. Brown rice's hardness is reduced by about 54.78% after treatment, as indicated in Table 2. This is due to brown rice's high carbohydrate

Table 2: Textural properties of UBR and TBR.

	Hardness (N)	Cohesiveness (N)	Chewiness (N)	Springiness (mm)
UBR	16.96 ± 1.02^a	0.43 ± 0.04^a	9.91 ± 0.86^a	0.26 ± 0.02^a
TBR	7.67 ± 0.98^b	0.73 ± 0.05^b	4.59 ± 0.45^b	0.41 ± 0.03^b

Note: All the data are expressed as mean ± standard deviations. Means with the different superscript letters in a row differ significantly ($P < 0.05$).

content. Amylose and amylopectin are the two principal constituents. Amylose contributes to the flavor of brown rice. This is due to the fact that when rice grains are roasted, their starch absorbs water and significantly swells, causing starch granule rupture and amylose leaching. As a consequence of the leaching components, brown rice's hardness is decreased and its viscosity is raised [29]. As seen in Figure 4, substantial cortical cracking occurred in TBR upon heating, and volume expansion occurred as well. Consequently, the pores between brown rice grains closed during cooking, enhancing the viscosity and softness of brown rice. The compact fiber structure of treated brown rice is broken down, making it easier for the brown rice to absorb water and gelatinize during the cooking process, resulting in greater flexibility. Because the treated brown rice is softer and simpler to chew, the chewiness of the precooked brown rice is lowered.

3.5. Pasting Properties. The features of starch gelatinization are critical in the deep processing and utilization of cereal meals. After completely absorbing and expanding the water, the starch granules rub against one another, thickening the paste to its peak viscosity. Processing completely disrupts the starch granule structure of brown rice flour, resulting in a reduction in mutual friction and a large drop in viscosity following water absorption and swelling. As a result, the peak viscosity of TBR decreased. The attenuation value is the difference between the peak and trough viscosities (Table 3). It is a measure of the swelling strength of starch granules as well as the shear resistance of starch paste. It may be used to ascertain the stability of starch paste. The greater the thermal stability, the less attenuation is required. Processing degrades starch molecules, impairing their ability to rearrange and interact [30]. The RVA findings indicate that processed brown rice flour has a higher level of edibility and stability than unprocessed brown rice flour.

3.6. Microstructure

3.6.1. Microstructure Observation of the Surface Structure of Brown Rice Grains. As seen in Figures 5(a) and 5(b), the structure of the surface bran layer of UBR is compact and complete, which is also the primary cause for the delayed entry of water into the rice grains during the brown rice cooking process, resulting in poor cooking quality. As seen in Figures 5(c) and 5(d), the surface of TBR has an obvious loose and porous structure. When brown rice is soaked and germinated over an extended period of time, the structure of the surface bran layer becomes softer. Utilizing microwave precooking and vacuum freeze-drying, it was prepared. It has been precooked in the microwave and then vacuum freeze-dried [31]. The bran layer on the surface of brown rice is broken to generate a porous structure. The treated brown rice bran layer is looser, enabling more water and starch to come into contact during the gelatinization process, resulting in a higher quality of brown rice cooking.

3.6.2. Microstructure Observation of Brown Rice Flour. As a result of the close contact of starch and protein, untreated rice flour granules exhibit irregular fissures and rough cross-sections, as seen in Figures 5(e) and 5(f). After germination, microwave precooking and vacuum freeze-drying, gelatinized brown rice flour has a smoother surface and greater gaps within the grains, as seen in Figures 5(g) and 5(h). Gelatinization caused the starch granules to collapse by melting the crystallites, disrupting hydrogen bonds, unwinding the double helices, and weakening the cell-cell adhesion microstructure [32, 33]. Smaller sizes, more voids, and more channels in contact with water all assist in water conduction [34]. This proved that TBR is easier to gelatinize.

3.7. Important Flavor Compounds in UBR and TBR. As seen in Table 4, the taste components of brown rice mostly consist of aldehydes, alcohols, aromatic hydrocarbons, esters, and ketones. Due to the lack of odor activity, the detected alkanes are not included. UBR has a total of 14 chemicals, including four aldehydes, five alcohols, two terpenes, and two ketones. Five aldehydes, five alcohols, three terpenes, two esters, two aromatic hydrocarbons, and two ketones were discovered in TBR.

The kinds of volatile compounds in brown rice altered throughout processing as a result of germination treatment and the action of several enzymes. These volatile compounds are classified primarily as aldehydes, alcohols, esters, ketones, and hydrocarbons. Aldehydes are mostly formed through the oxidation and breakdown of lipids. The largest relative amount of hexanal was found in UBR, which had an oily and grassy odor. Heptaldehyde, nonanal, and decanal are degraded in brown rice by oleic acid hydroperoxide, but hexanal and valeraldehyde are degraded by linoleic acid. The relative proportion of hexanal in TBR, on the other hand, was significantly reduced, possibly due to fat loss in brown rice during processing. Alcohols are produced during the oxidation of unsaturated fatty acids, and n-hexanol microstrips exhibit aromas of wine, fruit, and fat [30, 35]. Volatile alcohols also add to the taste of brown rice by emitting an odor. TBR includes ethyl acetate and butyl acetate, but their concentrations are insignificant. Brown rice esters are esters generated by low-grade fatty acids that have a distinct fruit taste. Esters have a very low

Figure 4: Photos of brown rice before and after cooking ((a, b) UBR; (c, d) germinated brown rice; (e, f) TBR).

Table 3: Gelatinization characteristics of brown rice flour after processing.

	Peak viscosity	Trough viscosity	Attenuation value	Final viscosity	Retrogradation value
UBR	3369 ± 5.32^a	2084 ± 2.98^a	1285 ± 5.36^a	3881 ± 12.65^a	1797 ± 8.65^a
TBR	3028 ± 4.36^b	2574 ± 3.26^b	454 ± 3.25^b	3785.5 ± 10.22^a	1211.5 ± 7.32^b

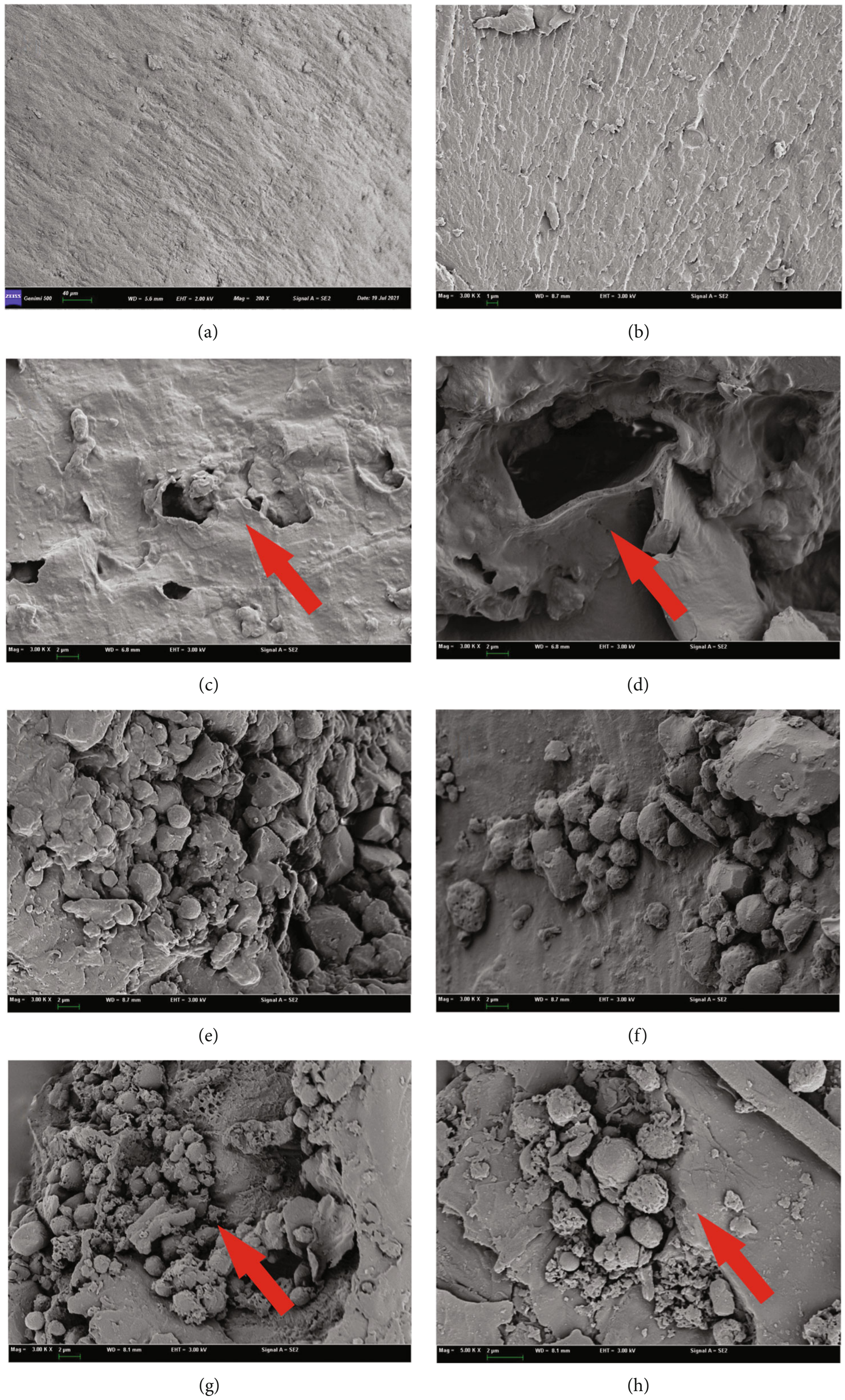

Figure 5: Microstructure observation of the surface structure of (a, b) UBR and (c, d) TBR. Microstructure observation of (e, f) UBR flour and (g, h) TBR flour.

threshold value and are significant taste components of brown rice. The relative proportion of ketones in germinated brown rice rose after precooking and freeze-drying, which might be a result of the Maillard reaction and amino acid breakdown during precooking, which produced a mostly fruit scent [36]. Aroma enhancement during brown

Table 4: Relative percentage content of important flavor compounds in brown rice.

Number	Compounds	Retention time	Smell characteristics	Relative percentage content/% UBR	TBR
	Aldehydes				
A_1	Pentanal	9.12	Fruity flavor	—	0.52
A_2	Hexanal	10.23	Grassy flavor	0.62	0.16
A_3	Heptanal	14.44	Fruity flavor	0.44	0.6
A_4	Nonanal	17.846	Citrus flavor	0.16	0.32
A_5	Decanal	20.36	Citrus flavor	0.35	0.48
	Alcohols				
B_1	Ethanol	6.78	Alcohol flavor	—	0.18
B_2	1-Butanol	3.85		3.92	4.36
B_3	2,3-Butanediol	11.06		2.65	6.32
B_4	1-Hexanol,2-ethyl-	19.06	Fruity flavor	0.77	1.38
B_5	1-Hexanol	13.26	Fruity flavor	0.47	0.69
B_6	1-Hexanol,2-ethyl-	19.06	Fruity flavor	0.28	—
	Terpenes				
C_1	2,4-Dimethyl-1-heptene	12.49		0.4	0.69
C_2	Alpha-Pinene	14.65	Pine terpene flavor	1.32	2.36
C_3	D-limonene	19.34	Lemon flavor	—	0.27
	Esters				
D_1	Ethyl acetate	7.91	Fruity flavor	—	0.26
D_2	Acetic acid, butyl ester	9.63	Fruity flavor	—	0.62
	Arenes				
E_1	Toluene	10.42		1.32	1.54
E_2	p-Xylene	13.56		—	0.58
	Ketone				
F_1	2-Heptanone	35.32	Flower flavor	0.44	0.86
F_2	Acetophenone	46.25	Fruity flavor	0.23	0.89

Note: (1) The result of relative percentage content is the ratio of material peak area to total peak area; (2) —: not detected.

rice processing was associated with an increase in total nonanal, ethyl acetate, and p-xylene concentrations. TBR's distinctive perfume is a result of the combined action of several volatile chemicals.

4. Conclusion

The purpose of this research is to determine the effect of microwave precooking, freezing, and drying on germinated brown rice used in the food industry. The prefreezing time, filler content, and freeze-drying time all had an effect on the rate of rehydration and sensory quality of germinated brown rice, whereas the solid-liquid ratio, power, and heating time all had an effect on the degree of gelatinization and sensory quality of germinated brown rice. Brown rice's nutritional quality was enhanced by microwave precooking and freeze-drying after germination. Cooked TBR has a lower hardness than uncooked TBR, making it easier to chew. After treatment, the surface of the rice grains becomes rough and porous, the internal structure becomes more porous, the water fluidity of brown rice is increased, and the cooking quality improves. Following brown rice germination, macromolecular compounds such as lipids, starch, and protein can be degraded by enzymes to produce precursors of fatty acids, soluble sugars, and amino acids that can be converted to volatile flavor compounds, further increasing the volatile flavor compound content after microwave precooking and freeze-drying. This article proposes novel ideas and ways for enhancing the quality of brown rice in order to increase its consumption.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Ethical Approval

Ethical approval was obtained from Jiangsu University of Science and Technology.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Authors' Contributions

Huanan Guan was responsible for the conceptualization, methodology, and validation. Yongcun Wu managed the methodology, validation, data curation, and writing. Xiaofei Liu carried out the conceptualization, methodology, and resources. All authors have seen and agreed with the contents of the manuscript.

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