Effect of high temperature cooking on the quality of rice porridge

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Abstract: In order to explore the effect of high-temperature cooking instant porridge on the taste and quality of porridge, this study explored the changes in the taste quality of rice porridge under different heating times (15 min, 20 min, 25 min and 30 min) at a higher initial temperature (100 ℃), and compared with that cooked at room temperature (25 ℃), and explained the reasons for the change.   From the perspective of migration rate in moisture content, the rice porridge with special treatment has a more rapid moisture change, which makes texture, whiteness, smell and other factors change in a shorter time and increases the taste quality.   It was concluded that under special treatment condition of starting with 100 ℃ water and heating for 15 min, the kinds of rice flavor increased 2.2 times, the white of rice decreased by 10.04%, hardness decreased by 3.54 times, and the elasticity decreased by 35.48% respectively.   In general, cooking with higher initial temperature (100 ℃) is more valuable than cooking from 25 ℃, in terms of the texture, flavor, saving time, and stable quality during the household and industrial production of instant porridge.
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1   Introduction

Rice is one of the most important staple foods in the world. Consumers in different regions have created a variety of rice cooking methods in daily life[1].   According to the amount of water added, cooking methods can be divided into excessive water cooking and absorption cooking.   Excessive water cooking refers to cooking rice grains in a large amount of water, followed with discarding part of the boiling water and the rest is placed above the fire to be partly absorbed by the rice and partly evaporated; or water is added to the rice about twice of the rice mass and then heated until the water is absorbed by the rice[2-4].   Unlike the treatment of rice in other countries, Chinese people usually add water about 20 times of rice weight and cook from environment temperature to make porridge.   In this process, since the output power of the heating device is constant, the process can be regarded as stable heating.   As the cooking progresses, the leached starch is first gelatinized and dispersed on the surface of the grains, which affects the diffusion of water in the rice grains, and affects the starch gelatinization of the core part of the whole rice, in turn the

hardness and the taste of the rice[5].   The importance of water migration has led many studies.   Zhu et al.[6] studied the water migration path and structuring role of water in rice grain during soaking, Tomita et al.[7,8] used a digital microscope to establish a low-cost visualization and quantification method for the rice soaking process, and further elaborated in comparison with NMR imaging.   The gelatinization of starch in rice will cause significant changes in eating quality, temperature and time are the direct influencing factors.   Li et al.[9] found that the starch gelatinization on the surface of rice grains is the key to reducing the viscosity of cooked rice.   Li et al.[10] studied the starch dissolution behavior of microboiled rice and found that the reduced viscosity of cooked rice may be due to the limited starch extraction behavior, i.e., stickiness was found to increase with decreasing amylose content in the whole grain, and, in the leachate, with increasing total amount of amylopectin, the proportion of short amylopectin chains, and amylopectin molecular size.   Balakrishna[11] studied the effect of HPP (high pressure processing) on the gelatinization of whole grain rice.

In addition, before gelatinization, during the soaking process, many researchers have found that different time and temperature will cause some physical changes in the rice[12,13].   High temperature immersion can hydrolyze the rice protein into free amino acids such as γ-amino butyric acid and serine, which can improve the nutritional quality[13,14], however high temperature soaking usually results in loss of solids and increases rice color[13]. At this stage, the research on rice is more focused on the changes of trace elements in rice[15], the effect of processing on starch in rice[16,17], and changes in the smell of rice bran during storage[18]. There is less research on rice porridge.   And with the rapid development of the food industry, more and more researches are focused on how to save processing time.   Using boiling water to cook porridge can quickly apply heat to the rice.   Compared with traditional rice porridge cooking, this method can save a lot of time

and is suitable for commercial production. So far, there has not been a theoretical analysis about the effect of boiling water on the texture of rice porridge and the sensory quality of the finished product. This study discusses the influence of high temperature on the eating quality of rice porridge, reveals the relationship between the texture, color, smell, moisture distribution and microstructure, and provides practice ideas about theoretical guidance and guidance for the industrial production of instant rice porridge and other grain products.

2   Materials and methods

2.1   Materials

Japonica rice (Jinjian Northeast Crystal Rice, Grade 2; moisture content 13.59% ±0.01%; protein content 6.2%±0.00%; carbohydrate content 78.9%±0.00%. The compositions were determined using the methods of GB 5009.3-2016, GB 5009.5-2016, GB/T 37493-2019, purchased from Yonghui supermarket (Haidian District, Beijing, China) in December, 2018 and stored in a bag at room temperature before examination. Test was conducted within two months following purchase.

2.2   Rice porridge cooking and sample preparation

100℃ constant temperature cooking: four 250mLbeakers with 200 mL boiling water and 10 g rice were heated on digital display heating magnetic stirrer for 15 min, 20 min, 25 min, 30 min, respectively.

Gradually raising temperature cooking: four 250 mL beakers with 200 mL of 25℃ water and 10 g rice were heated on a digital display heating magnetic stirrer for 15 min, 20 min, 25 min and 30 min, respectively.

2.3   Rice porridge whiteness and brightness measurement

After cooling at room temperature for 1 h, taking 2 g of cooked rice grains and draining the water, the whiteness index and brightness of rice were measured with a colorimeter CR-400 (Konica Minolta Sensor Company, Osaka, Japan). Four positions of the outer ring and four positions of the inner ring were taken for data collection, and recorded the parameters of luminosity (L^*), red-green ($+a^*/-a^*$) and yellow/blue ($+b^*/-b^*$). The whiteness index (W) calculation were performed using the following equation[19]:

$$W = 100 - [(100 - L^*)^2 + a^{*2} + b^{*2}]^{1/2}$$

2.4   Rice porridge Texture Profile Analysis (TPA)

Textural analysis of cooked rice was tested by a texture analyzer (Brookfield, USA) according to cooked rice grains (after cooled at room temperature for 2 h) were arrayed on the platform and tested. Textural analysis used a two-cycle compression program (TPA) and TPA parameters were as follow: strain 70%, pre-test speed/test speed/post-test speed were 1.0 mm/s, 0.5 mm/s and 1.0 mm/s, TA11/1000 cylindrical probe. Each sample was repeated 10 times.

2.5   Solid-phase microextraction gas chromatography-mass spectrometry (SPME/GC-MS) for rice porridge profiling

The 7890A-7000B gas-mass spectrometer equipped with EI ion source and NIST08 database (Agilent, U.S) was used to analyze the rice flavor volatiles. An extraction head (50/30 μm DVB/CAR/PDMS SPME fiber, Sulpelco, USA) was utilized for adsorption at 50℃ for 40 min and equilibration for 20 min. The desorption time and temperature were 4 min and 250℃ respectively. For gas chromatography-mass spectrometry, a DB-WAX capillary column (30 m×0.25 mm×0.25 mm, Supeleo, USA) was used for chromatographic separation. High-purity helium (99.9999%) as the carrier gas with a flow rate of 1.0 mL/min was selected. The program was initially set to 45℃

for 10 min, increased to 230℃ at a rate of 6℃/min, and then held for 6 min. The mass selective detector worked in 70 eV electron impact ionization mode, with a scanning range of 33 to 450 amu. The ion source temperature was 230℃ and the interface temperature was 250℃. The volatiles were identified by matching with the reference compound spectra in the NIST mass spectrometry library and the Wiley mass spectrometry library. The experiment was done in duplicate[20].

2.6   Low frequency nuclear magnetic resonance (LF-NMR) measurement

According to the method from Cheng et al.[21], the LF-NMR measurement was conducted using a nuclear magnetic resonance analyzer (NMI20-015V-I, Niumag Co., Ltd., Suzhou, China) with certain modifications. 2.0 g rice grains was taken for CPMG experiment, the parameters were set to: 21.3 MHz resonance frequency, magnetic field strength of 0.50 T, RF coil diameter of 15 mm, DRG1=3, SW=200 kHz, RG1=10.0 db, PRG=3, TW= 2000 ms, NECH=2500, TE=0.6 ms, P1=10.00 μs, P2=14.48 μs, SF=21 MHz, RFD=0.08 ms, NS=8.

2.7   Confocal laser scanning microscope (CLSM)

After a simple slice, samples were stained with 0.04% rhodamine and 0.4%FITC, and then placed in the CLSM (FV1200 Confocal/FLIM/FCS, Japan) for observation. The excitation/ emission wavelengths were 488/518 nm and 552/580 nm.

2.8   Porridge sensory evaluation

Sensory evaluation was required for each processed sample. The panel was composed of 10 members (5 males, 5 females, aged between 20 to30), the evaluation was conducted with reference to the national standard (GB/T15682-2008) with certain modifications. The sensory properties were determined from perspectives of fragrance, hardness, viscosity, whiteness and glossiness[22]. The samples were randomly provided to the group members and the subjects were asked to rinse their mouths thoroughly with purified water before each tasting. According to the corresponding importance degree, the score was divided into 0-15, where 0 point indicated that the sensory stimulation was the worst and 15 points meant the strongest stimulation.

2.9   Statistical analysis

Except for TPA, sample data were represented by average values. SPSS 24 software (SPSS, USA) was used for one-tailed ANOVA test and Duncan multiple test. The relationships between the total moisture content and LF-NMR parameters were investigated using the Pearson correlation coefficient by OriginPro 8 software (Origin Lab Corporation, MA, USA).

3   Results and Discussion

3.1   Porridge colorimetric analysis

The whiteness and brightness of rice porridge has a directly effect on consumers' choice, and the impact of processing conditions on the whiteness and lustrous should be fully considered during production. The results showed that the brightness and whiteness of rice porridge were significantly different under different heating time and processing methods (Table 1). With gradual temperature increase from 25℃, the brightness and whiteness of cooked rice in the porridge decreased. This phenomenon was the same as heating at 100℃. The only difference was that when heating at 100℃, the change in brightness and whiteness of rice grains was less obvious than heating at 25℃. And when comparing the two sets of data with the same heating time of 15 min, it was found that rice porridge heated at 100℃ appeared more non-whiteness. When the

conditions changed, the color gradually turned gray as the temperature increased which is consistent with Islam[23] research results. As the whiteness and brightness of the rice cooked decreased, the color was accompanied by a prominent yellow. Sila Bhattacharya[24] has similar results when studying the effects of high temperature and cooking time on the color of brown rice. This change may be due to the increased water absorption rate of rice as temperature increased, which increased the dissolution of reducing sugars and amino acids and accelerated the Maillard reaction[25, 26].

Table 1　Color parameters of rice porridge under different treatment conditions

Processing methods	Time /min	L^*	a^*	b^*	W
25 ℃	15	72.07±0.09[g]	−1.39±0.02[f]	0.32±0.00[h]	72.03±0.09[g]
	20	64.35±0.00[e]	−1.41±0.00[e]	−0.36±0.04[g]	64.32±0.00[e]
	25	63.85±0.11[d]	−1.97±0.01[d]	−1.48±0.01[d]	63.77±0.11[d]
	30	63.16±0.00[c]	−2.00±0.00[c]	−1.72±0.01[b]	63.07±0.00[c]
100 ℃	15	64.86±0.00[f]	−1.97±0.01[d]	−0.47±0.01[f]	64.80±0.00[f]
	20	62.01±0.00[b]	−2.07±0.01[b]	−1.35±0.00[e]	61.93±0.00[b]
	25	62.11±0.01[b]	−2.22±0.00[a]	−1.53±0.00[c]	62.01±0.01[b]
	30	60.74±0.00[a]	−2.22±0.00[a]	−2.02±0.02[a]	60.63±0.00[a]

Note: L^* is the lightness; W is the whiteness index; +a*/−a* are redness/greenness, +b*/−b* are yellowness/blueness; Data are expressed as mean ± standard deviation. Sample means with different lowercase letters in the same column are significantly different ($p \le 0.05$); the number of replications (n), $n \ge 8$.

3.2　Flavor analysis

Flavor is one of the most important quality indicators of rice products, which directly affects consumers' satisfaction, overall acceptance and the possibility of repeating purchases[27]. The flavor of rice products is not only related to the variety of rice[28], cooking methods are also an important factor that cannot be ignored[2]. More than 300 volatile compounds have been identified in various rice, including aldehydes, keto acids, esters, alcohols, hydrocarbons and heterocyclic compounds[27].

The content distribution of flavor substances is shown in Table 2, among all kinds of substances, aldehydes contributed most to the overall flavor. Previous studies have shown that aldehyde had a fruity aroma at very low concentrations, but increasing the concentration will produce an unpleasant smell of oil oxidation. Aldehyde is mainly derived from the oxidation of oil in rice bran, which is the product of oxidative degradation of oleic acid[20]. Ketones, aldehydes, and heterocyclic compounds are the reaction products produced at the final stage of the Maillard reaction. As Figure 1 shows, there are 11 kinds of compounds detected under initial temperature of 25 ℃ and 20 kinds of compounds detected when the initial temperature was 100 ℃, which can stimulate the aroma of rice more than 25 ℃, especially for aldehydes. The detail results are listed in Table 2. Besides, when the initial temperature was 100 ℃, the rice porridge emitted Alloaromadendrene, γ-muurolene and isocaryophyllene with woody aroma. In addition, Dodecane with alkane taste was also detected. It is speculated that the oil in the rice may have changed due to the rapid high temperature increase to produce oily taste, or c reaction produces by-products. This indicates that the rice structure has changed and needs to be further verified with a texture analyzer. Different from steamed rice, it is difficult to volatilize some water-soluble flavor factors due to the use of excessive water for cooking. Compared with steamed rice, the kinds and proportion of aroma molecules are less.

Table 2　Flavor of rice porridge with 25 ℃/100 ℃ initial cooking water

Flavor substances		15 min (25 ℃)	20 min (25 ℃)	25 min (25 ℃)	30 min (25 ℃)	Sensory perception
Aldehydes	Hexanal	9.203%	6.577%	6.804%	1.535%	grass, tallow, fat
Alcohols	1-hexanol	0.491%	--	0.476%	--	resin, flower, green
	Ethanol	--	--	--	0.150%	sweet
Ketones	2, 6-dimethyl-2, 6-undecadien-10-one	0.430%	0.468%	0.330%	--	magnolia, green
	6-methyl-5-hepten-2-one	--	--	0.388%	--	pepper, mushroom, rubber
Furan	2-pentylfuran, 2-n-amylfuran	--	2.562%	3.616%	--	green bean, butter
Other detected	Tetradecane	--	0.501%	--	--	alkane
	Undecane	--	0.087%	--	--	alkane
	(+)-(4R)-1-methyl-4-(1-methylethenyl) cyclohexene; (+)-carvene; D-1, 8-p-menthadiene, D-limonene	--	0.423%	--	0.390%	citrus, mint
	Tridecane	--	0.501%	--	--	alkane
	aromadendrene, [1ar-(1aalpha, 4aalpha, 7alpha, 7abeta, 7balpha)]-decahydro- 1, 1, 7-trimethyl-4-methylene-1H-cycloprop[e]azulene	--	0.481%	--	--	wood
Aldehydes	Hexanal	8.713%	2.800%	1.058%	2.152%	grass, tallow, fat
	Pentanal	0.268%	--	--	--	almond, malt, pungent
	2-methylbutanal	0.268%	--	--	--	cocoa, almond
	5-(hydroxymethyl)- 2-Furancarboxaldehyde, 5-hydroxymethyl-2-furfural	--	5.955%	--	--	cardboard
Alcohols	1-hexanol	0.491%	--	--	--	resin, flower, green
	Ethanol	0.351%	--	--	--	sweet
Ketones	2, 6-dimethyl-2, 6-undecadien-10-one	0.430%	0.197%	--	--	magnolia, green
	6-methyl-5-hepten-2-one	0.433%	--	--	--	pepper, mushroom, rubber
Furan	2-pentylfuran, 2-n-amylfuran	3.597%	1.466%	1.008%	--	green bean, butter

Flavor substances		Cooking method				Sensory perception
		15 min (25 ℃)	20 min (25 ℃)	25 min (25 ℃)	30 min (25 ℃)	
Other detected	Tetradecane	0.434%	--	0.537%	--	alkane
	Undecane	--	--	--	--	alkane
	(+)-(4R)-1-methyl-4-(1-methylethenyl) cyclohexene; (+)-carvene; D-1, 8-p-menthadiene, D-limonene	0.328%	0.159%	0.644%	0.286%	citrus, mint
	Tridecane	0.434%	0.380%	0.537%	--	alkane
	aromadendrene, [1ar-(1aalpha, 4aalpha, 7alpha, 7abeta, 7balpha)]-decahydro- 1, 1, 7-trimethyl-4-methylene-1H-cycloprop[e]azulene	0.405%	0.350%	--	--	wood
	Dodecane	1.495%	0.637%	--	--	alkane
	Alloaromadendrene	0.405%	--	--	--	wood
	γ-muurolene	0.405%	--	--	--	herb, wood, spice
	Isocaryophyllene	0.405%	--	--	--	wood
	β-selinene	--	0.350%	--	--	herb
	methyl-4-(1-methylethenyl) cyclohexene, p-mentha-1, 8-diene (mixture)	--	--	0.644%	--	lemon, orange

Note: The percentage in the figure refers to the ratio of the target compound odor to the total compound odor peak area; "--" means that the corresponding compound content is not detected.
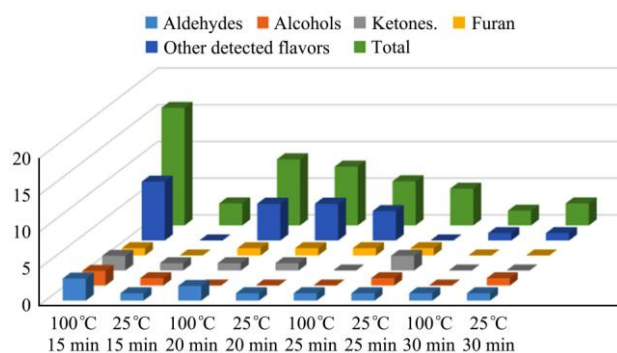

Figure 1   Amount and species of flavor compounds of cooked rice with different cooking methods

The flavor of rice porridge comes from the rice itself, oxidation during processing, and enzymatic reactions, etc. By comparing the different heating time, we can find that as the temperature increases, the flavor substances are gradually destroyed. Taking the aldehyde with obvious plant fragrance as an example, under the conditions of 25 ℃ treatment and 100 ℃ treatment, its percentage content gradually reduced.

When comparing the effects of different heating methods (25 ℃ and 100 ℃) on the flavor of rice porridge, it was found that heating for 15 min and 100 ℃ treatment conditions, the rice porridge volatilized more kinds of aroma substances, especially hydrocarbons and heterocyclic compounds with the aroma of plants, fruit, wood-scented, oils and fats. These mixed odors can bring a unique compound fragrance to the rice porridge, which could further affect consumers' choices.

3.3   The texture characteristics of rice porridge

As shown in Table 3, the TPA data clearly shows that, unlike the conventional 25 ℃ starting temperature cooking, 100 ℃ constant temperature cooking can significantly reduce the cooking hardness, improve the elasticity, and reduce the stickiness and chewiness. Compared with conventional cooking at 25 ℃, the hardness of rice porridge cooed at 100 ℃ was reduced by 71.7%, the elasticity increased by 35.5%, the adhesiveness decreased by 32.4%, and the chewiness increased by 20% at the same time for 15 min. When comparing the same treatment conditions, as the heating time increases, the hardness of the rice grains gradually decreased, and the change was significantly slower at 100 ℃ than 25 ℃. The elasticity of rice cooked at 100 ℃ and at the time of

15 min, 20 min, 25 min and 30 min increased by 35.5%, 39.1%, 44.2% and −11.9% respectively, compared with the porridge cooked from 25 ℃. Elasticity can be expressed as the initial compression that destroys the gel structure[8]. High elasticity usually manifests as the gel structure breaking into several large pieces during the first compression process, and the low elasticity is broken into many small pieces[29]. Compared with the size of the original rice grains, the rice grains absorb water and swell during the cooking process, the granules swell and break, and amylose leaches[30]. At higher temperatures, lower molecular weight amylopectin[31] may be extracted. The leaching amount of starch is a function of temperature, and the fine structure of amylose and amylopectin are related to the texture of rice[32,33]. It can be seen from formula[2] that when the absorbed heat is constant, the specific heat capacity of the same substance is stable, and when the starch in the rice is heavily dissolved, resulting in a decrease in the weight of a single grain of rice, the temperature inside and outside of the rice grain will change, which will further promote the rice starch gelatinization and uneven water distribution.

Table 3   Changes in the texture of rice porridge under different treatment conditions

Processing methods	Time /min	Hardness	Springiness	Cohesiveness	Chewiness
25 ℃	15	929.60±0.57e	0.31±0.00a	43.65±0.49d	0.20±0.01e
	20	213.00±0.00c	0.46±0.00c	30.00±0.00c	0.14±0.00c
	25	210.90±1.27c	0.52±0.01d	27.43±0.45b	0.13±0.01ab
	30	211.00±1.00b	0.59±0.01e	25.00±0.00a	0.13±0.00bc
100 ℃	15	262.65±0.35d	0.42±0.00b	29.50±0.36c	0.16±0.01d
	20	187.33±0.58a	0.64±0.01f	27.00±0.00c	0.13±0.01ab
	25	186.50±0.71a	0.75±0.00g	27.00±0.00c	0.12±0.01a
	30	188.20±1.13a	0.52±0.01d	25.15±0.21a	0.12±0.00ab

Note: Data were expressed as mean ± standard deviation. Sample means with different lowercase letters in the same column are significantly different ($p \leq$ 0.05).

Chewiness is another indicator to measure the taste quality of boiled rice, which has certain correlation with hardness. As can be seen from Table 3, under a single treatment condition, as the treatment time increases, the chewiness shows a significant downward trend, which is consistent with the change in hardness. Under 25 ℃ treatment conditions, from 15min to 20 min, the chewiness rate changes too fast, which is about 1.6 times the

change value of 100 ℃ under the same conditions.   When heated for 15 min at 25 ℃, due to the small amount of starch gelatinization, the rice cooked under this condition have great hardness, poor taste, continuous heating, reduced hardness, decreased cohesiveness, serious starch dissolution, and damaged rice cooked structure. When cooking for 30 min, both the initial temperature 25 ℃ and 100 ℃ showed similar results with hardness, cohesiveness, chewiness tend to be stable.   It is guessed that within a certain volume, the structure of rice will be destroyed and starch will dissolve seriously.   With the water evaporating gradually, the dissolved starch adheres to the surface of the rice and sticks to each other, which affects the flavor and improves the taste.   By comparison, heating for 15 min at 100 ℃, the rice cooked in the rice porridge have moderate hardness, elasticity, stickiness and chewiness.   Therefore, the processing method and heating time should be fully considered when processing rice.

3.4   Moisture distribution in rice grains during cooking

The maintenance of the shape of rice grains is related to the distribution and proportion of water molecules in the rice grains. Rice with different moisture distributions has very different tastes.

During the cooking process, the starch on the surface of the grain is first gelatinized and then dispersed in excess water.   Due to the continuous penetration of water, the structure of the rice is destroyed and the adhesiveness is reduced.   Especially as the cooking time increases, the water diffusion becomes more intense, and the rice grains have changed more significantly.   Changes in the distribution of water cause changes in the palatability of rice porridge, which is also consistent with the analysis of TPA.

The T_2 value of the inversion spectrum is T_{21} (0.1-2 ms), T_{22} (2-20 ms) and T_{23} (20-1000 ms).   The change of T_2 value may be closely related to the change of microstructure[34].   The state of water molecules existing in the starch-protein gel skeleton can be reflected by the T_{21} parameter. T_{23} can reflect the state of free-flowing water molecules in the large voids and large grids in the microstructure, and T_{22} can reflect the degree of water molecule changes binding between the two.   The length of time T_2 represents the ease of migration of water molecules under certain circumstances.   The shorter the time, the more difficult it is to migrate water[35], and make the rice structure more complete during cooking[34].

It can be seen from Table 4 that with the change of the heating time, the time of T_{21} gradually becomes longer, which indicates that the protons in the starch-protein structure that are not easy to flow have exchanged with the external water molecules.   As the time becomes longer, the proton exchange becomes longer.   The rice grain structure is destroyed and the original grain structure cannot be maintained, showing the collapse of the grain[36]. Unlike cooking at 100 ℃, in Figure 3 we can see clearly the changes in the moisture content of water in different treatments.

It can be found from Table 4 that the free-flowing water content under the conditions of 100 ℃ for 15 min of heating is significantly higher than that under the conditions of 25 ℃.   The same result can also be seen from the trend after T_{23} in Figure 2a.   Combined with Table 4 and Figure 2, we find that with the increase of heating time, T_{21} gradually becomes larger, indicating that the effect of external temperature has affected the exchange of moisture inside the rice grains at this moment, so that the water molecules inside the rice grains and the macromolecules migrate, the rice grains rupture.   At the same time of water exchange, it causes the starch to dissolve and produce a substance with a characteristic flavor of rice.   While improving the flavor, it might accelerate the Maillard reaction, deepen the color and change the hardness, which deeply affect the consumer's choice of rice porridge eating quality.

3.5   Starch−protein framework

According to previous reports, both protein and starch interact with water at high temperature, causing starch gelatinization and protein thermal denaturation.   Due to the different distribution of protein in starch, starches that are adjacent to the protein are more likely to contact water than starches that are farther away, and gelatinize first, thereby affecting the taste quality of rice[37]. When using excess water to cook, the rice can be more easily combined with water, gelatinize faster, and make the rice softer. In order to understand the effect of initial temperature on starch and protein of whole rice grains, starch-protein framework in cooked rice were visualized for further study.

As shown in the Figure 3, under the treatment condition of 25 ℃, the degree of protein denaturation gradually increases with the increase of cooking time, causing serious damage to the starch-protein backbone.   During the whole process, the protein in the mesenchymal endosperm cells is first denatured when heated, and the three-dimensional network structure formed by disulfide bonds surrounds the amyloid, preventing the gelatinization of the inner starch[38], which affects the distribution of flavor substances and reduces the quality of eating.   When the heating time was extended, water entered quickly, starch gelatinization was sufficient, starch-protein skeleton was seriously damaged, and rice porridge began to become sticky.   This change can be verified from the changes in TPA.   When the initial temperature was 100 ℃, as shown in Figure 4, the outer protein that first absorbed water was rapidly denatured, and the formed network structure made it difficult for water to enter, making the T_{21} value longer, the outer protein and starch were completely thermally denatured, the Maillard reaction intensified and emitted more aroma, while increasing the color of rice.   This result is consistent with the whiteness and GC-MS results.   As time increased, under high temperature conditions, the inner layer of starch gelatinizes, water entered quickly, and the starch-protein structure was completely destroyed, making less difference between the two treatments.

Table 4   Moisture distribution of rice grains in rice porridge under different treatment conditions

Processing method	Time/min	T_{21}/ms	A_{21}/%	T_{22}/ms	A_{22}/%	T_{23}/ms	A_{23}/%
25 ℃	15	0.91 ±0.15[a]	17.76 ±1.12[c]	9.18 ±1.49[ab]	5.71 ±0.01[a]	54.00 ±0.00[a]	76.52 ±1.13[a]
	20	1.35 ±0.18[bc]	7.18 ±0.14[ab]	9.61 ±1.56[ab]	3.81 ±1.91[a]	78.16 ±0.00[c]	89.01 ±2.05[a]
	25	1.47 ±0.00[bc]	5.25 ±0.31[a]	12.32 ±0.80[abc]	4.50 ±0.07[a]	89.88 ±5.87[de]	90.25 ±0.24[a]
	30	1.50 ±0.05[c]	6.61 ±0.67[ab]	11.77 ±0.77[abc]	3.93 ±0.17[a]	87.75 ±2.87[de]	89.46 ±0.83[a]
100 ℃	15	1.09 ±0.35[ab]	7.34 ±1.45[ab]	8.71 ±0.28[a]	3.98 ±0.96[a]	66.51 ±2.17[b]	88.69 ±0.49[a]
	20	1.41 ±0.09[bc]	6.35 ±0.45[ab]	12.03 ±0.39[abc]	4.70 ±0.17[a]	81.94 ±5.35[cd]	88.94 ±0.62[a]
	25	1.47 ±0.00[bc]	8.41 ±1.80[b]	12.76 ±2.89[bc]	4.07 ±0.85[a]	91.90 ±3.00[e]	87.52 ±2.64[a]
	30	1.47 ±0.00[bc]	5.35 ±0.72[a]	13.56 ±1.77[c]	4.35 ±0.97[a]	91.90 ±3.00[e]	90.30 ±0.25[a]

Note: Data were expressed as mean ± standard deviation.   Sample means with different lowercase letters in the same column are significantly different ($p \leq 0.05$).

a. Initial temperature of 25 °C/100 °C for heating 15 min

b. Initial temperature of 25 °C/100 °C for heating 20 min

c. Initial temperature of 25 °C/100 °C for heating 25 min

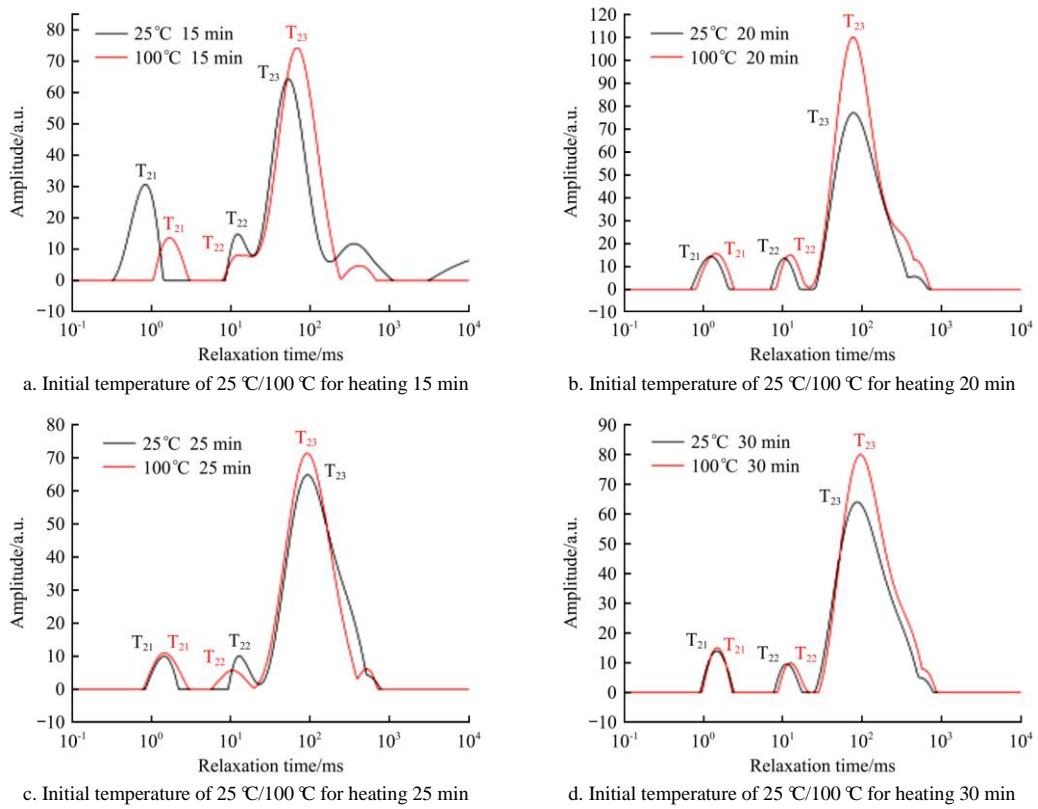d. Initial temperature of 25 °C/100 °C for heating 30 min

Figure 2   Distribution of water content of rice grains in rice porridge at different relaxation time under different treatment methods
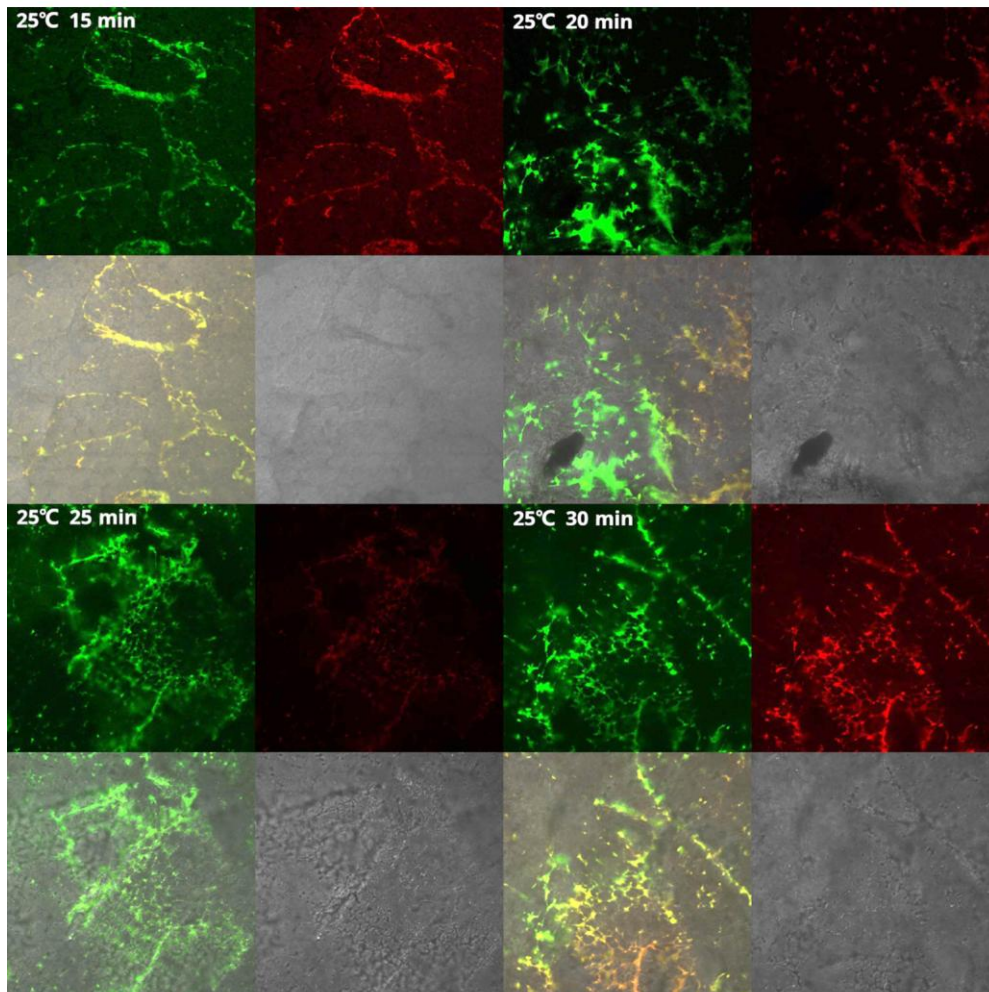

Figure 3   Starch-protein framework of cooked rice from 25 °C by CLSM (There are four schematic diagrams under the same processing time, from top to bottom representing the structural damage of protein and starch under different wavelengths)
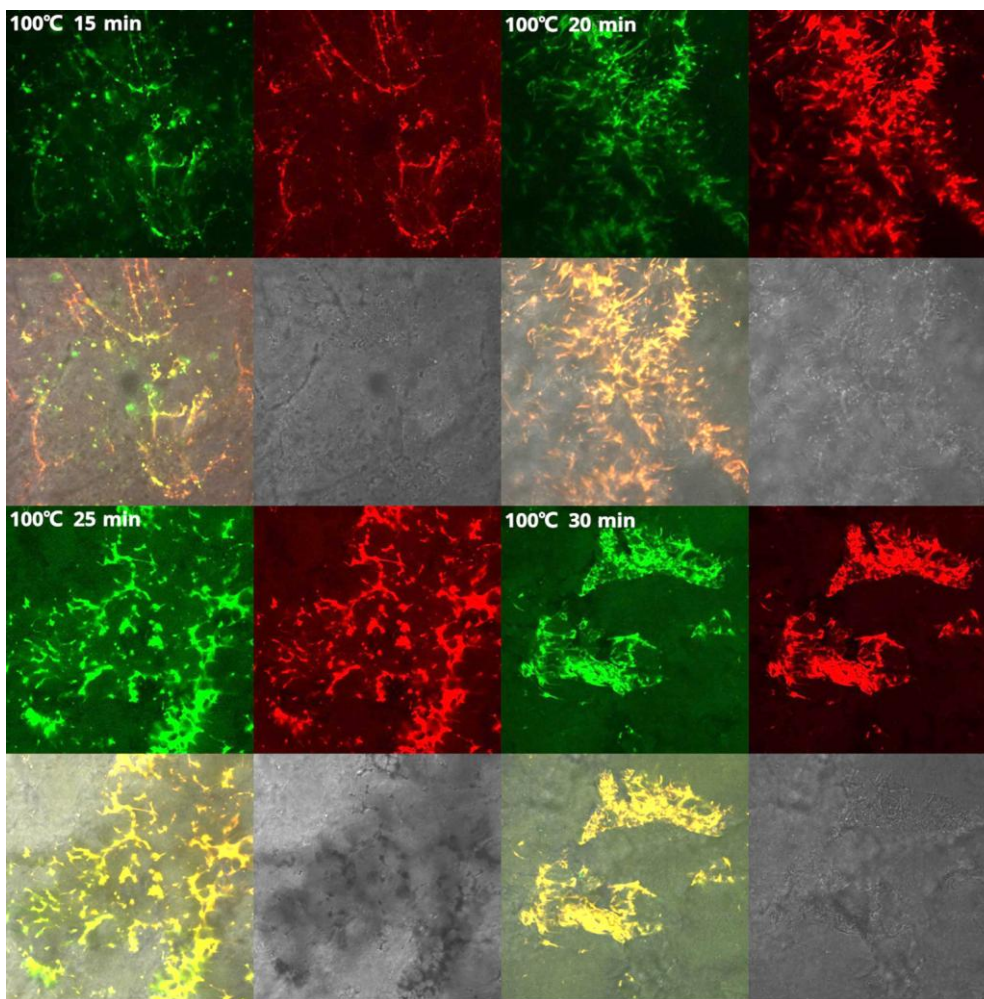
Figure 4   Starch-protein framework of cooked rice under 100 ℃ by CLSM (There are four schematic diagrams under the same processing time, from top to bottom representing the structural damage of protein and starch under different wavelengths)

3.6   Sensory evaluation

Ten members of the sensory evaluation team conducted sensory evaluations on the two treatment methods of a total of 8 samples.   The results are shown in Figure 5.   The evaluation was carried out from five aspects of odor, hardness stickiness whiteness and glossiness.   The evaluation results showed that porridge hardness was the highest when treated with 25 ℃ initial cooking water for 15 min, but its aroma was far inferior to that treated at 100 ℃ for 15 min.   In the sensory evaluation experiment, it was found that the longer the heating time, the lower the score.   In addition to the effect of texture factors on the taste, the significant reduction of aroma components is also an important factor.   The

sensory evaluation was consistent with the results obtained by GC-MS, with the best odor when treated at 100 ℃ for 15 min. The results of whiteness and glossiness showed that the higher temperature and longer heating time were, the darker the rice was. The sensory evaluation results were consistent with the colorimetric results (as shown in Table 1), indicating that Maillard reaction could have a great influence on the color change of rice products.   From the sensory evaluation index, it can be seen that the results were consistent with the statistical results of the test data. The total score showed that the rice porridge produced at 100 ℃ for 15 min was preferred by the consumer.

4   Conclusions

This study clearly shows that the color, texture, moisture distribution, micro structure and flavor of cooked rice porridge were affected by cooking conditions.   On this basis, sensory evaluation was used to further verify and improve the reliability of the research.   By comparing rice porridge products under different treatment conditions at 25 ℃ and 100 ℃, it was found that heating at 100 ℃ for 15 min can stimulate the release of more aroma substances, accelerate the maturation of rice grains, and profoundly change the taste of rice porridge.   In addition, the results of low frequency nuclear magnetic resonance and CLSM revealed the influence of water distribution on texture, color and smell.   The temperature change caused by the dissolution of starch affected the speed of water entering the rice grains, and further influenced the distribution of water in the rice grains, resulting in the destruction
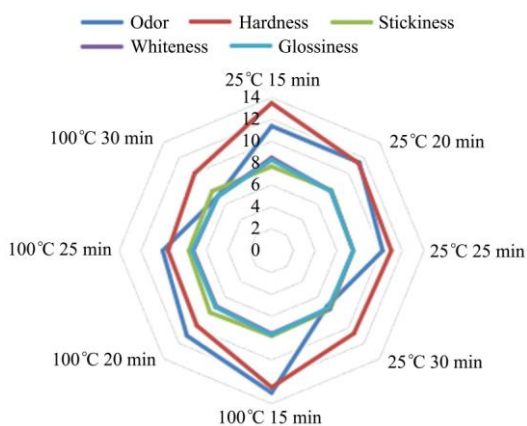

Figure 5   Sensory evaluation score of rice porridge

of the microstructure of the rice grains and changing the taste of the porridge. These findings indicate that cooking rice porridge at 100 ℃ can effectively improve the palatability of rice porridge and effectively shorten the processing time. Further research is needed to verify whether instant rice porridge with high palatability can be produced in a relatively short time under the industrial production scale.

Acknowledgements

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