Pasting, cooking, and digestible properties of Japonica rice with different amylose contents

Wei Zhang, a,b, Yuxuan Liu, a Xianli Luo, a and Xuefeng Zeng c

aCollege of Food Science and Engineering, Wuhan Polytechnic University, Wuhan, China; bKey Laboratory for Deep Processing of Major Grain and Oil (Wuhan Polytechnic University), Ministry of Education, Wuhan, China; cSchool of Liquor and Food Engineering, Guizhou University, Guiyang, China

ABSTRACT
Pasting, cooking, and digestible properties of Japonica rice with different amylose contents were investigated. Low-, medium-, and high-amylose Japonica rice (waxy, 18.8% amylose content, and 33.3% amylose content) were cooked and evaluated for water absorption, volume expansion, molecular mobility, microstructure, crystalline structure, and starch digestibility. The results showed that high-amylose rice had lower peak viscosity but higher pasting temperature and final viscosity than low- and medium-amylose rice. After cooking, high-amylose rice showed slightly higher water absorption ratio but lower volume expansion ratio than the other two rice varieties. Water was more evenly distributed in cooked low- and medium-amylose rice than in cooked high-amylose rice. After cooking, starch in low- and medium-amylose rice kernels almost lost the entire crystalline structure, but starch of cooked high-amylose rice still exhibited strong V-type crystallinity. Cooked high-amylose rice contained higher content of resistant starch than cooked rice of other two varieties.

Introduction
Rice (Oryza sativa L.) is one of the most significant grains and serves as a staple food source for more than three billion people all around the world. Asia is the world’s largest producing and consuming region of rice. Indica and Japonica are the two major subspecies of Asian cultivated rice. Indica rice, featured by long and thin grains, is the major type of rice grown in the tropics and subtropics, for example, central and southern China, Thailand, and India. Japonica rice, usually with short and round grains, is mainly distributed in the temperate and cooler zones, for example, northern and eastern China, Japan, and Korea.

As staple grains, rice is primarily consumed as intact kernels after cooking. Upon cooking of rice, water migrates from the surface of kernel to the interior layer and moistened starch granules gradually gelatinize under the action of heat. Starch gelatinization resulted in the volume expansion of rice kernels, leading to the softening of the rigid kernels. Rice can then be edible and the included starch becomes prone to enzyme hydrolysis.

Amylose content is one of the key factors influencing the physicochemical and digestible properties of rice starch, which can further affect the quality of rice. Varavinit et al. found that the low-amylose rice starch (Thai rice) had higher peak viscosity and lower setback viscosity than medium- and high-amylose starches. Zhou et al. reported that amylose content was positively correlated with resistant starch (RS) content of Indica rice starch. Pang et al. reported that rice containing high level of amylose tend to have a low gelatinization temperature. Singh et al. reported that rice (India cultivars) with high amylose content required less time for cooking and had a hard texture. Li et al. found that Indica rice starch containing more amylose normally had a slower digestion rate.
Starchy foods with high-amylose contents are promising food ingredients for calory-reduced foods. Amylose content of *Japonica* rice was generally lower than 20%. To date, there have been few systematic researches reported on properties of *Japonica* rice with amylose content above 20%. In recent years, many novel high-amylose *Japonica* varieties have been bred with the development of breeding technology.\[12\] In previous research, our team compared the properties of starch of a high-amylose *Japonica* rice (33.3% amylose content) with starches of low- and medium-amylose varieties (waxy and 18.8% amylose content), and found that starch of the high-amylose rice had higher pasting temperature and RS content, but lower peak viscosity, breakdown viscosity, and swelling power than starches of other two rice varieties.\[13\] This research aimed to investigate the differences of the three *Japonica* rice in pasting, cooking, and digestible properties. This research can provide fundamental reference for the development of functional cereal products and the breeding of application-specific rice varieties.

**Materials and methods**

**Materials**

Low- and medium-amylose *Japonica* rice (waxy; variety Taihunuo; medium-amylose; variety Huai5) were obtained from a local grain trader (Hubei, China). High-amylose *Japonica* rice (variety Jiangtangdao1) was kindly supplied by Shanghai Academy of Agricultural Sciences (Shanghai, China). Total starch assay kit and glucose oxidase/peroxidase (GOPOD) kit were purchased from Megazyme International Ireland Ltd. (Bray Co., Wicklow, Ireland). Porcine pancreatic α-amylase (P7545), pepsin (P7000), and amyloglucosidase (A7095) were obtained from Sigma Chemical Co. (St. Louis, Mo., U.S.A.). Other chemical reagents were of analytical grade without otherwise stated.

**Proximate analysis**

The total starch content of rice was determined enzymatically (AACC method 76–13.01) using the total starch assay kit from Megazyme International Ireland Ltd. (Wicklow, Ireland). The amylose content of rice was determined according to the method of Lin et al. \[14\] The protein content of rice was determined by AOAC 992.23. The fat content of rice was determined according to AACC Method 30–20.01.

**Pasting property measurement**

A rapid visco-analyzer 4 (RVA-4) (Newport Scientific, Warriewood, New South Wales, Australia) was used to analyze the pasting properties of rice flours. Rice flours (3.0 g, dry weight) was weighed exactly into an RVA canister, and distilled water was added to make a total weight of 28 g. The suspensions (12% w/w) were equilibrated at 50°C for 1 min, heated at a rate of 12°C/min to 95°C, maintained at 95°C for 2.5 min, cooled at a rate of 12°C/min to 50°C, and then held at 50°C for 1.5 min. The speed of the mixing paddle was 960 rpm for the first 10s and then 160 rpm for the remainder of the experiment.

**Cooking process of rice**

Rice (20 g) was washed thoroughly in water at ambient temperature. The washed rice was soaked in distilled water (1.3 volume folds of rice) for 10 min before cooking. Rice was steamed using an electronic rice cooker (MG-TH559, Foshan Shunde Median Home Appliance Co. Ltd., Foshan, Guangdong, China).
Determinations of water absorption ratio (WAR) and volume expansion ratio (VER) of rice after cooking

Cooked rice samples were blotted with filter paper to remove surface water and then weighed. An increase in its weight was calculated. The WAR of rice was expressed as weight of water adsorbed by one gram of raw rice in dry basis. The volumes of both raw and cooked rice were measured. The VER of rice was expressed as the ratio of the volume of cooked sample to that of raw sample.

Low-field nuclear magnetic resonance (LF-NMR) measurement

Proton distributions were measured with a NMI20-040 V–I LF-NMR analyzer (Niumai Instruments, Suzhou, China). Cooked rice grains at different cooking durations were collected and rapidly transferred into sample bottles. The sample was balanced at 25°C for 20 min before measurement. The transverse relaxation (T2) curves were measured using the Carr-Purcell-Meiboom-Gill pulse sequence (CPMG). The experimental parameters were set as follows: SW = 200 kHz (Receiver bandwidth), TW = 2000 ms (Repeat sampling wait time), RGI = 15 db (Analog gain), DRGI = 3 (Digital gain), PRG = 3 (Pre-amplifier gain), NECH = 10000 (Number of echoes), TE = 0.1 ms (Echo time), and a total of 16 scans.

X-ray diffraction (XRD) analysis

Cooked rice samples were frozen with liquid nitrogen and then freeze dried. The dried rice was ground to flour, which pass through 100-mesh screen. The dried kernels were used as sample for scanning electron microscopy (SEM). The rice flours were used for analyses of XRD and in vitro starch digestibility. The crystalline structure of cooked rice flours was analyzed using an X-ray diffractometer (PANalytical B.V., Almelo, The Netherlands) equipped with Cu radiation at 30 kV and 30 mA. All samples were scanned over an angular range of 3–40° at a step size of 0.02.

Scanning electron microscopy (SEM)

Cooked rice kernels were obtained upon freeze drying using liquid nitrogen and carefully fractured into halves. Samples were fixed on aluminum specimen stubs, sputtered with gold, and then observed by SEM (S-3000 N, Hitachi High-Technologies Corp., Tokyo, Japan).

In vitro starch digestibility

Starch digestibility of rice was analyzed according to the method described by Englyst et al.[15] with minor modifications. Porcine pancreas α-amylose (3.6 g) was dispersed in water (32 mL) by magnetic stirring for 5 min. The dispersion was then centrifuged for 10 min at 10,000 × g, and a portion of the supernatant (21.6 mL) was transferred to a beaker. Amyloglucosidase (2.56 mL) was diluted to 3.2 mL, and the diluted amylglucosidase solution (2.4 mL) was then added to the beaker of α-amylose solution to make an enzyme mixture. The mixed enzyme solution was freshly prepared for the digestion analysis.

Cooked rice flours (100 mg, dry weight) was added to polypropylene screw-capped centrifuge tubes. Then, pepsin (0.01 g) and HCl (0.025 mol·L−1, 2 mL) were mixed into each tube, followed by incubation in a water bath (37°C) with agitation (150 rpm) for 30 min. Five milliliter of sodium acetate buffer (0.5 mol·L−1, pH 5.2) were added to each tube. The tubes with cooked rice flour samples were incubated at 37°C in a shaking water bath. Following this, 1 mL of the enzyme mixture (α-amylose and amyloglucosidase) were added, and the mixture was shaken at 150 rpm in a water bath at 37°C. After 20 and 120 min of incubation, the hydrolyzate (0.1 mL) was collected, which was added with 4 mL of 95% ethanol to stop the reaction. The amount of released glucose was determined using a glucose oxidase assay kit. The glucose content of the
enzymatic hydrolyzates at 0, 20, and 120 min of hydrolysis was determined to calculate the rapidly digestible starch (RDS, digested within 20 min), slowly digestible starch (SDS, digested between 20 and 120 min) and resistant starch (RS, undigestible starch after 120 min).

**Statistical analysis**

Data are averages of duplicate determinations. One-way analysis of variance (ANOVA) and Tukey’s test (p < .05) were evaluated using the SPSS 25.0 Statistical Software Program (SPSS Inc., Chicago, IL, USA).

**Results and discussion**

**Chemical composition of raw rice**

The chemical compositions of low-, medium-, and high-amylose rice are shown in Table 1. There were slight differences among the three varieties in chemical composition of rice. High-amylose rice contained slightly higher levels of starch, protein, and fat than the other two varieties. Compared with low-amylose rice, medium-amylose rice showed a slight decrease in fat content, but the two rice varieties did not show significant difference in protein and starch contents.

**Pasting property of raw rice**

The pasting curves of low-, medium-, and high-amylose rice are shown in Figure 1, and their pasting parameters are shown in Table 2. Pasting temperature (PT) of high-amylose rice was higher than those of low- and medium-amylose varieties. This result was in agreement with our previous research in starch.\[^{13}\] The increase of amylose content can enhance the stability of starch granules, resulting in the delaying of gelatinization.\[^{16}\] The peak viscosity (PV), trough viscosity (TRV), and breakdown viscosity (BDV) of high-amylose rice was lower than two other rice. Park et al.\[^{17}\] suggested that amylose-rich starch was more resistant to swelling, thus showing a lower pasting viscosity. Similarly, final viscosity (FV) and setback viscosity (SBV) of high-amylose rice were significantly lower than those of medium-amylose rice. However, compared with low-amylose rice, high-amylose rice exhibited an increase in FV and SBV. This result might be due to the different retrogradation behaviors of starches of the two rice varieties. It is well accepted that amylose-rich starch is more readily to retrograde than amyllopectin-rich starch.\[^{18}\]

**Water absorption and volume expansion of rice during cooking**

The WARs and VERs of low-, medium-, and high-amylose rice during cooking are shown in Figure 2. All three varieties of rice exhibited great increase in WAR and VER at the initial cooking stage (0–10 min). This would be attributed to the sharp swelling of starch granules immediately upon high-temperature heating. As cooking duration increased from to 10 min to 30 min, only slight changes in WAR and VER were observed for all three rice varieties. After the whole cooking process, the high-amylose rice showed slightly higher WAR value but lower VER value than the other two rice varieties.

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**Table 1. Chemical components of low-, medium- and high-amylose Japonica rice**

| Rice variety | Moisture (%) | Starch (%) | Amylose (%) | Protein (%) | Fat (%) |
|--------------|--------------|------------|-------------|-------------|---------|
| Low-amylose  | 11.5 ± 0.1[^a] | 80.97 ± 0.10[^a] | - | 7.63 ± 0.05[^a] | 1.98 ± 0.03[^b] |
| Medium-amylose | 13.1 ± 0.1[^b] | 80.77 ± 0.24[^b] | 18.8 ± 0.23[^b] | 7.80 ± 0.05[^a] | 1.46 ± 0.08[^a] |
| High-amylose | 13.2 ± 0.1[^b] | 82.33 ± 0.25[^b] | 33.3 ± 0.42[^b] | 8.29 ± 0.20[^b] | 2.46 ± 0.04[^b] |

[^a]All data represent the mean of triplicates. Values in each column with different superscripts are significantly different (p < 0.05).
The relatively lower kernel expansion of high-amylose rice during cooking could be associated with the swelling behavior of starch granules. As reported, starch rich in amylose was more resistant to swelling since amylose can enhance the stability of granules.\cite{16,17}

**Molecular mobility of water and components in rice kernels**

The proton distributions of uncooked and cooked low-, medium-, and high-amylose rice are shown in Figure 3. According to the difference in transverse relaxation time ($T_2$), the $T_{21}$ population was assigned to the limited exchanging protons of starch and protein; $T_{22}$ and $T_{23}$ were linked to the exchanging protons in the intra-granular and extra-granular space, respectively; $T_{24}$ mainly consisted of protons of bulk water and soluble substance.\cite{19} For all three rice varieties, uncooked rice exhibited similar distribution of water, with more distribution of $T_{22}$ peak and less distributions of $T_{21}$ and $T_{23}$ peaks. After cooking, $T_{21}$ and $T_{22}$ peaks merged to a peak. Zhu et al.\cite{19} suggested that the swelling and gelatinization of starch during cooking affected the mobility of water and biopolymers, resulting in the shift of peaks. After cooking, the total areas of peaks significantly increased. This can be attributed to the absorption of water during cooking. The area percentage of $T_{23}$ peaks of cooked high-amylose rice (87.6%) were significantly higher than cooked low-amylose (81.2%) and medium-amylose rice (83.5%). Compared with low- and medium-amylose starches, the increased amylose of high-amylose starch would inhibit granules from swelling, leading to the decrease of exchanging protons in intra-granular space.
Figure 2. WAR and VER of *Japonica* rice during the cooking process. (A) low-amylose rice; (B) medium-amylose rice; (c) high-amylose rice. WAR: water absorption ratio. VER: volume expansion ratio.
Figure 3. Proton distributions of uncooked and cooked *Japanica* rice. (A) low-amylose rice; (B) medium-amylose rice; (c) high-amylose rice.
Microstructure of cooked rice

The inner structure of three varieties of rice was photographed by SEM (Figure 4). For all three rice cultivars, the inner part of raw kernel was compact. After cooking, evenly distributed pores were observed in the grains of low- and medium-amylose cultivars. Similar results were reported by Leelayutsoontorn and Thipayarat\textsuperscript{20} and Ghasemi et al. \textsuperscript{21} Li et al.\textsuperscript{22} suggested that the pore structure of cooked rice was attributed to the penetration of water along with the gelatinization of starch. High-amylose rice showed different inner structure from low- and medium-amylose rice in inner structure of cooked kernel. After cooking, high-amylose rice only exhibited cracks or fissures rather than pores. The high amount of amylose content can restrain the granules from swelling, resulted in the unevenly penetration of water into the cooked kernel.

Crystallinity structure of cooked rice

XRD patterns of flours of cooked rice are presented in Figure 5. Flours of uncooked low- and medium-amylose rice exhibited peaks at 2θ angles of 15.0, 17.0, 17.9, and 23.0°, indicating that the included starches were of A-type crystalline structure.\textsuperscript{23} However, flour of uncooked high-amylose rice exhibited characteristic peaks at 2θ angles of 5.6, 15.0, 17.0, 20, and 23°, suggesting a C-type crystalline structure of the contained starch.\textsuperscript{24} Flours of cooked low-amylose rice shows an amorphous pattern.

Figure 4. SEM images of uncooked and cooked Japonica rice. (A) low-amylose rice; (B) medium-amylose rice; (c) high-amylose rice.
Figure 5. XRD patterns of uncooked and cooked Japonica rice. (A) low-amylose rice; (B) medium-amylose rice; (c) high-amylose rice.
Table 3. RDS, SDS, and RS contents of starch in uncooked and cooked low-, medium-, and high-amylose Japonica rice.

| Cooking duration | RDS (%)   | SDS (%)   | RS (%)   |
|------------------|-----------|-----------|----------|
| 0 min            |           |           |          |
| Low-amylose      | 17.63 ± 0.35<sup>a</sup> | 16.22 ± 0.50<sup>a</sup> | 66.15 ± 0.21<sup>a</sup> |
| Medium-amylose   | 18.74 ± 0.57<sup>b</sup> | 13.21 ± 0.30<sup>b</sup> | 68.04 ± 0.41<sup>b</sup> |
| High-amylose     | 20.67 ± 0.39<sup>c</sup> | 5.12 ± 0.14<sup>c</sup> | 74.21 ± 0.23<sup>c</sup> |
| 30 min           |           |           |          |
| Low-amylose      | 80.45 ± 0.54<sup>c</sup> | 16.57 ± 0.34<sup>c</sup> | 2.98 ± 0.11<sup>c</sup> |
| Medium-amylose   | 53.03 ± 0.33<sup>b</sup> | 43.72 ± 0.31<sup>c</sup> | 3.24 ± 0.06<sup>b</sup> |
| High-amylose     | 17.41 ± 0.16<sup>c</sup> | 40.19 ± 0.20<sup>b</sup> | 42.40 ± 0.51<sup>b</sup> |

<sup>†</sup> All data represent the mean of triplicates. Values in each column with different superscripts are significantly different (p < 0.05). RDS: rapid digestible starch. SDS: slowly digestible starch. RS: resistant starch.

This suggested that crystalline structure of starch in low-amylose rice kernels was completely destroyed after the cooking process. Similar to low-amylose rice, flours of medium-amylose rice lost most of the crystalline structure after cooking, but showed two small peaks at 20° angles of 13 and 20°, representing the V-type crystallinity of amylose-lipid complexes. After cooking, flour of high-amylose rice cultivar exhibited a pronounced decrease in peak intensities of 5.6, 15.0, and 23°, but showed a new peak at 13° and an increase in peak intensities of 20°. These results suggested that cooking only partly damaged the crystalline structure of high-amylose rice, and amylose-lipid complex can be formed after cooking.

Starch digestibility of cooked rice

RDS, SDS, and RS contents of uncooked and cooked rice are presented in Table 3. For uncooked rice, high-amylose rice contained higher proportions of RS and RDS contents than low- and medium-amylose rice. The RDS, SDS, and RS contents of uncooked rice samples were in the ranges of 17.63–20.67%, 5.12–16.22%, and 66.15–74.21%, respectively. For low- and medium-amylose rice, RS content of starch sharply decreased and RDS content greatly increased after cooking. This result can be due to the gelatinization of starch during the cooking process. The RS content of high-amylose rice decreased, but the decrease ratio was significantly reduced compared with other two rice varieties. After the whole cooking process, the RS contents of starch in low- and medium-amylose rice were 3.24% and 2.98%, respectively; while, for high-amylose rice, the RS content of starch was still high at 42.40%. The high RS content of starch in cooked high-amylose rice might be due to the generation of amylose-lipid complex and un-entirely gelatinized starch.

Conclusion

High-amylose rice had higher pasting temperature and lower peak viscosity than low- and medium-amylose rice. After cooking, high-amylose rice had a slight increase in volume expansion and a slight decrease in water absorption compared with other two rice varieties. Water penetrated well in low- and medium-amylose rice during cooking, but was unevenly distributed in high-amylose rice. The crystalline structure of starch in low- and medium-amylose rice kernels were seriously destroyed by the cooking process, but starch of high-amylose rice exhibited strong V-type crystallinity after cooking. Cooked high-amylose rice contained 42.40% of resistant starch, much higher than those of other two cooked rice. The unique cooking property of high-amylose Japonica rice can be utilized to develop functional foods. Further research work will be done on the cooking performance of the high-amylose Japonica rice at other cooking conditions, for example, high-pressure cooking and microwave-assisted cooking.
Disclosure statement

No potential conflict of interest was reported by the author(s)

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References

[1] Sporchia, F.; Thomsen, M.; Caro, D. Drivers and Trade-offs of Multiple Environmental Stressors from Global Rice. Sustain. Prod. Consum. 2021, 26, 16–32.
[2] Najafi, E.; Pal, I.; Khanbilvardi, R. Climate Drives Variablity and Joint Variability of Global Crop Yields. Sci. Total Environ. 2019, 662, 361–372.
[3] Mahajan, G. Basmati Rice in the Indian Subcontinent: Strategies to Boost Production and Quality Traits. Adv. Agron. 2018, 151, 159–213.
[4] Mitsuko, M.; Shuichi, F.; Chikako, T.; Seiya, T.; Hiroyuki, S. Evaluation of Major Japanese Rice Cultivars for Resistance to Bacterial Grain Rot Caused by Burkholderia Glumae and Identification of Standard Cultivars for Resistance. Breeding Sci. 2018, 68, 413–419.
[5] Zhu, L.; Wu, G.; Cheng, L.; Zhang, H.; Qi, X. Investigation on Molecular and Morphology Changes of Protein and Starch in Rice Kernel during Cooking. Food Chem. 2020, 316, 126262.
[6] Wang, S.; Li, P.; Zhang, T.; Yu, J.; Wang, S.; Copeland, L. In vitro Starch Digestibility of Rice Flour Is Not Affected by Method of Cooking. LWT-Food Sci. Technol. 2017, 84, 536–543.
[7] Varavinit, S.; Shobsngob, S.; Varananyon, W.; Chinachoti, P.; Naivikul, O. Effect of Amylose Content on Gelatinization, Retrogradation and Pasting Properties of Flours from Different Cultivars of Thai Rice. Starch-stärke. 2010, 55(9), 410–415.
[8] Zhou, X.; Ying, Y. N.; Hu, B. L.; Pang, Y. H.; Bao, J. S. Physicochemical Properties and Digestibility of Endosperm Starches in Four Indica Rice Mutants. Carbohydr. Polym. 2018, 195, 1–8.
[9] Pang, Y.; Ali, J.; Wang, X.; Franje, N. J.; Revilleza, J. E.; Li, Z. Relationship of Rice Grain Amylose, Gelatinization Temperature and Pasting Properties for Breeding Better Eating and Cooking Quality of Rice Varieties. Plos One. 2016, 11(12), e0168483.
[10] Singh, N.; Kaur, L.; Sodhi, N. S.; Sekhon, K. S. Physicochemical, Cooking and Textural Properties of Milled Rice from Different Indian Rice Cultivars. Food Chem. 2005, 89(2), 253–259.
[11] Li, N.; Guo, Y.; Zhao, S.; Kong, J.; Qiao, D.; Lin, L.; Li, Q.; Zhang, B. Amylose Content and Molecular-order Stability Synergistically Affect the Digestion Rate of Indica Rice Starches. Int. J. Biol. Macromol. 2020, 144, 373–379.
[12] Cui, Y.; Zhu, M. M.; Xu, Z. J.; Chen, W. F. The Breeding of Japonica Rice in Northern China: An 11-year Study (2006-2016). J. Integr. Agr. 2020, 19(8), 1941–1946.
[13] Luo, X.; Cheng, B.; Zhang, W.; Shu, Z.; Wang, P.; Zeng, X. Structural and Functional Characteristics of Japonica Rice Starches with Different Amylose Contents. CyTA-J. Food. 2021, 2021, 19(1), 532–540.
[14] Lin, L. S.; Zhang, Q.; Zhang, L.; Wei, C. X. Evaluation of the Molecular Structural Parameters of Normal Rice Starch and Their Relationships with Its Thermal and Digestion Properties. Molecules. 2017, 22(9), 526.
[15] Englyst, H. N.; Kingman, S. M.; Cummings, J. H. Classification and Measurement of Nutritionally Important Starch Fractions. Eur. J. Clin. Nutr. 1992, 46, S33–S50.
[16] Zhou, W.; Yang, J.; Hong, Y.; Liu, G.; Zheng, J.; Gu, Z.; Zhang, P. Impact of Amylose Content on Starch Physicochemical Properties in Transgenic Sweet Potato. Carbohydr. Polym. 2015, 122, 417–427.
[17] Park, I.-M.; Ibañez, A. M.; Zhong, F.; Shoemaker, C. F. Gelatinization and Pasting Properties of Waxy and Non-waxy Rice Starches. Starch-stärke. 2007, 59(8), 388–396.
[18] Li, Z.; Kong, X.; Zhou, X.; Zhong, K.; Zhou, S.; Liu, X. Characterization of Multi-scale Structure and Thermal Properties of Indica Rice Starch with Different Amylose Contents. RSC Adv. 2016, 6(109), 107491–107497.
[19] Zhu, L.; Zhang, H.; Wu, G.; Qi, X.; Qian, H. Effect of Structure Evolution of Starch in Rice on the Textural Formation of Cooked Rice. Food Chem. 2020, 342, 128205.
[20] Leelathussontorn, P.; Thipayarat, A. Textural and Morphological Changes of Jasmine Rice under Various Elevated Cooking Conditions. Food Chem. 2006, 96(4), 606–613.
[21] Ghasemi, E.; Mosavian, M. T. H.; Khodaparast, M. H. H. Effect of Stewing in Cooking Step on Textural and Morphological Properties of Cooked Rice. Rice Sci. 2009, 16(3), 243–246.
[22] Li, J.; Han, W.; Xu, J.; Xiong, S.; Zhao, S. Comparison of Morphological Changes and in Vitro Starch Digestibility of Rice Cooked by Microwave and Conductive Heating. *Starch - Stärke.* 2014, 66(5–6), 549–557.

[23] Ding, L.; Zhang, B.; Tan, C. P.; Fu, X.; Huang, Q. Effects of Limited Moisture Content and Storing Temperature on Retrogradation of Rice Starch. *Int. J. Biol. Macromol.* 2019, 137, 1068–1075.

[24] Deng, M.; Reddy, C. K.; Xu, B. Morphological, Physico-chemical and Functional Properties of Underutilized Starches in China. *Int. J. Biol. Macromol.* 2020, 158, 648–655.

[25] Kang, X.; Liu, P.; Gao, W.; Wu, Z.; Sun, C. Preparation of Starch-lipid Complex by Ultrasonication and Its Film Forming Capacity. *Food Hydrocolloid.* 2020, 99, 105340.