

Texture and digestion properties of hybrid rice: A comparison between two cultivars released 18 years apart

Min Huang^{a,*}, Liqin Hu^a, Jialin Cao^a, Ruichun Zhang^b, Jiana Chen^a, Fangbo Cao^a,
Longsheng Liu^c, Shengliang Fang^c, Ming Zhang^c

^a Rice and Product Ecophysiology, Key Laboratory of Ministry of Education for Crop Physiology and Molecular Biology, Hunan Agricultural University, Changsha 410128, China

^b Institute of Agricultural Resource and Environment, Hengyang Academy of Agricultural Sciences, Hengyang 421101, China

^c Institute of Plant Protection and Farming Technology, Hengyang Academy of Agricultural Sciences, Hengyang 421101, China

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ABSTRACT

Field experiments were conducted to compare two hybrid rice cultivars—a recently released high-quality cultivar (Jingliangyou 1468, JLY1468) and a relatively older cultivar (Liangyoupeijiu, LYPJ). Results showed that hardness, springiness, cohesiveness, resilience, and chewiness of cooked milled rice were all lower in JLY1468 than in LYPJ, due to its lower amylose content and altered paste properties of milled rice flour. Active digestion duration of cooked milled rice was 26% shorter and the glucose production rate from starch digestion was 33% faster in JLY1468 compared with LYPJ. Texture and starch digestion properties of cooked milled rice as a factor of temperature during the grain-filling period were different between LYPJ and JLY1468 due to differing amylose contents and gel consistencies of milled rice flour in response to temperature. This study highlights that attention should be paid to potential health risks associated with the development of high-quality hybrid rice cultivars with soft texture.

Introduction

China is the world's most populous country with over 1.4 billion people, or 18%, of the world's population (Worldometer, 2021). Food security in China is not merely a matter of national interest but also has an obvious bearing on global food security (Bruins and Bu, 2006). Ensuring adequate supply of rice is a crucial factor in promoting food security in China, where more than 65% of the population depends on rice as a staple food (Hsiaoping, 2005). With continuous increases in rice yields since the 1980s, rice self-sufficiency has been achieved in China (Deng et al., 2019). The development of hybrid rice, which out-yields inbred rice by 10–20% (Peng et al., 1999; Cheng et al., 2004), has played an important role in this achievement (Yuan, 2014).

However, the higher yields of hybrid rice alone may not necessarily make hybrid rice technology acceptable outside of China, and poor grain quality has been a major constraint in the adoption of hybrid rice in certain countries (Virmani and Zaman, 1998). This constraint is also a challenge in the development of hybrid rice in China, where the demand for high-quality rice has increased as living standards have improved

(Peng, 2016). To meet this challenge, many Chinese hybrid rice breeders have worked to improve grain quality.

Rice grain quality is a composite trait that includes milling, appearance, cooking, eating, and nutritional qualities (Huang et al., 2017). The eating quality is generally considered the most important for rice consumer satisfaction, and thus its improvement has been one of the most important objectives in rice breeding programs (Phing Lau et al., 2016; Sattari et al., 2015). In China, rice consumers generally prefer to eat soft-textured rice, and Chinese rice breeders have specifically focused on this trait preference when developing new rice cultivars (Yang et al., 2013; Zhou et al., 2015). Accordingly, the physicochemical properties relating to the texture of cooked rice such as amylose content, gel consistency, and paste properties, have attracted great interest by Chinese rice researchers in recent years (Tong et al., 2014; Zhang et al., 2020; Zhu et al., 2013).

Additionally, improving living standards is driving up the demand for healthy food in China (Huang and Hu, 2021). White or milled rice (the most common form consumed) is generally categorized as a food having a high glycemic index, and there is ample evidence that higher

* Corresponding author.

E-mail address: mhuang@hunau.edu.cn (M. Huang).

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consumption of milled rice is associated with an increased risk of type 2 diabetes in Asian populations, including the Chinese (Villegas et al., 2007; Hu et al., 2012; Ma et al., 2014). At present, China has the highest number of diabetics (mainly type 2) in the world; 116 million Chinese people had diabetes in 2019, which accounts for 25% of the global diabetes population (Saeedi, et al., 2019). Moreover, it is estimated that China has a pre-diabetic population that may number around 500 million people (Xu et al., 2013). For these reasons, Huang and Hu (2021) appealed that Chinese rice breeders should begin considering low glycemic index as another key target for rice production.

In recent years, through dedicated breeding efforts, multiple hybrid rice cultivars with high grain quality have been developed in China, and these cultivars generally have low amylose content and consequently a softer texture of the cooked rice (Huang, 2021; Huang and Hu, 2021). However, soft-textured rice with a lower amylose content is generally less resistant to digestion and has a higher glycemic index (Fitzgerald et al., 2011), although there is no direct report of this being observed in any high-quality hybrid rice cultivar with low amylose content. This potential contradiction highlights the need to fully evaluate the texture and digestion properties and related physicochemical traits of the high-quality soft-textured hybrid rice cultivars with low amylose content. In this study, comparisons between two hybrid rice cultivars released 18 years apart—a recently released cultivar with high grain quality and a relatively older cultivar with high yield potential—are made focusing on traits such as texture profiles and starch digestion properties of cooked milled rice as well as amylose and protein content, gel consistency, and paste properties of milled rice flour.

Materials and methods

Site and soil

Field experiments were conducted at the research farm of the Hengyang Academy of Agricultural Sciences (26°53' N, 112°28' E, 71 m asl), Hunan Province, China in 2019 and 2020. The soil was mostly clay with a pH of 5.86, organic matter content of 31.0 g kg⁻¹, available N content of 145 mg kg⁻¹, available P content of 14.1 mg kg⁻¹, and available K content of 187 mg kg⁻¹.

Experimental details

Two rice cultivars, Liangyoupeijiu (LYPJ) and Jingliangyou 1468 (JLY1468), were used in this study. LYPJ is a high-yielding hybrid cultivar (Peiai 64S × 9311) released in 1999 and was the first super hybrid rice cultivar approved by the Ministry of Agriculture of China. This cultivar has been widely commercialized, being planted on wide agroclimatic regions in southern China and southeastern Asia (e.g., Vietnam and Philippines) from 12° to 35° N (Lü and Zou, 2003). JLY1468 is a high-quality hybrid cultivar (Jing 4155S × R1468) released in 2017 that is a recommended cultivar in the High-Quality Rice Project of Hunan Province. This cultivar is widely adapted to the Yangtze River basin and south China (China Rice Data Center, 2021) as well as other regions and countries with similar agroclimatic conditions.

Four sowing dates—May 15th and 25th, and June 4th and 14th—were employed for each cultivar in each year in order to run the experiment under the different weather conditions that typify temperature during the grain-filling period, a major environmental factor affecting starch accumulation and grain quality in rice (Wang et al., 2021). The average daily mean temperature during the grain filling period ranged from 19.0 to 29.3 °C depending on the cultivar, year, and sowing date (Fig. 1).

The two cultivars were arranged in a completely randomized block design with three replicates for each sowing date. The plot size was 30 m². Pre-germinated seeds were sown in a seedbed, and 25-day-old seedlings were manually transplanted at a hill spacing of 20 cm × 20 cm with two seedlings per hill. N fertilizer was applied in three splits: 75

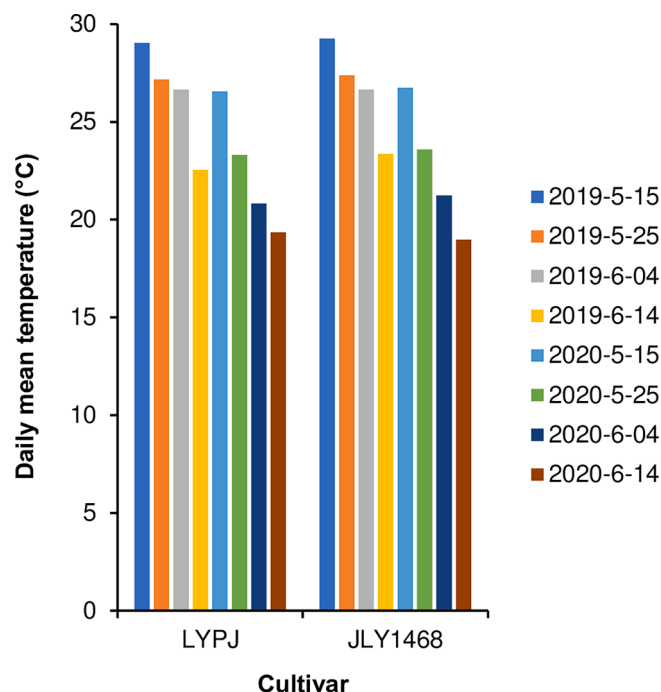


Fig. 1. Average daily mean temperature during the grain-filling period of the two hybrid rice cultivars, Liangyoupeijiu (LYPJ) and Jingliangyou 1468 (JLY1468), grown during four sowing dates across two years.

kg N ha⁻¹ one day before transplanting, 45 kg N ha⁻¹ seven days after transplanting, and 30 kg N ha⁻¹ at panicle initiation. P fertilizer (75 kg P₂O₅ ha⁻¹) was applied one day before transplanting. K fertilizer (150 kg K₂O ha⁻¹) was split equally at one day before transplanting and at panicle initiation. A floodwater depth of 5–10 cm was maintained from transplanting until seven days before maturity, when plots were drained. Insects, pathogens, and weeds were controlled by chemical application as required.

Sampling and measurements

About 500 g of rice grains were collected from each plot and dried in the sun. The sundried grains were stored at room temperature and humidity for three months and then processed into milled rice with a laboratory-scale milling machine (JGMJ8098, Shanghai Jiading Cereals and Oils Instrument Co., Ltd., Shanghai, China).

About 5 g of whole milled rice was ground into flour with a high-speed blender (YS-02, Yanshan Zhengde Machinery Equipment Co., Ltd., Beijing, China) to determine amylose and protein content, gel consistency, and paste properties (peak, trough, breakdown, final, setback, and consistency viscosities; time to peak viscosity; and paste temperature). The amylose and protein content and gel consistency were measured according to the methods reported by Huang et al. (2013). The paste properties were measured using a Rapid Visco Analyzer (RVA-Super 4; Newport Scientific Pty Ltd., Warriewood, Australia) following standard procedures (AACC, 1999).

Approximately 10 g of whole milled rice were soaked in 16 ml of distilled water in an aluminum cup for 30 min, and then the aluminum cup was covered with its lid and placed in an electric rice cooker (GDF-2003; Zhuhai Gree Group Co., Ltd., Zhuhai, China) containing about 700 ml of boiling water and allowed to steam for 40 min. Texture profiles (hardness, springiness, cohesiveness, resilience, and chewiness) of the cooked rice were determined using a texture analyzer (Rapid TA⁺; Shanghai Tengba Instrument Technology Co. Ltd., Shanghai, China). About 100 mg samples of the cooked rice were subjected to *in vitro* digestion to determine the amount of glucose produced per unit fresh

weight at six digestion times (15, 60, 120, 180, 240, and 300 min) using a Glycemic Index Analyzer (NutriScan GI20; Next Instruments, Condell Park, NSW, Australia). The starch digestion process of the cooked rice (i. e., the change in the amount of glucose produced over time) was fitted to the exponential association model for calculating starch digestion parameters, including active digestion duration, total glucose production, and glucose production rate (Huang et al., 2021).

Statistical analysis

All measured parameters were compared between the two cultivars using analysis of variance at the $p < 0.05$ probability level. Pearson's correlation analysis was employed to evaluate relationships of texture profiles and starch digestion properties of cooked milled rice as well as physicochemical properties of milled rice flour against average daily mean temperature during the grain-filling period for each cultivar separately at the $p < 0.05$ and $p < 0.01$ probability levels. The data analysis was performed using Statistix 8.0 (Analytical software, Tallahassee, FL, USA).

Results

Texture and digestion properties of cooked milled rice

All texture profiles of cooked milled rice were significantly different between the two rice cultivars (Table 1). Hardness, springiness, cohesiveness, resilience, and chewiness of cooked milled rice were lower in JLY1468 than in LYPJ by 37%, 4%, 15%, 17%, and 49%, respectively. There was significant difference in active digestion duration of cooked milled rice between the two cultivars (Table 2). The active digestion duration was 26% shorter in JLY1468 compared with LYPJ. Total glucose production from starch digestion of cooked milled rice was the same between the two cultivars. The difference in the glucose production rate from starch digestion of cooked milled rice was significant between the two cultivars, occurring 33% faster in JLY1468 than in LYPJ.

Physicochemical properties of milled rice flour

Amylose content of milled rice flour significantly differed between the two cultivars, showing 27% lower in JLY1468 compared with LYPJ (Table 3). The difference in protein content of milled rice flour was not

Table 2

Starch digestion properties of cooked milled rice from the two hybrid rice cultivars, Liangyoupeijiu (LYPJ) and Jingliangyou 1468 (JLY1468), grown during four sowing dates across two years.

Cultivar	Year-Sowing date	Active digestion duration (min)	Total glucose production (mg g ⁻¹)	Glucose production rate (mg g ⁻¹ min ⁻¹)
LYPJ	2019-5-15	114	351	3.07
	2019-5-25	115	347	3.04
	2019-6-04	104	325	3.13
	2019-6-14	124	329	2.74
	2020-5-15	135	374	2.94
	2020-5-25	153	385	2.69
	2020-6-04	140	357	2.56
	2020-6-14	132	333	2.63
	Mean	127 a	350 a	2.85 b
	SE	6	6	0.10
JLY1468	2019-5-15	88	342	3.92
	2019-5-25	90	358	4.14
	2019-6-04	93	355	3.90
	2019-6-14	92	350	3.81
	2020-5-15	91	348	3.83
	2020-5-25	107	344	3.35
	2020-6-04	97	345	3.56
	2020-6-14	96	356	3.75
	Mean	94 b	350 a	3.78 a
	SE	3	4	0.11

Means of cultivars sharing the same letter are not significantly different at the $p < 0.05$ probability level.

Table 1

Texture profiles of cooked milled rice from the two hybrid rice cultivars, Liangyoupeijiu (LYPJ) and Jingliangyou 1468 (JLY1468), grown during four sowing dates across two years.

Cultivar	Year-Sowing date	Hardness (g)	Springiness	Cohesiveness	Resilience	Chewiness (g)
LYPJ	2019-5-15	1173	0.784	0.615	0.433	557
	2019-5-25	1150	0.796	0.653	0.454	634
	2019-6-04	1057	0.790	0.614	0.445	561
	2019-6-14	946	0.764	0.617	0.451	499
	2020-5-15	1041	0.784	0.615	0.445	465
	2020-5-25	985	0.795	0.633	0.425	479
	2020-6-04	967	0.786	0.610	0.435	452
	2020-6-14	879	0.778	0.617	0.439	383
	Mean	1025 a	0.785 a	0.622 a	0.441 a	504 a
	SE	20	0.002	0.003	0.002	15
JLY1468	2019-5-15	510	0.691	0.466	0.319	165
	2019-5-25	574	0.723	0.514	0.361	215
	2019-6-04	669	0.746	0.545	0.371	275
	2019-6-14	716	0.761	0.533	0.364	293
	2020-5-15	554	0.736	0.507	0.344	199
	2020-5-25	640	0.770	0.534	0.374	252
	2020-6-04	739	0.783	0.565	0.401	331
	2020-6-14	780	0.791	0.587	0.396	339
	Mean	648b	0.750b	0.531b	0.366b	259b
	SE	19	0.007	0.007	0.005	12

Means of cultivars sharing the same letter are not significantly different at the $p < 0.05$ probability level.

Table 3

Amylose and protein content and gel consistency of milled rice flour prepared from grains of the two hybrid rice cultivars, Liangyoupeijiu (LYPJ) and Jingliangyou 1468 (JLY1468), grown during four sowing dates across two years.

Cultivar	Year-Sowing date	Amylose content (mg g ⁻¹)	Protein content (mg g ⁻¹)	Gel consistency (mm)
LYPJ	2019-5-15	239	91.4	84.0
	2019-5-25	238	89.5	85.3
	2019-6-04	240	89.1	84.7
	2019-6-14	237	96.1	84.7
	2020-5-15	241	88.8	84.7
	2020-5-25	237	87.7	86.0
	2020-6-04	232	88.3	87.0
	2020-6-14	229	95.4	86.3
	Mean	237 a	90.8 a	85.3 a
	SE	1	0.8	0.4
JLY1468	2019-5-15	162	85.5	77.7
	2019-5-25	167	92.6	78.7
	2019-6-04	177	92.2	78.0
	2019-6-14	182	93.8	80.0
	2020-5-15	166	81.9	81.7
	2020-5-25	169	80.7	79.3
	2020-6-04	180	92.6	74.3
	2020-6-14	186	98.0	77.7
	Mean	174 b	89.7 a	78.4 b
	SE	2	1.3	0.6

Means of cultivars sharing the same letter are not significantly different at the $p < 0.05$ probability level.

significant between the two cultivars. There was a significant difference in gel consistency of milled rice flour between the two cultivars, with JLY1468 being 8% lower than LYPJ. The differences were significant between the two cultivars for all paste properties of milled flour except for trough viscosity (Table 4). Peak and breakdown viscosities were 23% and 62% higher in JLY1468 than in LYPJ, respectively, whereas final, setback, and consistency viscosities were 8%, 219%, and 15% lower in JLY1468 than in LYPJ, respectively. The time to peak viscosity was 2% shorter in JLY1468 compared with LYPJ. JLY1468 had 3% lower paste temperature than LYPJ.

Table 4

Paste properties of milled rice flour prepared from grains of the two hybrid rice cultivars, Liangyoupeijiu (LYPJ) and Jingliangyou 1468 (JLY1468), grown during four sowing dates across two years.

Cultivar	Year-Sowing date	Viscosity (cP)						Time to peak viscosity (min)	Paste temperature (°C)
		Peak	Trough	Breakdown	Final	Setback	Consistency		
LYPJ	2019-5-15	3343	1983	1360	3842	498	1858	5.62	81.0
	2019-5-25	3376	2102	1274	3922	545	1819	5.67	80.8
	2019-6-04	3298	1966	1332	3728	430	1762	5.64	80.5
	2019-6-14	3148	1943	1204	3676	529	1733	5.76	79.4
	2020-5-15	2920	1791	1129	3123	203	1332	5.91	79.2
	2020-5-25	2439	1525	914	2754	315	1229	6.02	77.3
	2020-6-04	2321	1491	830	2657	335	1166	6.18	76.3
	2020-6-14	2021	1307	714	2457	436	1150	6.15	80.3
	Mean	2858b	1764 a	1095b	3270 a	411 a	1506 a	5.87 a	79.4 a
	SE	106	59	51	117	25	63	0.05	0.6
JLY1468	2019-5-15	4392	2084	2308	3385	-1007	1301	5.49	77.6
	2019-5-25	4167	1953	2214	3395	-772	1442	5.51	77.4
	2019-6-04	4055	1824	2231	3433	-622	1609	5.51	77.1
	2019-6-14	3884	1778	2106	3357	-527	1579	5.53	77.4
	2020-5-15	3331	1595	1736	2639	-692	1045	5.78	74.4
	2020-5-25	3017	1662	1355	2698	-319	1036	6.05	72.8
	2020-6-04	2835	1597	1238	2709	-127	1111	6.06	71.3
	2020-6-14	2408	1401	1006	2557	149	1156	6.09	86.5
	Mean	3511 a	1737 a	1774 a	3022b	-490b	1285b	5.75b	76.8b
	SE	141	48	102	82	75	47	0.06	0.9

Means of cultivars sharing the same letter are not significantly different at the $p < 0.05$ probability level.

Relationships between rice quality traits and temperature during the grain-filling period

The relationships between texture profiles of cooked milled rice and average daily mean temperature during the grain-filling period were not consistent in the two cultivars (Fig. 2). For LYPJ, hardness and chewiness were significantly positively while springiness, cohesiveness, and resilience were not significantly related to average daily mean temperature during the grain-filling period. For JLY1468, all texture profiles were significantly negatively related to average daily mean temperature during the grain-filling period. The relationships between starch digestion properties of cooked milled rice and average daily mean temperature during the grain-filling period were also not consistent in the two cultivars. In particular, a significantly positive relationship between the glucose production rate from starch digestion and average daily mean temperature during the grain-filling period was observed for LYPJ but not for JLY1468.

Some inconsistent relationships between physicochemical properties of milled rice flour and average daily mean temperature during the grain-filling period were also observed between the two cultivars (Fig. 2). Amylose content was significantly positively related to average daily mean temperature during the grain-filling period for LYPJ, while for JLY1468 this relationship was reversed. Gel consistency was significantly negatively while final and consistency viscosities were significantly positively related to average daily mean temperature during the grain-filling period for LYPJ; none of these relationships were significant for JLY1468. The relationship between setback viscosity and average daily mean temperature during the grain-filling period was not significant for LYPJ, whereas this relationship was significantly positive for JLY1468.

Additionally, there were some consistent and significant relationships between physicochemical properties of milled rice flour against average daily mean temperature during the grain-filling period in the two cultivars (Fig. 2). Namely peak, trough, and breakdown viscosities were significantly positively related to average daily mean temperature during the grain-filling period in both LYPJ and JLY1468.

Discussion

In China, rice consumers generally prefer soft-textured rice with low amylose content (Huang and Hu, 2021), and satisfying these trait

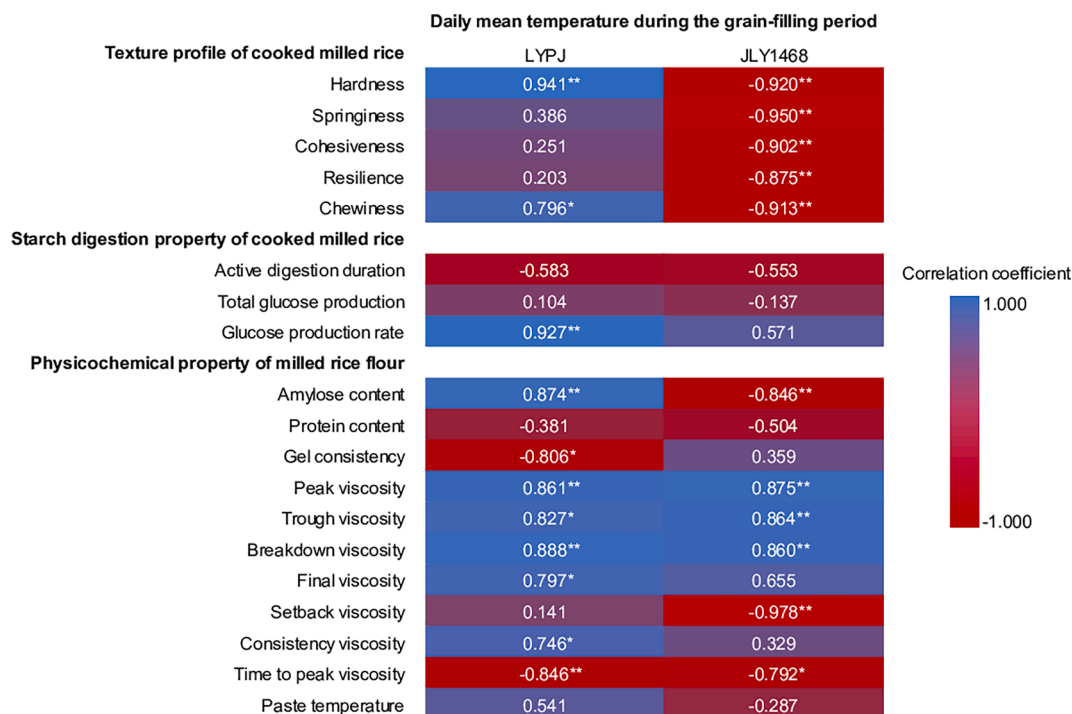


Fig. 2. Pearson's correlation coefficients of texture profiles and starch digestion properties of cooked milled rice as well as physicochemical properties of milled rice flour against average daily mean temperature during the grain-filling period for the two hybrid rice cultivars, Liangyoupeijiu (LYPJ) and Jingliangyou 1468 (JLY1468). The data used in the analysis are from Tables 1–4 and Fig. 1 ($n = 8$). * and ** denote significant correlation coefficients at the $p < 0.05$ and $p < 0.01$ probability levels, respectively.

preferences of consumers has been a major pursuit for rice breeders in recent years (Yang et al., 2013; Zhou et al., 2015). These trait preferences are supported by the results of this study, which showed that the recently developed high-quality cultivar JLY1468 had lower hardness, springiness, cohesiveness, resilience, and chewiness of cooked milled rice and lower amylose content of milled rice flour than the relatively older cultivar LYPJ.

The gel consistency of milled rice flour is also an important physicochemical property determining the texture of cooked milled rice, and higher gel consistency is generally associated with softer texture (Binodh et al., 2006). However, in this study, the difference in gel consistency of milled rice flour did not explain the texture difference of cooked milled rice from the two cultivars, with lower gel consistency and softer texture being observed in JLY1468, compared with LYPJ. Despite this, the gel consistency in JLY1468 (78.4 mm) is still within the scope of gel consistency for soft rice (greater than 60 mm) (Table 3; Binodh et al., 2006).

Paste properties are physicochemical traits that have become commonly used for evaluating rice eating quality in recent years (Zhang et al., 2017; Peng et al., 2021). Zhu et al. (2013) evaluated relationships between paste properties of milled rice flour and texture profiles of cooked milled rice. Their results showed that trough, final, and setback viscosities were significantly positively, breakdown viscosity was significantly negatively, and peak viscosity, the time to peak viscosity, and paste temperature were not significantly or consistently related to most texture profiles. These results were partly confirmed by the results of this study, which showed that final and setback viscosities were significantly lower but breakdown viscosity was significantly higher in JLY1468 having the softer texture, than in LYPJ. However, in this study, we also found significant differences in other paste properties of milled rice flour between these two cultivars with contrasting texture profiles, with JLY1468 showing higher peak viscosity, lower consistency viscosity, shorter time to peak consistency, and lower paste temperature than LYPJ. This finding suggests that more investigations on various rice

cultivars are needed in order to establish more reliable relationships between paste properties of milled rice flour and texture profiles of cooked milled rice.

Importantly, and for the first time, this study evaluated the starch digestion properties of the recently developed high-quality rice. The results showed that active digestion duration of cooked milled rice was significantly shorter, while the glucose production rate from starch digestion was significantly faster in the more recently developed high-quality cultivar JLY1468 than in the relatively older cultivar LYPJ. In this regard, it has been reported that amylose is resistant to digestion in comparison to other starch molecules due to the strong interaction among the linear polymers of amylose (retrogradation) and between amylose and lipids that results in complex formation on the surface of starch granules (Svihus et al., 2005). Therefore, in this study, the faster glucose production rate from starch digestion in JLY1468 could be partially explained by its lower amylose content compared to LYPJ. These indicate that the starch digestion rate of cooked milled rice should have been increased in China in recent years as a result of the development of soft-textured rice with low amylose content that is preferred by consumers. Because rice starch with less resistance to digestion has a higher glycemic index (Fitzgerald et al., 2011), the increase in the starch digestion rate of cooked milled rice may lead to an increase in the risk of type 2 diabetes associated with rice consumption. This view is supported by a population-based study showing that the consumption of rice with a high glycemic index was negatively associated with glucose homeostasis in 3,918 Chinese adults aged 23–69 years (Cheng et al., 2017).

Prior to this study, the risk of type 2 diabetes associated with milled rice consumption has been documented in China (Villegas et al., 2007; Hu et al., 2012; Ma et al., 2014), but no attention has been given to how the potential contributions of these more recently developed low amylose, soft-textured rice lines—which have received unprecedented interest and support in rice research and production in China in recent years—on the risk of developing type 2 diabetes. We hope that the results of our study will serve to attract attention and help raise societal

awareness of the health risks associated with this type of rice in China and other major rice-consuming countries. The results of this study also highlight the need to find feasible approaches to resolve the potential contraindication between rice eating quality and the risk of type 2 diabetes in rice consumers.

Additionally, this study observed that relationships of texture profiles of cooked milled rice with regards to temperature during the grain-filling period varied by cultivar; namely, cooked milled rice became harder with increasing temperature during the grain-filling period in LYPJ, whereas a reverse trend was observed in JLY1468. Reports showing that increasing temperature during the grain-filling period resulted in increased and decreased amylose content of milled rice flour in rice cultivars with high and low amylose content, respectively (Zhong et al., 2005; Zhang et al., 2019), which may explain the results of this study. However, the physiological mechanisms for the opposing effects of temperature during the grain-filling period on amylose content in rice cultivars with high and low amylose content are not well documented and require further investigation.

This study revealed that relationships between starch digestion properties of cooked milled rice and temperature during the grain-filling period were dependent on cultivar; namely, cooked milled rice became faster to digest with increasing temperature during the grain-filling period in LYPJ, but no significant trend was observed in JLY1468. Amylose content is an important factor influencing starch digestion in rice, and faster digestion rate is generally associated with lower amylose content (Fitzgerald et al., 2011). However, the change in amylose content of milled rice flour did not explain the difference in the starch digestion rate of cooked milled rice with regard to increasing temperature during the grain filling period in LYPJ in this study, where both amylose content of milled rice flour and starch digestion rate increased with increasing temperature. This could be attributed to the starch digestion of rice is being affected not only by its amylose content, but also other starch traits, such as starch gelatinization and retrogradation properties, the particle size of starch granules, the ratio of amylose to amylopectin, the crystallite structure of amylopectin, starch resistance against enzymatic hydrolysis, and interactions of starch with other components (Kaur et al., 2016). Park et al. (2017) observed that starch digestion rate was negatively correlated with gel consistency in rice. Therefore, in this study, the increased starch digestion rate of cooked milled rice correlated with increasing temperature during the grain-filling period in LYPJ could be attributed to decreased gel consistency of milled rice flour. The results of this study also highlight the need for further understanding of the effect of temperature during the grain-filling period on gel consistency in different cultivars.

Conclusions

The recently developed high-quality hybrid rice cultivar JLY1468 has a softer texture of cooked milled rice than the relatively older hybrid rice cultivar LYPJ, due to its lower amylose content and altered paste properties including, but not limited to, lower final and setback viscosities, and higher breakdown viscosity. A faster starch digestion rate (which generally means a higher glycemic index) is associated with JLY1468 compared with LYPJ, indicating a potential health risk associated with the development of soft-textured high-quality hybrid rice. In addition, this study finds that relationships between texture and starch digestion properties of cooked milled rice with temperature during the grain-filling period are different in LYPJ and JLY1468, due to varied amylose contents and gel consistencies in response to temperature.

CRedit authorship contribution statement

Min Huang: Conceptualization, Formal analysis, Writing – original draft, Funding acquisition. **Liqin Hu:** Investigation. **Jialin Cao:** Investigation. **Ruichun Zhang:** Investigation. **Jiana Chen:** Investigation. **Fangbo Cao:** Investigation. **Longsheng Liu:** Investigation. **Shengliang**

Fang: Investigation. **Ming Zhang:** Investigation.

Declaration of Competing 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.

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