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Effects of grain thickness on yield and quality of rice varieties in Jilin province

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Abstract

The correlation between the grain thickness and the yield and quality of brown rice was studied using 9 japonica rice varieties harvested in Jilin Province in 2019. The results showed that there were significant differences between the grain thickness of different varieties. The grading of different grain thickness had a great influence on the grains per panicle and the seed setting rate in the yield components. Further, there was no significant correlation between grain thickness and grain type (aspect ratio), while a strong and significant negative correlation was identified between grain-thickness grading (< 2.0 mm) and processing quality. In addition, grain thickness was found to have a positive effect on the quality of taste. In conclusion, grain length, width, and thickness are independent genetic traits. The ratio of thicker grain-thickness-grading would increase with an improvement in the yield and processing quality, and an increase in the thinner grain-thickness-grading ratio would lead to degradation with regard to appearance and taste. The grain thickness of brown rice has an important impact on the quality of the rice.

Keywords: rice; grain thickness; yield; quality.

Practical Application: Rice processing and rice quality inspection.

1 Introduction

The rice crop occupies a dominant position in China. With the increase in population and construction land, the demand for rice has increased, which implies significant pressure for rice production within the originally reduced cultivated land area (Jiao, 2018; Li, 2018). Meanwhile, with the improvement of living standards, people's demand for rice has gradually shifted to become more about the taste aspect. People now pay more attention to the taste of rice, and this has become the primary factor when gauging rice quality (Ma et al., 2021). In recent years, there have been many studies on rice quality. The production of high-quality edible rice, and especially the collaborative research on rice quality and high yield, has become an urgent area of study (Xiong et al., 2021). At present, the main factors that could clearly affect the taste of rice are protein content, amylose content, thermal gelatinization, and viscoelasticity (Amjad et al., 2022). However, the determination of these characteristics is time- and labor-consuming, where more generations need to be selected during the early stages of breeding, and this cannot be used as a rapid and effective screening standard for a breeding system for japonica rice with high taste quality.

Rice grain traits are directly related to yield growth and quality improvement (You, 2014; Wu, 2018). These traits include grain length, width, thickness, and aspect ratio, which are not only important for appearance quality but also affect yield by altering grain weight (Xue, 2018). In recent years, many research reports on the grain traits and quality of brown rice have been published (Ruan & Tian, 2013). Matsue et al. (2001) graded brown rice based on its grain thickness. According to the findings regarding its taste-related characteristics and physicochemical properties, the higher the grain thickness, the better the evaluation results of taste-related experiments (Lima et al., 2022). Compared with 1000 grain weight, a strong correlation was identified between taste-related characteristics and grain thickness, in which the correlation between protein content and grain thickness was the most significant (Mongkontanawat et al., 2022). The study of the grain weight and grain thickness of rice varieties could have an important impact on yield and quality improvement (You, 2014; Wu, 2018).

Therefore, to improve rice yield and quality and provide guidance and support for the cultivation and breeding of high-quality rice in the future, this study investigates the relationship between grain thickness and yield and taste-related characteristics.

2 Materials and methods

2.1 Materials

The experiment was conducted in the experimental paddy field (43.96° N, 126.48° E) of Jilin Agricultural Science and Technology University in 2019. This region has a typical northern temperate, continental monsoon climate, with an annual mean rainfall and temperature of 703.6 mm and 5.2 °C, respectively. The soil of the experimental paddy field was classified as Arborols, and the field covered an area of 1000 m^2. Further, the test materials comprised nine varieties of local japonica rice from Jilin Province (Table 1). Before transplantation, a complex fertilizer (N: P_2O_5: K_2O = 17:17:17) was utilized at the rate of 650 kg/ha as the base fertilizer. Urea (N ≥ 47%) was added at the rate of 30 kg/ha during the tillering stage and at the rate of 130 kg/ha during

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Table 1. Tested varieties.

Number	Varieties
1	Jijing561
2	Jihong9
3	Jijing812
4	Jijing515
5	Wuyoudao4
6	Jinongda168
7	Tianlongyou619
8	Jijing816
9	Jinongda528

the booting stage as topdressing. The experimental paddy field contained 187 kg/ha of N, 105 kg/ha of P_2O_5, and 105 kg/ha of K_2O. The other processes involved in each treatment were carried out according to the conventional management of the university.

2.2 Method

The yield was measured before the harvest, and the theoretical yield of the tested varieties was calculated according to the results. All varieties were naturally dried after being harvested and threshed and hulled when the water content was 22-23%. After obtaining the brown rice, the follow-up test was carried out in the grain analysis room of Jilin Agricultural Science and Technology University.

The obtained brown rice from each tested variety was sorted using sieves with mesh sizes of 2.2 mm, 2.0 mm, 1.8 mm, and 1.6 mm; thus, brown rice with grain thicknesses of > 2.2 mm, 2.0-2.2 mm, 1.8-2.0 mm, 1.6-1.8 mm, and > 1.6 mm was obtained. After being weighed, the different groups of rice were milled. Once white rice was obtained, the water, amylose, and protein content of the groups was measured using a near-infrared rapid quality analyzer (Infratec); the whole milled rice rate and the chalkiness rate of the rice groups were measured using a rice appearance quality detector (JMWT12). Further, the taste parameter was measured using a taste detector (STA1B), while hardness, viscosity, and elasticity were measured using a viscosity and hardness analyzer (RHS1A).

2.3 Data analysis

Excel 2010 and the JMP statistical software were used for the creation of charts and data analysis.

3 Results and analysis

3.1 Correlation between different grading ratios and stratification

Table 2 shows the grading and stratification ratios of rice with different grain thicknesses. The highest grading ratio for the grain thickness of > 2.2 mm was 89.03% for Jinongda528, and the lowest was 7.62% for Jijing561. In contrast, the highest grading ratio for 2.0-2.2 mm grain thickness was 77.15% for Jijing561, while the lowest was 8.62% for Jinongda528. The highest and lowest grading ratios for 1.8-2.0 mm grain thickness was 27.07% for Tianlongyou619 and 1.60% for Jihong9, respectively. The highest grading ratio for 1.6-1.8 mm grain thickness was 3.84% for Tianlongyou619, while the lowest was 0.40% for Jihong9 and Jinongda528. The highest and lowest grading ratios for < 1.6 mm grain thickness was 1.41% for Tianlongyou619 and 0.09% for Jihong9. There were significant differences in the grading ratios of the studied varieties. Next, the stratification ratio for the different grain thicknesses was calculated. The stratification ratio for the grain thickness of > 2.0 mm for all tested varieties was more than 90%, except for Jijing561, Wuyoudao4, and Tianlongyou619; of these, the lowest was 67.68% for Tianlongyou619. There was little difference in the stratification ratios for the tested varieties with a thickness of > 1.8 mm and > 1.6 mm. The average of stratification ratio for a grain thickness of > 2.2 mm was 54.94%, for > 2.0 mm was 89.80%, for > 1.8 mm was 97.91%, and for > 1.6 mm was 99.45%. The average stratification ratio for a thickness of > 2.2 mm and > 2.0 mm presented significant differences among the studied varieties.

Figure 1 displays the histogram of the average grading ratios of the tested varieties. The largest average grading ratio of brown rice grain thickness was > 2.2 mm, which then decreased gradually with a decrease in grain thickness. The overall sample of brown rice was mainly composed of two grading ratios with grain thicknesses of > 2.2 mm and 2.0-2.2 mm, and the proportion of the whole sample was close to 90%.

Table 3 illustrates the correlation between the grading of different grain thicknesses. There was a negative correlation between the grain thickness grading of > 2.2 mm and other thickness gradings, and all were significant, except the grading thickness of < 1.6 mm. The correlation between the grain thickness grading of > 2.2 mm and 2.0-2.2 mm was -0.943, that between the grain thickness grading of > 2.2 mm and 1.8-2.0 mm was -0.750, and that between the grain thickness grading of > 2.2 mm and 1.6-1.8 mm was -0.763; the correlation between the grain thickness grading of 2.0-2.2 mm and 1.8-2.0 mm was not significant. Further, the grain thickness grading of 1.8-2.0 mm and 1.6-1.8 mm showed a strong positive correlation with that of 1.6-1.8 mm and < 1.6 mm. The correlation between the grain thickness grading of 1.8-2.0 mm and 1.6-1.8 mm was 0.969, while that between the grain thickness grading of 1.8-2.0 mm and < 1.6 mm was 0.928. Finally, the correlation between the grain thickness grading of 1.6-1.8 mm and < 1.6 mm was 0.949.

3.2 Correlation between different grain thicknesses and yield

The correlation between different grain thicknesses and yield components and yield is shown in Table 4. There was a significant positive correlation between the grain thickness grading of > 2.2 mm and the grains per panicle, and the correlation coefficient was 0.722. Furthermore, the grain thicknesses of 1.8-2.0 mm, 1.6-1.8 mm, and < 1.6 mm presented significant negative correlations with the grains per panicle, for which the correlation coefficients were -0.806, -0.828, -0.796, respectively. Barring one positive correlation between the grain thickness grading of > 2.2 mm and the seed setting rate, there was a negative correlation between all other grain thicknesses and seed setting rates. The correlation coefficients between the seed setting rates and grain thicknesses of > 2.2 mm, 1.8-2.0 mm, and

Table 2. Grading and stratification ratios for different grain thicknesses.

Number	Variety	Grading ratio (%)					Stratification ratio (%)			
		> 2.2	2-2.2	1.8-2.0	1.6-1.8	< 1.6	> 2.2	> 2.0	> 1.8	> 1.6
1	Jijing561	7.62	77.15	12.63	2.00	0.60	7.62	84.77	97.39	99.40
2	Jihong9	79.28	18.62	1.60	0.40	0.09	79.28	97.90	99.51	99.91
3	Jijing812	48.25	45.02	5.25	1.21	0.28	48.25	93.26	98.51	99.72
4	Jijing515	68.00	27.60	3.00	0.80	0.60	68.00	95.60	98.60	99.40
5	Wuyoudao4	41.70	40.89	13.56	2.83	1.01	41.70	82.59	96.15	98.99
6	Jinongda168	65.19	29.58	3.62	1.21	0.40	65.19	94.77	98.39	99.60
7	Tianlongyou619	28.48	39.19	27.07	3.84	1.41	28.48	67.68	94.75	98.59
8	Jijing816	66.87	27.11	4.42	1.20	0.40	66.87	93.98	98.39	99.60
9	Jinongda528	89.03	8.62	1.80	0.40	0.15	89.03	97.65	99.46	99.86
Average		54.94	34.86	8.11	1.54	0.55	54.94	89.80	97.91	99.45
Varieties		***	***	***	**	*	***	**	NS	NS

*There were significant differences at the levels of 5%. **There were significant differences at the levels of 1%. ***There were significant differences at the levels of 0.1%. NS: There was no intentional difference. The unit used for mesh size was mm.

Table 3. Correlation between different grain thicknesses.

	2.0-2.2	1.8-2.0	1.6-1.8	< 1.6
> 2.2	-0.943***	-0.750*	-0.763*	-0.641
2.0-2.2		0.487	0.515	0.374
1.8-2.0			0.969***	0.928***
1.6-1.8				0.949***

*There were significant differences at the level of 5%. ***There were significant differences at the level of 0.1%.

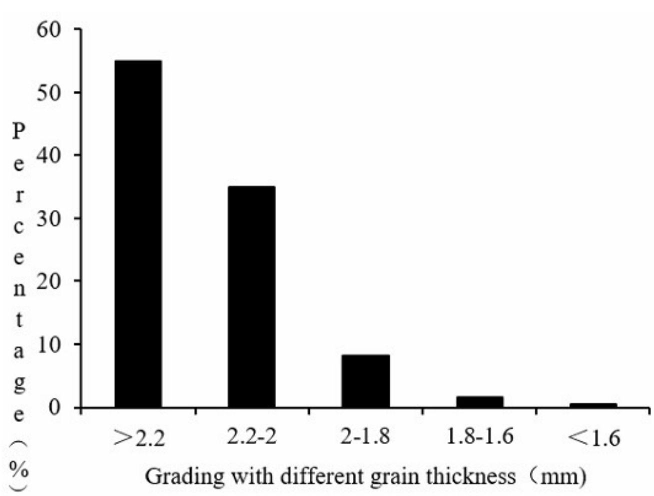

Figure 1. Grading of average grain thickness.

1.6-1.8 mm was 0.725, -0.749, and -0.752, respectively. There was no significant correlation between grain thickness, 1000 grain weight, and panicle number. There was a positive correlation between the grain thickness of > 2.2 mm and yield, but it was not significant. In addition, there was a negative correlation between other grain thicknesses and yield. There was a strong and significant negative correlation between grain thickness grading and yield in the range of 1.8-2.0 mm, 1.6-1.8 mm, and < 1.6 mm, and the correlation coefficients were -0.912, -0.909, and -0.927, respectively.

3.3 Correlation between different grain thicknesses and processing and appearance quality

Table 5 showed the correlation between different grain thicknesses and processing and appearance quality. There was a positive correlation between the grain thickness grading of > 2.2 mm and processing quality, but it was not significant. There was also a negative correlation between the other grain thicknesses and processing quality. Further, there was a strong and significant negative correlation between grain thickness grading and processing quality for the range of 1.8–2.0 mm, 1.6-1.8 mm, and < 1.6 mm. The correlation coefficients between the brown rice rate and grain thickness grading of 1.8-2.0 mm, 1.6-1.8 mm, and < 1.6 mm was -0.945, -0.900, and -0.869, respectively. Furthermore, the correlation coefficients between the milled rice rate and grain thickness grading of 1.8-2.0 mm, 1.6-1.8 mm, and < 1.6 mm were -0.938, -0.925, and -0.911, respectively. The correlation coefficients between the head rice rate and grain thickness grading of 1.8-2.0 mm, 1.6-1.8 mm, and < 1.6 mm was -0.960, -0.946, and -0.909, respectively. However, there was no strong correlation between grain thickness grading and appearance quality.

3.4 Correlation between different grain thicknesses and physicochemical properties and taste quality

Table 6 shows the correlation between different grain thickness grading and physicochemical properties and taste quality. There was a significant positive correlation between the grain thickness grading of > 2.2 mm and the appearance, texture, and taste parameters of rice. The correlation coefficients between

Table 4. Correlation between different grain thicknesses and yield.

	> 2.2	2.0-2.2	1.8-2.0	1.6-1.8	< 1.6
Grains per panicle	0.722*	-0.544	-0.806**	-0.828**	-0.796*
Seed setting rate	0.725*	-0.582	-0.749*	-0.752*	-0.546
1000 grain weight	-0.049	-0.017	0.170	0.111	0.095
Panicle number	-0.338	0.520	-0.148	-0.072	-0.240
Yield	0.589	-0.316	-0.912***	-0.909***	-0.927***

*There were significant differences at the levels of 5%. **There were significant differences at the levels of 1%. ***There were significant differences at the levels of 0.1%.

Table 5. Correlation between different grain thicknesses and processing and appearance quality.

	Processing quality			Appearance quality				
	Brown rice rate	Milled rice rate	Head rice rate	Chalky grain rate	Chalkiness	Imperfect grain rate	Yellow rice rate	Grain type (Aspect ratio)
> 2.2	0.593	0.528	0.642	0.174	0.144	-0.254	0.302	-0.663
2.0-2.2	-0.309	-0.223	-0.363	-0.385	-0.373	0.003	-0.191	0.656
1.8-2.0	-0.945***	-0.938***	-0.960***	0.305	0.362	0.66	-0.406	0.421
1.6-1.8	-0.900**	-0.925***	-0.946***	0.301	0.333	0.629	-0.395	0.537
< 1.6	-0.869**	-0.911***	-0.909***	0.29	0.305	0.636	-0.517	0.441

**There were significant differences at the level of 1%. ***There were significant differences at the level of 0.1%.

Table 6. Correlation between different grain thicknesses and physicochemical properties and taste quality.

	> 2.2	2.0-2.2	1.8-2.0	1.6-1.8	< 1.6
Protein content	0.230	-0.102	-0.385	-0.473	-0.474
Amylose content	-0.131	0.131	0.073	0.144	0.129
Milled rice taste value	-0.435	0.397	0.356	0.299	0.422
Hardness	-0.662	0.625	0.513	0.399	0.348
Viscosity	0.073	-0.075	-0.058	0.052	-0.047
Balance degree	0.182	-0.160	-0.174	-0.062	-0.159
Elasticity	0.133	-0.161	-0.040	-0.021	0.184
Appearance	0.770*	-0.825**	-0.389	-0.364	-0.225
Texture	0.723*	-0.752*	-0.408	-0.417	-0.274
Taste	0.786*	-0.825**	-0.435	-0.389	-0.249

*There were significant differences at the level of 5%. **There were significant differences at the level of 1%.

the grain thickness grading of > 2.2 mm and appearance, texture, and taste value of rice were 0.770, 0.723, and 0.786, respectively. In contrast, the grain thickness grading of 2.0-2.2 mm showed a significant negative correlation with appearance, texture, and rice taste value. The correlation coefficients between the grain thickness grading of 2.0-2.2 mm and the appearance, texture, and taste of rice were -0.825, -0.752, and -0.825, respectively. The correlation between other grain thickness grading and taste quality was not strong.

3.5 Multiple regression analysis between different grain thickness stratification and yield

A multiple regression analysis was carried out with different grain thickness stratification as the independent variables and yield, chalkiness, milled rice rate, milled rice taste, and rice taste as the dependent variables. The results are shown in Table 7. There was a strong and significant correlation between different grain thickness stratification and yield, chalkiness, milled rice rate, milled rice taste, and rice taste. The multiple correlation coefficients of yield, chalkiness, milled rice rate, milled rice taste, and rice taste were 0.952, 0.833, 0.975, 0.727, and 0.869, respectively. The determination coefficients of milled rice rate and yield exceeded 0.9, while those of taste and chalkiness were about 0.7. In addition, the determination coefficient of different grain thickness stratification and milled rice taste was the lowest, at 0.529. The weight for the grain thickness of > 2.2 mm, > 2.0 mm, > 1.8 mm, and > 1.6 mm for yield was 11.52%, 40.04%, 8.46%, and 39.98%, respectively. From the weight obtained for the different grain thicknesses from the partial regression coefficients, the grain thickness stratification of > 2.0 mm had the greatest impact on yield. The weight for the grain thickness stratification of > 2.2 mm, > 2.0 mm, > 1.8 mm, and > 1.6 mm for chalkiness was 18.29%, 15.78%, 34.12%, and 31.81%, respectively. The stratification of > 1.8 mm had the greatest influence on chalkiness. The weight for the grain thickness stratification of > 2.2 mm, > 2.0 mm, > 1.8 mm, and > 1.6 mm for milled rice rate was 10.08%, 36.44%, 31.77%, and 21.71%, respectively. The milled rice rate was the most affected by the grain thickness stratification of > 2.0 mm. The weight for the grain thickness stratification of > 2.2 mm,

Table 7. Multiple regression analysis between different grain thicknesses and yield.

	Multiple correlation coefficient	Coefficient of determination	Partial regression coefficient (Weight)			
			> 2.2	> 2.0	> 1.8	> 1.6
Yield	0.952***	0.906	-0.175 (11.52%)	0.608 (40.04%)	-0.128 (8.46%)	0.607 (39.98%)
Chalkiness	0.833**	0.694	1.165 (18.29%)	-1.005 (15.78%)	-2.173 (34.12%)	2.025 (31.81%)
Milled rice rate	0.975***	0.951	-0.245 (10.08%)	0.885 (36.44%)	0.772 (31.77%)	-0.527 (21.71%)
Milled rice taste	0.727*	0.529	-0.707 (7.67%)	-1.284 (13.92%)	4.300 (46.64%)	-2.930 (31.77%)
Rice taste	0.869**	0.755	1.122 (26.46%)	0.960 (22.64%)	-1.776 (41.87%)	0.383 (9.03%)

*There were significant differences at the level of 5%. **There were significant differences at the level of 1%. ***There were significant differences at the level of 0.1%.

> 2.0 mm, > 1.8 mm, and > 1.6 mm for milled rice taste was 7.67%, 13.92%, 46.64%, and 31.77%, respectively. The milled rice taste was most affected by the stratification of > 1.8 mm. The weight for the grain thickness stratification of > 2.2 mm, > 2.0 mm, > 1.8 mm, and > 1.6 mm for the taste parameter of the rice was 26.46%, 22.64%, 41.87%, and 9.03%, respectively. The biggest influence on the taste of the rice was observed for the stratification of > 1.8 mm.

4 Results and discussion

The studied rice is composed of brown rice with various grain thicknesses. Since changes in the grain thickness of brown rice directly reflects the richness of the stored substances, it also affects the taste of the rice and the characteristics of its physics and chemistry. In rice production, to achieve uniform quality after rice drying, other processes should be carried out, such as husking, grain selection, and milling. Among these processes, removing foreign matter and bad grains from rough rice and further grading the rice to obtain high-quality brown rice is called grain selection. This method of brown rice grain selection was used to remove broken rice (immature rice, dead rice, broken rice, etc.) with small grain thicknesses, i.e., the so-called grain thickness selection method. After that, near-infrared light screening was used to irradiate the rice to identify the different colored grains and white immature grains; next, a color separator using high-pressure gas to eliminate such grains was developed, which is widely used in joint drying and particle separation storage facilities around the country.

The traditional grain thickness selection method employed in Japan involves selecting the whole grain according to the 1.8 mm standard. However, with continuous growth in the market requirements for rice quality, this selection standard has been further strengthened. Now, the 1.85-1.90 mm standard is widely used in the production of high-quality edible rice. There are also areas that pay more attention to the production of high-quality edible rice with large investments and have developed the use of the 1.95-2.00 mm standard for granular separation. There is a significant correlation between the thickness and taste of brown rice. The comprehensive evaluation of the taste of rice with large grain thickness has been improved, and the taste of rice with a grain thickness of less than 1.90 mm has been significantly reduced. For the same variety, selecting rice grains with large grain thickness can improve the taste aspect, which was the conclusion of previous studies (Matsue et al., 2001; Ishizuki et al., 2013; Arroyo et al., 2022). However, the larger the standard grain thickness, the lower the rice yield, and the greater the loss for the producers. Japan has put into practice a new method for selecting high-quality edible rice grains whose grain thickness is lower than the standard grain thickness, coupled with color selection equipment. Abdelbasset et al. (2022) clarified the level that contributes to the improvement of qualities by combining optical (color) sorting and grain thickness sorting in "Kirara 397" produced in Hokkaido, while Sato & Kyoya (2005) clarified the level that contributes to the improvement of qualities. We presented the optimum sieving process using color selection to improve the grain size ratio of "Akitakomachi," "Menkoina," and "Hitomebore." In Iwate Prefecture, "Hitomebore," which has been sorted by a grain thickness of 2.0 mm or more and has cleared a certain taste value, is called "Iwate Junjou Premium Hitomebore" and is being branded (Sato & Kyoya, 2005). However, there are no known examples of evaluating the effect of grain thickness selection on instrumental analysis scores, such as taste meters, or of clarifying the optimum selection level using Chinese paddy rice varieties. Therefore, this study selected nine japonica rice varieties bred in Jilin Province and analyzed the grain thickness classification characteristics of the same as well as examined the correlation between different grain thicknesses and yield and quality.

The analysis of the grain thickness of nine main japonica rice varieties from Jilin Province revealed that the grain thickness grading ratio of the tested varieties decreased from large to small (Figure 1). The average ratio for > 2.2 mm was 54.94%, was 34.86% for 2.0-2.2 mm, was 8.11% for 1.8-2.0 mm, was 1.54% for 1.6-1.8 mm, and was 1.54% for > 1.6 mm. There were significant differences among the varieties in terms of grain thickness grading. The grain thickness grading of > 2.0 mm accounts for about 90%. There was a negative correlation between grain thickness of > 2.2 mm and other grain thicknesses; this indicated that other grading ratios begin to decrease with an increase in the proportion of high-grain-thickness brown rice.

However, the thickness grading of < 2.0 mm showed a strong, positive, and significant correlation with the secondary grading, which suggested that the proportion of low-grain-thickness grading increases or decreases together (Table 3). Different grain thicknesses had a significant influence on the grains per panicle and seed setting rate. There was a significant positive correlation between the grains per panicle and seed setting rate and the grain thickness grading of > 2.2 mm, and there was a significant negative correlation with the grain thickness grading < 2.0 mm (Table 4). This showed that the increase in the grains per panicle and seed setting rate would increase the grain thickness of brown rice and vice versa. In terms of panicle type, large panicle and loose panicle varieties produced brown rice with thicker grain thickness relatively more easily. As for the influence of grain thickness on processing quality, a strong and significant negative correlation was identified between each grain thickness of < 2.0 mm and processing quality (Table 5). This indicated that the low-grain-thickness brown rice was easy to break and involved the production of broken rice during processing, which had poor processing quality. The correlation between different grain thicknesses and appearance quality was not strong. In this study, a significant positive correlation was observed between the grain thickness grading of > 2.2 mm and the appearance, texture, and rice taste parameters. In contrast, the grain thickness grading of 2.0-2.2 mm presented a significant negative correlation with appearance, texture, and rice taste. Because the grain thickness grading in this experiment mainly involved the two grain thicknesses of > 2.2 mm and 2.0-2.2 mm, the proportion of other grain thicknesses was relatively small. Therefore, it can be concluded that grain thickness had a positive effect on taste quality, i.e., taste quality improved with an increase in grain thickness, which is consistent with previous studies (Zhang, 2017; Meng et al., 2009). However, in this study, the correlation between each grain thickness grading and the physicochemical and viscoelastic properties was not strong (Table 6). The results of the multiple regression analysis with different grain thicknesses as the independent variables and various quality characteristics of the rice varieties as the dependent variables demonstrated that there was a strong and significant correlation between the different grain thicknesses and the various quality characteristics. The grain thickness of > 2.0 mm had a significant impact on the yield and processing quality, while that of > 1.8 mm had a considerable influence on appearance and taste (Table 7).

Combined with the above analysis results, it could be concluded that the ratio of high-grain-thickness brown rice would increase with an improvement in yield and processing quality; further, an increase in the low-grain-thickness grading ratio would lead to a decline in appearance and taste. The results of the analysis of the correlation between different rice yield characteristics and grain thicknesses are shown in Figure 2. In the early stages of cultivation and management, the grains per panicle and seed setting rate were found to affect the grain thickness during the formation of yield components. The varieties with a higher number of grains per panicle and a higher seed setting rate also produced thicker grains of brown rice. On the contrary, it was thinner. Higher grain thickness was positively correlated with taste quality, while lower grain thickness was negatively correlated with taste, processing quality, and yield. However, in this study, the correlation between grain thickness and physicochemical properties was found to be insignificant, which is different from previous studies (Zhang, 2019). It was speculated that the reason behind this may be that all the tested varieties used in this study were japonica rice varieties, which were different from the indica rice varieties used in past research (Xu & Chen, 2004).

In conclusion, it can be said that the grain thickness of brown rice has a considerable impact on rice yield and quality. The higher the grain thickness of brown rice, the stronger the positive effect on its yield and quality, and the weaker the negative effects. Previous studies have confirmed that grain length, width, and thickness are independent genetic traits (Andrade et al., 2015). The results of this study also suggest that there are no significant correlations between grain thickness and grain type (aspect ratio), indicating that grain thickness could be recombined with other traits through genetic pathways. Based on the observed effect of grain thickness on yield and quality in this study, it could be beneficial to pay attention to the grain-related traits of the bred varieties, especially the choice of grain thickness in future breeding processes. Ensuring that the grain thickness of brown rice exceeds 2.0 mm is mostly done to meet the requirements of the market with regard to rice output quality.

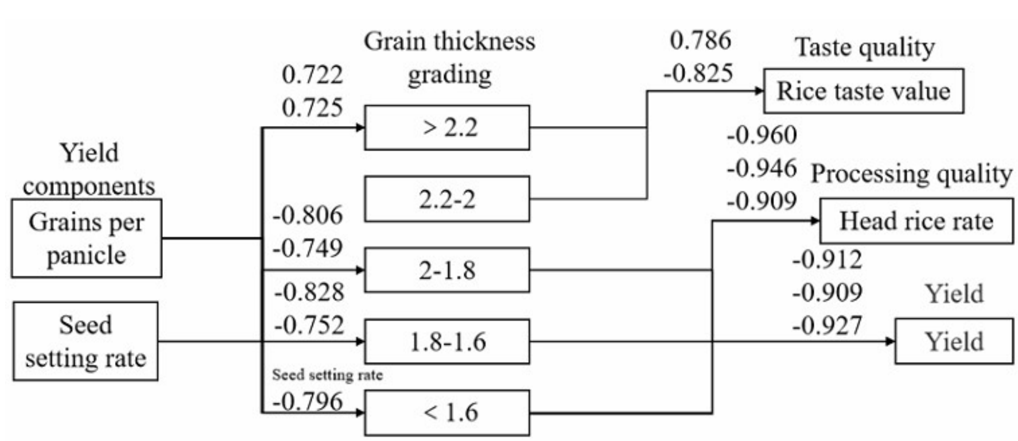

Figure 2. Correlation between grain thickness grading and rice characteristics.

Ethical approval

Not applicable.

Conflict of interest

The authors declare that they have no competing interests.

Availability of data and material

The datasets analyzed during the current study are not publicly available due some reason but are available from the corresponding author on reasonable request.

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Author contributions

Bing He, Chao Li & Xipeng Pan: Wrote original draft, participated in literature search and analyses, evaluations and manuscript preparation, as well as wrote the paper. Ziyu Wang, Junshi Zhao, Jianping Wang: Conceived and designed the manuscript, interpreted the data, and participated in project administration including resources, software, validation, visualization, conceptualization, investigation and methodology. Dianyuan Chen: Provide guidance on research proposals and provide provident fund support.

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