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Research article

EFFECTS OF DIFFERENT BROWN RICE BLENDING RATIOS ON TEXTURAL PROPERTIES, EATING QUALITY, AND GLYCEMIC INDEX IN RICE VARIETIES WITH VARIED GRAIN TYPES

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ABSTRACT
To determine the optimal blending ratio of white rice and brown rice that maintains acceptable eating quality while reducing glycemic index (GI), this study investigated rice varieties with different grain types from Jilin Province. Brown rice was blended with white rice at ratios of 10%, 15%, 20%, 25%, 30%, and 35%, followed by comparative analyses of textural properties, eating quality, and GI. Results demonstrated significant negative correlations between hardness and eating characteristics, with correlation coefficients above 0.7. Both the taste value of instrumental measurements and sensory evaluation exhibited significant declines when brown rice blending ratios exceeded 25%, with varietal differences observed in eating quality responses to blending ratios. The incorporation of brown rice effectively reduced postprandial blood glucose levels, with GI showing a pronounced decreasing trend as blending ratios increased. Multiresponse optimization revealed maximum desirability at a 20.52% brown rice blending ratio, yielding a sensory evaluation taste value of 2.29 and GI of 96.57.

1. Introduction

Jilin Province, one of China's primary rice (*Oryza sativa L.*) production regions, faces persistent challenges in agricultural profitability despite its leading position in rice cultivation area and yield. This situation underscores the urgent need to develop high-value-added rice products to enhance farmers' income. In recent years, with the increasing awareness of health and changes in lifestyle, brown rice has gained significant attention due to its rich nutritional value and health benefits (Jan *et al.*, 2020; Mir *et al.*, 2020). Brown rice retains the bran layer of the rice grain, making it richer in protein, fat, minerals, vitamins, and bioactive compounds such as phenolic acids, flavonoids, γ-oryzanol, and GABA compared to white rice. Brown rice contains stronger antioxidants, anticancer properties, and various other potential health benefits (Saleh *et al.*, 2019; Wu *et al.*, 2013), while white rice, which undergoes processing that removes the bran layer, has fewer nutrients but cooks quicker and has a softer texture (Gondal *et al.*, 2021). As a result, brown rice has certain disadvantages in terms of texture and convenience compared to white rice (Dror *et al.*, 2020). However, when white rice and brown rice are blended in different proportions, the soft texture of white rice can partially mask the coarse texture of brown rice, thereby enhancing the eating quality. Champagne *et al.* (2010) demonstrated significant varietal differences in both textural and eating quality of rice. Concurrently, Zhu *et al.* (2021) reported strong correlations between amylose content and textural properties across varieties with distinct grain types. Consequently, it is imperative to elucidate the effects of brown rice blending in white rice on quality parameters, particularly for varieties exhibiting significant grain-type variations.

At the same time, the high fiber and low GI characteristics of brown rice can effectively improve postprandial blood glucose response, contributing to the management of diabetes and metabolic syndrome. The composite rice produced by blending brown rice retains some of its beneficial properties while maintaining a desirable taste and helping manage blood glucose levels (Kaur *et al.*, 2016). But current research has primarily focused on the glycemic effects of rice with varying milling degrees (Sasaki *et al.*, 2016) or pure brown rice (Panlasigui & Thompson, 2006), leaving a critical gap in understanding how brown rice blending in white rice modulates glycemic response and GI dynamics.

Therefore, exploring the optimal blending ratio of white rice and brown rice to improve the eating experience while balancing nutritional value is an important research direction. As highlighted earlier, few studies have systematically investigated the combined impacts of brown rice-to-white rice blending ratios on both rice eating quality parameters and GI, particularly for dominant grain-type varieties in Jilin Province. To address this knowledge gap, the present study selected representative rice varieties with distinct grain types from Jilin Province. The study conducted systematic blending experiments with white rice and brown rice at graded ratios. This was followed by comprehensive analyses of the resultant eating quality modifications and glycemic implications. The findings will provide data support and theoretical insights for future improvements in rice marketing and branding in Jilin Province.

2. Materials and methods

2.1. Materials and experimental design

Table 1. Amylose and protein content of test varieties.

Varieties	Milling	Amylose content(%)	Protein content(%)
Wuyoudao4	Brown rice	15.77±0.05d	10.43±0.02a
	White rice	18.38±0.05c	7.69±0.02c
Jijing516	Brown rice	18.72±0.05b	9.90±0.02b
	White rice	19.26±0.05a	7.57±0.02d

Different lowercase letters indicate significant differences at the 5% level based on the Tukey-HSD test.

Two representative high-eating-quality rice varieties from Jilin Province were selected: the long-grain type Wuyoudao4 (grain length-to-width ratio = 2.7) and the short-grain type Jijing516 (grain length-to-width ratio = 1.7). Grain type data were obtained from the China Rice Data Center. All samples were harvested in autumn 2024 from adjacent fields under identical fertilization and irrigation management in Yilaxi Town, Yongji County, Jilin City, Jilin Province (126°12′ E, 43°63′ N).

For each variety, 5 kg of paddy rice was naturally dried to 18% moisture content. Brown rice was obtained by dehusking using a laboratory-scale huller (FC-2K; Otake, Aichi, Japan), followed by polishing to 90% milling yield using a compact rice mill (VP-32; Yamamoto, Yamagata, Japan) to produce white rice. The unmixed white rice served as the control, hereafter denoted as CK. Amylose and protein contents of CK samples and brown rice were determined using a near-infrared grain analyzer (Infratec; FOSS, Denmark), with results provided in Table 1. Six blending treatments were prepared by blending brown rice with white rice at ratios of 10%:90%, 15%:85%, 20%:80%, 25%:75%, 30%:70%, and 35%:65%, hereafter denoted as 10%, 15%, 20%, 25%, 30%, and 35%, respectively.

2.2. Methods

2.2.1. Textural properties and instrumental eating characteristics

Textural properties and instrumental eating characteristics of CK and blended samples were analyzed following modified protocols from Xu *et al.* (2019) and Yang *et al.* (2025). For each sample, 30 g of rice was rinsed for 30 s, soaked in a 1:1.2 rice-to-water ratio for 30 min, and steamed for 30 min followed by 10 min of equilibration. After cooling for 10 min, 8 g of cooked rice was compressed into a cake using a stainless steel ring with 10 s compression.

Textural properties (hardness, viscosity, balance, and elasticity) were quantified using a hardness-stickiness texture analyzer (RHS1A; Satake Corporation, Hiroshima, Japan). Instrumental eating characteristics (appearance, mouthfeel, and taste value) were measured with a rice taste meter (STA1B; Satake Corporation, Hiroshima, Japan).

2.2.2. Sensory evaluation

Sensory evaluation followed Kawada *et al.* (2024) with modifications. Informed consent was obtained from all subjects involved in the study. CK and blended samples were rinsed 3–4 times, soaked for 30 min, and cooked in a 1:1.2 rice-to-water ratio using a household rice cooker (CFXB50FC9133Q-75; Supor, Zhejiang, China). Cooked samples were maintained at 30 °C for evaluation in a controlled environment free from external interference.

A panel of 25 trained evaluators (11 males, 14 females; age range: 20–49 years) from Jilin Agricultural Science and Technology University participated. The white rice of the Jiyujing variety, grown under identical agronomic conditions in the same field, served as the benchmark. Sensory scores for hardness, taste, stickiness, and taste value were recorded using criteria outlined in Table 2.

Table 2. Sensory Evaluation Criteria

Item	Score		
Hardness, Taste, Stickiness, Taste value	+3~+1	0	-1~-3

Hardness: hard (+), soft (-); Taste: smooth and sweet, delicious (+), opposite (-); Stickiness: chewy and sticky (+), dry and not sticky (-); Taste value: like it more than the standard (+), dislike it (-).

±3: Feel very strong; ±2: Can clearly feel the difference after just one bite. ±1: Can't tell the difference clearly after one bite, but after two or three bites get the feeling. 0: No difference no matter how many bites.

2.2.3. Blood glucose measurement and GI calculation

Postprandial blood glucose levels were measured following Kawada *et al.* (2024). The study was approved by the Experimental Research Ethics Committee of Jilin Agricultural Science and Technology University (Ethics No. LLSC202506001). Fifteen healthy volunteers from Jilin Agricultural Science and Technology University (9 males, 6 females; age range: 20–23 years; BMI range: 18.6–24.1 kg/m2) participated. Participants had no history of metabolic disorders, recent medication/supplement use (including contraceptives), or serious illnesses/hospitalizations within the preceding three months. After fingertip disinfection, blood samples were collected using sterile lancets, and glucose concentrations were quantified with an automated glucometer (GU200; YUWELL, Jiangsu, China). Baseline fasting blood glucose (0 min) was measured prior to consumption. Test meals included: 50 g glucose dissolved in water (reference), CK, Brown rice-blended samples (prepared identically to sensory evaluation protocols). Participants consumed each meal within 12–15 min. Subsequent glucose measurements were taken at 30, 60, 90, and 120 min postprandially.

Glycemic Index (GI) was calculated using the formula:

$$\text{GI} = \left(\frac{\text{Area under the blood glucose curve of the test meal (120 min)}}{\text{Area under the blood glucose curve of 50g glucose (120 min)}}\right) \times 100\% \quad (1)$$

Multiresponse Optimization Based on Regression Models and Desirability Function

The Harrington (1965) desirability function and Derringer and Suich (1980) multiresponse optimization methodology were applied. Regression models were established between brown rice blending ratios and two responses: sensory evaluation taste value with linear model and GI with quadratic model.

Desirability functions:

Sensory taste value: Larger-the-better characteristic.

Lower limit: 1.90 (predicted at 35% blending ratio).

Upper limit: 2.88 (predicted at 0% blending ratio).

$$d_{\text{Sensory taste value}} = \frac{Y_{\text{Sensory taste value}} - 1.90}{2.88 - 1.90} \quad (2)$$

GI: Smaller-the-better characteristic

Lower limit: 92.20 (predicted at 35% blending ratio).

Upper limit: 99.95 (predicted at 0% blending ratio).

$$d_{\text{Gi}} = \frac{99.95 - Y_{\text{GI}}}{99.95 - 92.20} \quad (3)$$

Overall desirability (D) was calculated as:

$$D = \sqrt{d_{\text{Sensory taste value}} \times d_{\text{Gi}}} \quad (4)$$

2.3. Data analysis

All data were analyzed using JMP 18 Pro (SAS Institute, North Carolina, USA). Graphical representations were generated with Origin 2025 (OriginLab, Saitama, Japan) .

3. Results and discussions

3.1. Textural properties

Figure 1 illustrates the textural properties of different treatments for the tested varieties. Ren *et al.* (2020) demonstrated that cooked brown rice exhibits significantly higher hardness than white rice. Zhang *et al.* (2015) attributed this to the cellulose and hemicellulose in the bran layer of brown rice, which hinder starch granule hydration and gelatinization, thereby increasing hardness. The results of this experiment showed the hardness varied significantly across treatments, with a pronounced increase as brown rice blending ratios rose.

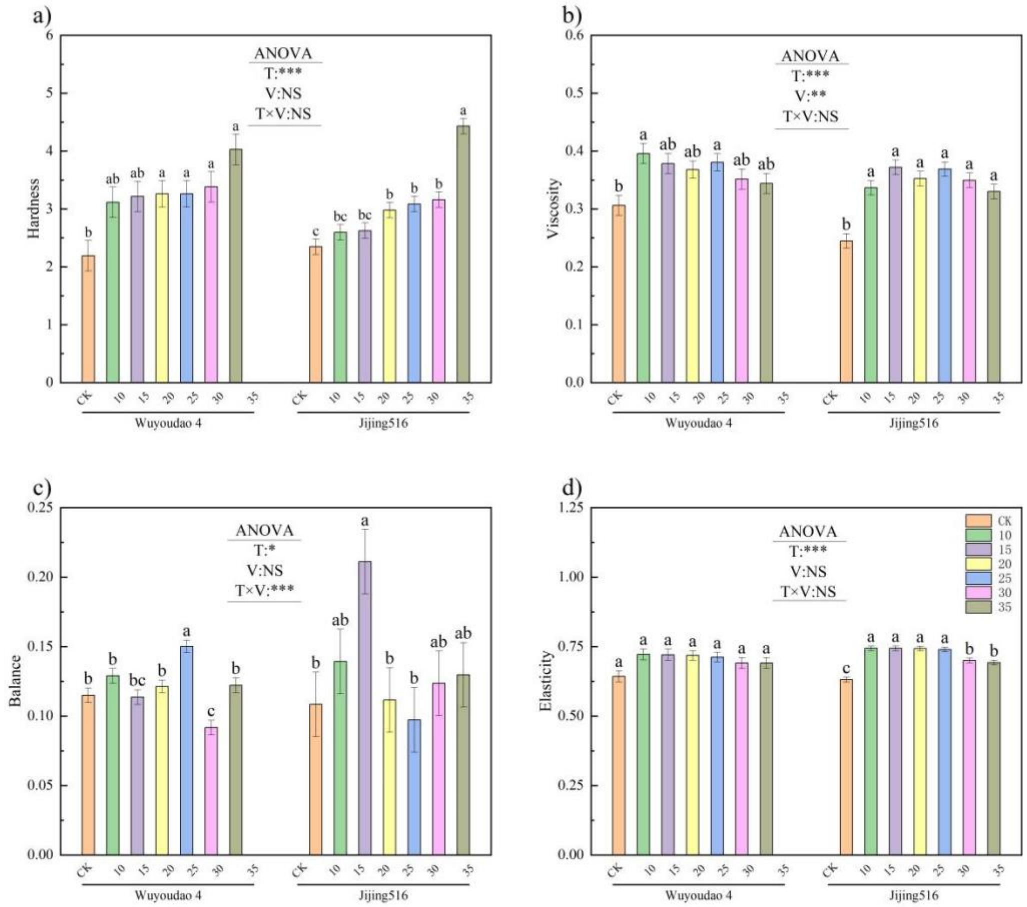

Figure 1. Texture Properties. Different lowercase letters indicate significant differences at the 5% level based on the Tukey-HSD test

The CK hardness values for Wuyoudao4 and Jijing516 were 2.19 and 2.35, respectively, both substantially lower than treatments with ≥ 20% brown rice blending. At 35% blending, hardness surged to 4.03 for Wuyoudao4 and 4.43 for Jijing516. Ahmad *et al.* (2017) further confirmed that higher milling degrees increase water absorption during cooking, resulting in softer texture and faster gelatinization. This phenomenon can be attributed to amylose–aroma compound complexes in brown rice, which enhance intermolecular interactions during cooling, thereby amplifying hardness (Wang *et al.*, 2022). Viscosity also exhibited significant treatment-dependent variations. Both varieties peaked at 15% and 25% blending ratios before decreasing. The CK viscosity for Wuyoudao4 was 0.31 and for Jijing516 was 0.24, were markedly lower than blended treatments. This aligns with Kim *et al.* (2012) observation of similar trends in thermal pasting properties when blending white rice with germinated brown rice. This is likely due to the release of crude fiber from brown rice into cooking water, which elevates viscosity (Oppong *et al.*, 2021). Li *et al.* (2024) established strong correlations between textural properties and amylose content, corroborating the varietal differences in viscosity observed. Wuyoudao4 exhibited higher viscosity than Jijing516, reflecting the latter's higher amylose content which was shown in Table 1. Elevated amylose content suppresses starch gelatinization, reducing viscosity (Tao *et al.*, 2019; Zhang *et al.*, 2013). Pang *et al.* (2016) noted that long-grain varieties generally have lower amylose content than short-grain types, though Kitara *et al.* (2019) identified a weak negative correlation between amylose content and grain morphology, potentially due to genetic variability across populations. There were significant differences in balance between treatments, and it showed significant treatment

× variety interactions in this experiment. For Wuyoudao4, balance peaked at 0.15 under the 25% blending ratio, while Jijing516 reached its maximum of 0.21 at 15% blending. Wuyoudao4 showed no significant inter-treatment differences in elasticity, though its CK elasticity of 0.64 was lower than blended treatments. Conversely, Jijing516's CK elasticity of 0.63 was notably lower than other treatments. Balance and elasticity also varied significantly across treatments driven by differences in physicochemical traits, particularly amylose content (Singh *et al.*, 2005). While elasticity mirrored the viscosity trend, increasing initially before declining at higher blending ratios.

3.2. Eating characteristics

Figure 2 presents the instrumental measurement eating characteristics of different treatments for the tested varieties. Significant treatment and variety dependent differences were observed across all instrumental measurement eating characteristics. CK for Wuyoudao4 scored 8.28 in appearance and 7.57 in mouthfeel, while Jijing516 achieved 7.79 and 7.49, respectively. Both metrics showed a progressive decline with increasing brown rice blending ratios, reaching the lowest values at the 35% blending ratio. Rodríguez-Arzuaga *et al.* (2016) reported superior appearance in white rice compared to brown rice, consistent with our findings. Gondal *et al.* (2021) highlighted consumer preference for white rice over brown rice due to differences in texture and color. Tran *et al.* (2004) further demonstrated that reduced milling degrees correlate with declining taste values. Significant treatment × variety interactions were detected for instrumental appearance and taste value, indicating divergent responses to blending ratios between varieties.

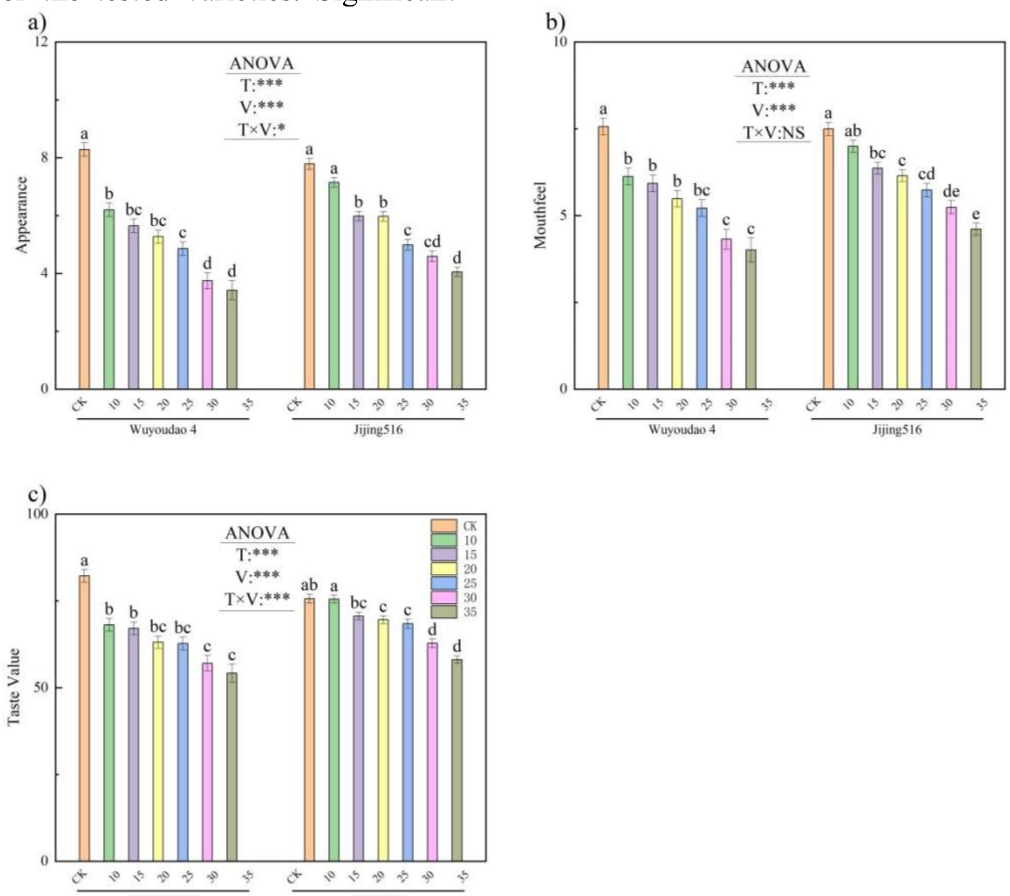

Figure 2. Instrumental measurement eating characteristics. Different lowercase letters indicate significant differences at the 5% level based on the Tukey-HSD test

Similarly, Da Graça *et al.* (2024) noted that despite masking strategies by specific dishes, consumers still prefer white rice over brown rice. Figure 3 displays the sensory evaluation eating characteristics of different treatments. The CK hardness values for Wuyoudao4 and Jijing516 were 1.32 and 1.68, respectively, both significantly lower than blended treatments and increasing linearly with higher blending ratios. Conversely,taste and stickiness decreased linearly with higher blending ratios. CK taste for Wuyoudao4 was 2.84 and Jijing516 was 2.72, along with stickiness were 2.64 and 2.32, respectively. Hardness, stickiness, and taste value exhibited significant varietal differences, with Wuyoudao4 outperforming Jijing516 in all three metrics. A notable treatment × variety interaction was observed for hardness, at 35% blending, Wuyoudao4 hardness surged to 2.64 with 100% increase over CK, whereas Jijing516 increased only 45.2%.

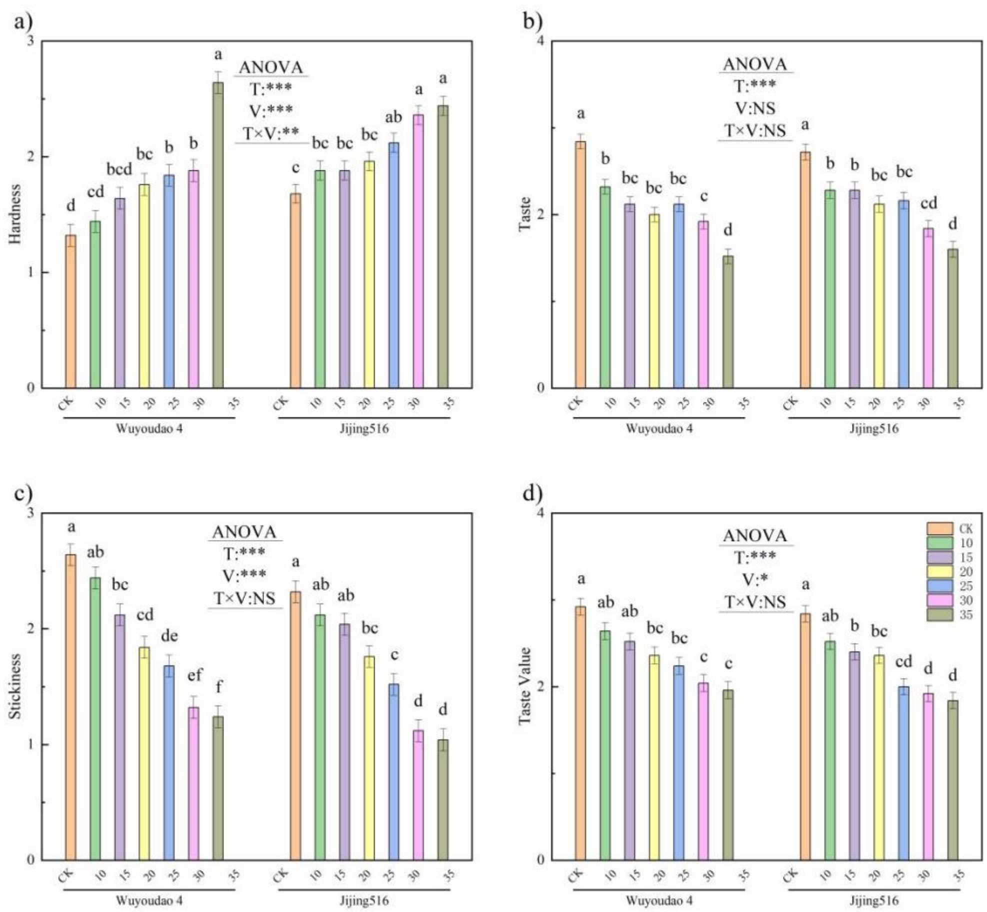

Figure 3. Sensory evaluation eating characteristics. Different lowercase letters indicate significant differences at the 5% level based on the Tukey-HSD test.

3.3. Relationships between textural and eating characteristics

Figure 4 illustrates the correlations between textural properties, instrumental measurements and sensory eating characteristics across treatments. The correlation coefficient between viscosity and elasticity was 0.78 ($p = 0.0010$). As shown in Figures 1b and 1d, both parameters exhibited an initial increase followed by a decline with rising brown rice blending ratios. Meullenet *et al.* (1998) reported a strong linear correlation between the hardness instrumental and sensory, whereas Rousset *et al.* (1995) identified a weaker correlation ($r=0.58$). In this study, textural hardness and sensory hardness showed a significant positive correlation. The correlation coefficient between the textural hardness and sensory hardness was 0.71 ($p = 0.0043$). With the exception of sensory hardness, all instrumental and sensory eating characteristics exhibited strong positive correlations. Notably, the correlation coefficient between instrumental taste value and sensory taste value was 0.84 (p = 0.0002). Instrumental taste value and sensory taste value demonstrated a highly significant correlation, indicating consistent evaluations across methods.

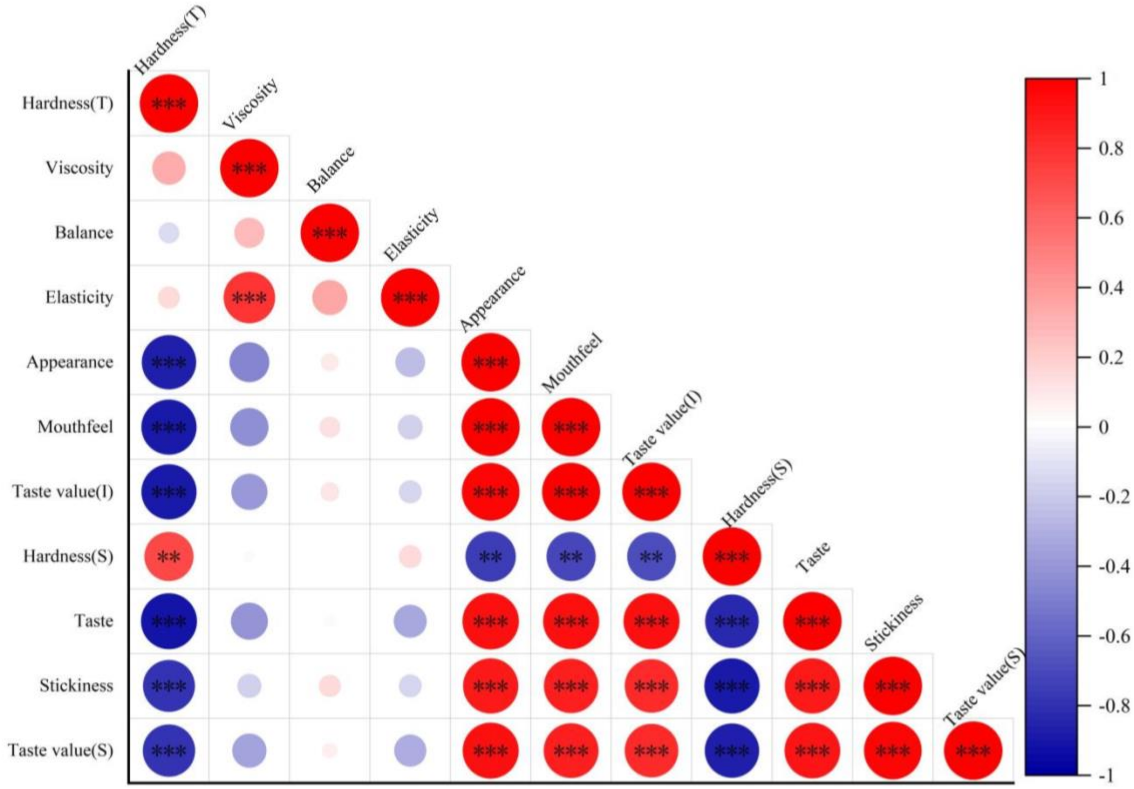

Figure 4. Correlations between textural properties, instrumental measurements and sensory eating characteristics. (T): textural properties, (I): instrumental measurements eating characteristics, (S): sensory eating characteristics. *: p≤0.05, **: p≤0.01, ***: p≤0.001.

The correlation coefficient between textural hardness and instrumental taste value was -0.90 (p = 0.0001), and sensory taste value was -0.80 (P = 0.0006). While the correlation coefficient between sensory hardness and instrumental taste value was -0.70 (p = 0.0057), and sensory taste value was -0.87 (p = 0.0001). Prior studies have established texture as the dominant sensory attribute for foods with low flavor intensity (Izutsu & Wani, 1985). Honma *et al.* (2019) through principal component analysis of 18 sensory attributes in brown rice, identified textural properties as the primary determinant of eating quality. Ma *et al.* (2021) further corroborated this by demonstrating the predominant influence of textural properties on taste value across 39 Chinese japonica rice varieties. In this study, textural hardness and sensory hardness both showed significant negative correlations with other eating characteristics. These results confirm that increased hardness corresponds to declining taste values. The inferior palatability of brown rice is attributed to the bran layer tightly encasing the endosperm, which impedes water penetration into the grain (Horigane *et al.*, 2013). This structural barrier delays starch hydration and gelatinization, resulting in prolonged cooking times, increased hardness, and insufficient chewiness. Based on these findings, hardness in brown rice-blended samples emerges as the most critical factor influencing taste value.

3.4. Effects of variety and brown rice blending ratios on taste value

Zhao *et al.* (2023) demonstrated that rice varieties exhibit distinct sensory, pasting, and taste properties under varying milling degrees. Jiao *et al.* (2022) identified a significant positive correlation between grain length-to-width ratios and taste scores among 22 japonica rice varieties in Jilin Province. There were significant differences in the instrumental measurement taste values and sensory taste values of the tested varieties among the treatments as shown in Figure 2c and 3d. To compare taste value differences between varieties across blending ratios, 3D plots of instrumental and sensory taste values were generated in Figure 5.

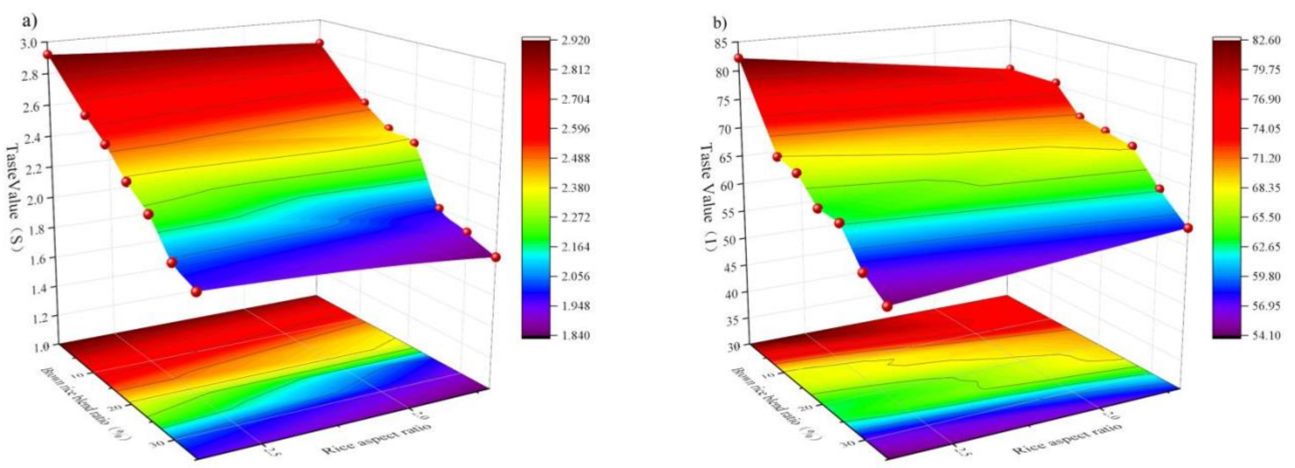

Figure 5. 3D plots of instrumental and sensory taste values. (I): instrumental measurements eating characteristics, (S): sensory eating characteristics.

The CK for Wuyoudao4 (grain length-to-width ratio = 2.7) achieved instrumental and sensory taste values of 82.2 and 2.92, respectively, surpassing 75.60 and 2.84 of Jijing516 (length-to-width ratio = 1.7). Moreover, the sensory evaluation taste values of Wuyoudao4 in different treatments were higher than jijing516. When the brown rice blending ratio was 35%, the sensory taste value of Wuyoudao4 was 1.96 and Jijing516 was 1.84. In contrast, the instrumental measurement taste values of Wuyoudao4 in different treatments were lower than that of Jijing516. When the brown rice blending ratio was 35%, the instrumental measurement taste value of Wuyoudao4 was 54.17 and Jijing516 was 58.07. Both the sensory and instrumental measurement taste values decreased significantly when the brown rice blending ratio > 25%. Gyawali *et al.* (2022) reported a marked decline in taste value with higher blending ratios, yet 83% of participants favored the 25% blending treatment. In this study, both instrumental and sensory taste values for the tested varieties declined more rapidly at blending ratios > 25%, with the 30% and 35% treatments showing significantly lower values than others as shown in Figures 2c and 3d. These results indicate that brown rice blending in white rice substantially alters taste value, with the magnitude of impact varying by variety. A critical threshold exists at 25% blending, exceeding this ratio significantly reduced taste values.

3.5.Postprandial blood glucose dynamics and GI

Tran *et al.* (2004) demonstrated that sucrose content in rice increases with higher milling degrees. Huang *et al.* (2021) confirmed that cooked brown rice reduces glucose generation rates by 31% and lowers total glucose production from starch digestion by 11% compared to white rice. Mohan *et al.* (2014) further reported that substituting white rice with brown rice significantly attenuates glycemic responses. Figure 6 illustrates postprandial blood glucose trajectories and calculated GI for different brown rice blending treatments. Fasting blood glucose levels averaged 5.27 mmol/L across all participants, peaking at 30 min postprandially. A gradual decline occurred from 30 to 60 min, followed by a rapid decrease from 60 to 90 min, before stabilizing near 5.16 mmol/L by 120 min. Glucose-loaded meals, CK, and 10%-15% blended treatments elicited significantly higher 30-min glucose peaks than treatments with ≥25% blending. When blending ratios reached ≥20%, the postprandial glucose decline from 30 to 60 min accelerated significantly, resulting in lower 60-min glucose levels compared to CK. This trend persisted from 60 to 90 min, with ≥20% blends showing markedly lower 90 min glucose levels than ≤ 10% blends. The attenuated glycemic response in brown rice is attributed to its bran layer, which delays gastric emptying and slows glucose absorption (Pletsch & Hamaker, 2018).

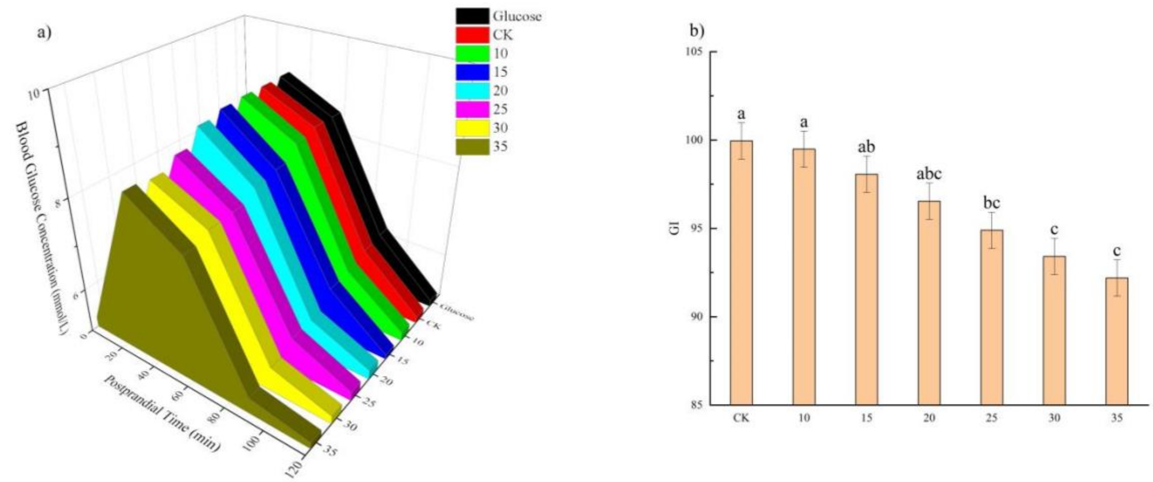

Figure 6. Postprandial blood glucose trajectories and calculated GI.

Numerous studies have established brown rice's lower GI compared to white rice (Kaur *et al.*, 2016; Kong *et al.*, 2011). The GI decreased significantly with the increase of brown rice blending ratio. The CK and 10% blend exhibited the highest GI of 99.95 and 99.49 respectively, while the 35% blend achieved the lowest GI of 92.20, representing a 7.75% reduction from CK. These findings align with Panlasigui and Thompson (2006) who reported a 12.1% GI reduction for pure brown rice. However, all treatments in this study exhibited GI ⩾92, classifying them as high-GI foods.

3.6. Optimal brown rice blending ratio screening via multiresponse desirability optimization

Zhang *et al.* (2010) revealed that Chinese adults consistently perceive brown rice as inferior in taste and quality. Brown rice consumption has demonstrated significant benefits for chronic disease management, including diabetes (Saleh *et al.*, 2019; Sun *et al.*, 2010). Thus, identifying a blending ratio that balances acceptable eating quality with glycemic control is critical. Jeong and Kim (2009) detailed the desirability function approach for optimizing multiple conflicting response variables, enabling mathematical reconciliation of competing objectives. In order to identify a blending ratio that balances acceptable eating quality with glycemic control. In this study, brown rice blending ratios were treated as the independent variable, with sensory taste value and GI as response variables. Regression models were established, and desirability curves derived from predicted values are shown in Figure 7. The sensory taste value followed a linear decline: Y = 2.883 - 0.029X (R^2 = 0.95, p =0.0001). GI exhibited a quadratic relationship: Y=101.821-0.2554X-0.004X2 (R^2 = 0.98, p=0.0394). Sensory taste value decreased linearly, while GI declined exponentially with increasing blending ratios. Correspondingly, desirability curves for both responses mirrored these trends, whereas overall desirability initially rose before declining beyond a threshold. Desirability curves of sensory taste value and GI intersect when the brown rice blending ratio was 20.52%. The overall desirability also reached the peak at a brown rice blending ratio of 20.52%. Multiresponse optimization identified 20.52%

as the optimal blending ratio, yielding a sensory taste value of 2.29 and GI of 96.57.

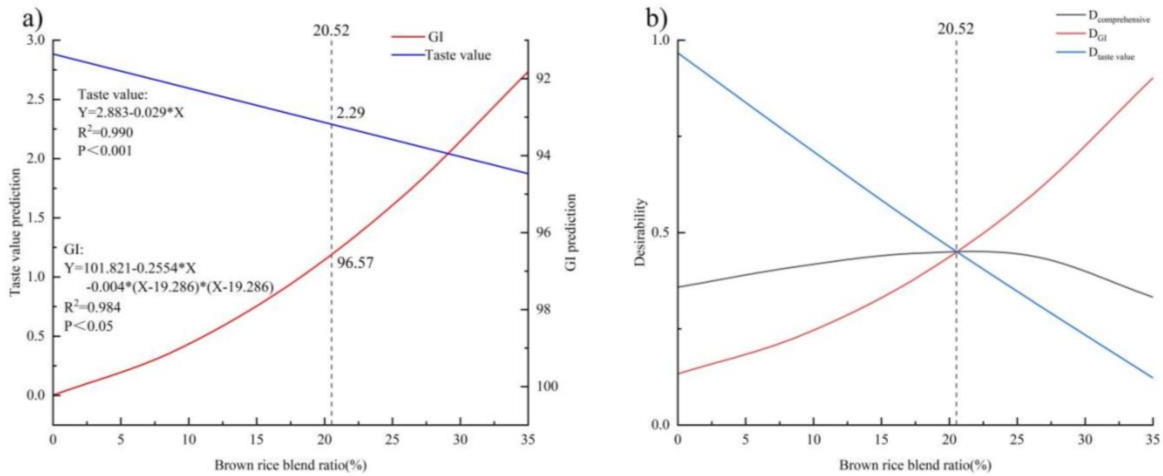

Figure 7. Regression models and desirability curves. The dotted line represents the maximum desirability.

4. Conclusion

This study systematically investigated the effects of brown rice blending ratios on eating quality and glycemic response using japonica rice varieties with distinct grain types from Jilin Province. The results demonstrated that increasing brown rice blending ratios induced significant treatment-dependent differences in both textural properties and eating characteristics, indicating progressive quality deterioration in these parameters. Hardness exhibited significant negative correlations with eating quality metrics with correlation coefficient > 0.70. Both the taste value of instrumental measurements and sensory evaluation exhibited significant declines when brown rice blending ratios exceeded 25%, with varietal differences observed in eating quality responses to blending ratios. The incorporation of brown rice effectively reduced postprandial blood glucose levels, with GI showing a pronounced decreasing trend as blending ratios increased. Multiresponse optimization revealed maximum desirability at a 20.52% brown rice blending ratio, yielding a sensory evaluation taste vaule of 2.29 and GI of 96.57.

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