

Article

Analysis of the Relationship Between Assimilate Production and Allocation and the Formation of Rice Quality

Jianming Tu ^{1,2,†}, Fengting Wen ^{1,3,†}, Feitong Li ⁴, Tingting Chen ¹ , Baohua Feng ¹, Jie Xiong ³, Guanfu Fu ¹ , Yebo Qin ^{5,*} and Wenting Wang ^{1,*}

¹ State Key Laboratory of Rice Biology and Breeding, China National Rice Research Institute, Hangzhou 310006, China; tujianming2025@126.com (J.T.); wft1538352651@163.com (F.W.); chentingting@caas.cn (T.C.); fengbaohuag@caas.cn (B.F.); fuguanfu@caas.cn (G.F.)

² Tongxiang Agricultural Science Research Institute, Jiaying Academy of Agricultural Sciences, Tongxiang 314500, China

³ School of Life Sciences and Medicine, Zhejiang Sci-Tech University, Hangzhou 310018, China; jhexiong@zju.edu.cn

⁴ Faculty of Life Sciences, Nanjing Agricultural University, Nanjing 210000, China; 10123110@stu.njau.edu.cn

⁵ Agricultural Technology Extension Center of Zhejiang Province, Hangzhou 310029, China

* Correspondence: qyb.leaf@163.com (Y.Q.); wwt_yzu@163.com (W.W.)

† These authors contributed equally to this work.

Abstract: Rice is one of China's primary staple crops, serving as the main food source for over 60% of the population. With the resolution of basic food security issues in China in recent years, the demand for high-quality rice has been steadily increasing. The taste quality of rice, a crucial indicator for evaluating rice quality, has attracted more attention from consumers. Although factors like variety, growing environment, and cultivation methods affect rice taste quality, the underlying mechanisms remain unknown, and no reliable control methods exist. This study selected 10 major rice cultivars, including 6 indica and 4 japonica varieties, and compared their differences in taste quality, focusing on yield and its components, taste quality, and dry matter accumulation. Among the tested varieties, Songxiangjing 1018 had the best taste quality, but not the highest yield. Zhongzheyong 8, Huazheyong 261, and Quanyousimiao showed both excellent taste quality and high yield. There was no significant correlation between taste quality and yield, suggesting the feasibility of breeding rice varieties with both superior taste and high productivity. Correlation analysis indicated that dry matter mass and net photosynthetic rate were significantly positively correlated with yield, but not with taste quality, highlighting the complexity of taste quality formation. Using a membership function comprehensive evaluation method (combines the outputs of multiple membership functions into a single composite value using specific rules (e.g., weighted average, extremum, logical operations) to produce a new membership degree.), a rice variety selection system balancing yield and quality was constructed, and three varieties (Zhongzheyong 8, Huazheyong 261, and Quanyousimiao) were identified as having both high yield and excellent quality. The results of this study can provide a theoretical basis for research on cultivation techniques and variety breeding aimed at synergistically improving rice yield and quality.

Keywords: rice; taste quality; yield; dry matter accumulation; variety selection; membership function



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1. Introduction

Rice, as one of the primary staple crops, plays an extremely important role in global food security, particularly in China as well as in East and Southeast Asia [1]. In recent years,

as living standards improve, the demand for high-quality rice has been increasing. Rice quality, which includes chalkiness, head rice rate, protein content, amylose content, and cooking quality, is influenced by various factors such as varietal characteristics, fertilizer and water management, and environmental conditions. These factors primarily affect the quality formation through the production and utilization of assimilates [2–4]. Non-structural carbohydrates (NSCs) are the main form of assimilates, primarily composed of soluble sugars and starch, with sucrose being the primary form of photosynthetic assimilates transported over long distances from source tissues to sink tissues [5]. Generally, the post-anthesis translocation of assimilates from leaf sheaths to filling grains significantly contributes to the yield of cereal crops [6,7]. The assimilates for rice grain filling mainly come from the photosynthetic assimilates produced by leaves during the grain-filling stage and the pre-stored non-structural carbohydrates in leaf sheaths and stems before heading [8–10]. Under normal conditions, the NSC content stored in leaf sheaths and stems before heading accounts for about 20% to 40% of the final grain yield [11]. Therefore, a higher NSC content in leaf sheaths is beneficial for grain filling.

The impact of assimilate production and utilization on rice yield has been extensively reported, but research on its relationship with the formation of grain quality is relatively scarce [12–14]. Recent studies suggest that the “source-sink-flow” relationship not only affects yield formation but also significantly influences the formation of rice quality and stress resistance [4]. Improving the “source-sink-flow” relationship, i.e., optimizing the production and utilization of assimilates, can synergistically enhance rice yield, quality, and stress resistance [15]. Generally, crop productivity can be increased by regulating source activity or sink strength; source activity is regulated through photosynthesis and nutrient transport rates, while sink strength is regulated through the synthesis rates of assimilates or macromolecules (such as starch and proteins). Insufficient sink strength or slow sugar transport can lead to carbohydrate accumulation in source organs, resulting in carbon imbalance and affecting the formation of rice yield and quality [16]. Photosynthesis is the physiological metabolic process by which crops synthesize carbohydrates, forming the basis of crop yield and biomass, and has a significant impact on the formation of crop yield and quality. However, the relationship between photosynthesis and grain quality remains to be further elucidated. This experiment aims to study the differential changes in photosynthesis, dry matter mass, and carbohydrates of different rice varieties during various growth stages and their effects on rice quality. Innovatively employing correlation analysis and membership comprehensive function, the study conducts multi-perspective evaluations of the influence degree and weight coefficients of various indicators at distinct growth stages on yield and quality parameters. The objectives are to explore the theoretical foundation for synergistic improvement of both rice yield and quality, and to provide regulatory strategies for achieving coordinated enhancement of production performance and grain quality characteristics.

2. Materials and Methods

2.1. Materials and Experimental Design

This experiment was conducted at the Fuyang Base of the China National Rice Research Institute from 2022 to 2023. The experimental materials used in this study included the following indica rice varieties: Meixiangzhan 2 (MXZ 2), Taoyouxiangzhan (TYXZ), Quanyousimiao (QYSM), Yixiangyou 2115 (YXY 2115), Zhongzheyu 8 (ZZY 8), and Huazheyu 261 (HZY 261); and the following japonica rice varieties: Nangeng 46 (NG 46), Songxianggeng 1018 (SXXG 1018), Xiushui 134 (XS 134), and Changligeng (CLG). The seeds were soaked in clean water at 32 °C for 48 h, germinated for 24 h, and then sown on May 23. Transplanting was carried out on June 17. When the plants reached the three-leaf

stage, uniformly growing seedlings were transplanted into the field with a spacing of 25 cm × 20 cm, with two seedlings per hill. The plot area was 16 m² (4 m × 4 m). During the rice growth stage, samples were taken to examine the dry matter weight, carbohydrate content, and net photosynthetic rate. After the rice maturity, samples were taken to evaluate the yield and rice quality.

2.2. Net Photosynthetic Rate

The net photosynthetic rate was measured using a portable photosynthesis system (Li-6800, Li-COR Biosciences Inc., Lincoln, NE, USA). During the rice jointing stage, the flowering stage, 10 days after flowering, and 20 days after flowering, the latest fully expanded leaves with consistent growth were selected. Measurements were taken between 9:00 AM and 11:00 AM, with three replicates.

2.3. Dry Matter Weight

At the jointing, flowering, and maturity stages of rice growth, six plants were randomly sampled from each plot. These plants were then separated into leaves, stems (including sheaths), and panicles for dry matter weight analysis. The samples were then killed at 105 °C for 120 min and dried at 80 °C until a constant weight was achieved.

2.4. Non-Structural Carbohydrate Content

The content of total soluble sugars and starch was determined according to the sulfuric acid-anthrone colorimetric method [17]. Approximately 0.1 g of the sample was immersed in 10 mL of distilled water, heated at 100 °C for 30 min, and extracted three times. The supernatant was collected, diluted to a constant volume, and treated with activated carbon to remove pigments. Following the improved method of Zhang et al. [18], the decolorized solution was analyzed for total soluble sugar content, while the filtered residue was subjected to starch extraction.

The dried residue was mixed with 2 mL of deionized water, boiled at 100 °C for 20 min, and then cooled. After cooling, 2 mL of 9.2 M HClO₄ was added, followed by another cooling step and the addition of 6 mL of deionized water. The mixture was centrifuged at 2000 rpm for 20 min, and the supernatant was collected. The residue was then mixed with 2 mL of 4.6 M HClO₄, and the extraction process was repeated. The supernatants from both extractions were combined and diluted to a constant volume for the determination of the soluble starch content. The sum of the soluble sugar and starch contents represents the non-structural carbohydrate (NSC) content. In this test, three replicates were used.

2.5. Determination of Yield and Quality

After rice maturation, the actual yield was measured by harvesting each plot. Nine hills were sampled from each replicate for yield component analysis to calculate the theoretical yield. Additionally, approximately 500 g of rice grains were weighed to determine processing and appearance quality. First, the husks were removed using a Japanese rice huller (otake-FC2R, Ōtake, Japan), followed by polishing with a rice milling machine. Finally, the head rice rate and chalkiness of the rice grains were measured using a rice appearance quality analyzer produced by Wanshen Detection Technology Co., Ltd., Hangzhou, China, with three replicates. The taste quality was determined by the Rice Research Institute of China, Hangzhou, China, with the reference varieties being Zhongzheyou 8 for indica rice and Longgeng 31 for japonica rice, with five replicates. Taste sensory evaluation was performed according to the Chinese National Standard (GB/T 15682-2008 [19] “Inspection of grain and oils—Method for sensory evaluation of paddy or rice cooking and eating quality”). The taste sensory evaluation team consisted of seven people of different genders and ages who were trained professionally to identify rice eating quality. The reference sample

was Yuzhenxiang (indica rice, 90 scores). Taste sensory evaluation included five aspects: cooked rice fragrance, appearance, palatability, taste, and cold rice texture. Each aspect included seven options: 0 = as control, 1 = slightly good, 2 = better, 3 = best, −1 = slightly poor, −2 = worse, −3 = worst. The taste sensory evaluation was in accordance with the Declaration of Helsinki.

The evaluation was conducted using the membership comprehensive function based on rice yield, head rice rate, chalkiness degree, and taste quality. The formula is as follows:

$$U(x) = (X - X_{\min}) / (X_{\max} - X_{\min})$$

2.6. Data Analysis

The experimental data were statistically analyzed using Excel and RStudio 2024.04.2 Build 764 (2009-2024 Posit Software, PBC).

3. Results

3.1. Yield and Yield Components

As summarized in Table 1, the following observations were made: (1) indica rice varieties demonstrated superior yield performance compared to japonica varieties. The average theoretical and actual yields of indica rice were 9.5 t/ha and 8.7 t/ha, respectively, whereas japonica rice exhibited lower yields of 7.0 t/ha and 6.1 t/ha, respectively. Taoyouxianzhan had the highest-yielding indica varieties (9.6 t/ha), while Meixiangzhan recorded the lowest yield (6.6 t/ha). In contrast, for japonica varieties, Changligeng yielded the highest (7.0 t/ha), whereas Xiushui 134 produced the lowest yield (5.1 t/ha). (2) The average 1000-grain weight of indica rice was lower than that of japonica rice, with notable varietal differences. Yixiangyou 2115 exhibited the highest 1000-grain weight (32.4 g) among indica varieties, while Meixiangzhan 2 had the lowest (17.1 g). For japonica varieties, Nangeng 46 displayed the highest 1000-grain weight (26.8 g), followed by Songxianggeng 1018 and Xiushui 134, whereas Changligeng had the lowest (21.7 g). (3) The average effective panicle number of indica rice (273.9/m²) was slightly lower than that of japonica rice (278.5/m²), with significant varietal variations. Meixiangzhan 2 had the highest effective panicle number (358.3/m²) in indica varieties, while Zhongzheyong 8 had the lowest (233.9/m²). Changligeng recorded the highest effective panicle number (361.3/m²) in japonica varieties, whereas Xiushui 134 had the lowest (215.9/m²). (4) The average number of grains per panicle of indica rice was significantly higher than that of japonica rice, at 205.5 and 124.8, respectively. Among indica varieties, Zhongzheyong 8 had the highest number of grains per panicle at 243.2, while Yixiangyou 2115 had the lowest at 152.8. In japonica varieties, Changligeng had the highest number of grains per panicle at 154.7, while Xiushui 134 had the lowest at 112.4. The coefficient of variation indicated that there were significant differences in the 1000-grain weight among the indica varieties, but smaller differences in seed-setting rate. (5) Among japonica varieties, there were significant differences in effective panicle number and grains per panicle, but smaller differences in seed-setting rate and 1000-grain weight.

Table 1. Changes in yield and yield components of different rice varieties.

Type	Cultivars	Effective Panicle Number (m ²)	Grains Per Panicle	Seed-Setting Rate (%)	Kernel Weight (g)	Theoretical Yield (t/ha)	Practical Yield (t/ha)
Indica	MXZ 2	358.3 ± 8.2 a	190.6 ± 5.4 b	69.8 ± 9.8 d	17.1 ± 1.0 f	8.1 ± 0.2 d	6.6 ± 0.2 e
	TYXZ	274.4 ± 13.6 b	198.9 ± 13.6 b	72.8 ± 8.5 d	24.2 ± 2.1 c	9.2 ± 0.3 c	9.6 ± 0.3 a
	QYSM	256. ± 12.3 bc	225.6 ± 9.5 a	78.9 ± 9.1 bc	24.3 ± 1.8 c	10.4 ± 0.4 a	9.5 ± 0.1 a
	YXY 2115	257.9 ± 7.8 bc	152.8 ± 7.9 c	73.2 ± 4.0 d	32.4 ± 1.9 a	9.5 ± 0.2 c	8.7 ± 0.1 b
	ZZY 8	233.9 ± 18.3 d	243.2 ± 10.9 a	74.9 ± 5.3 cd	24.9 ± 4.7 c	9.8 ± 0.2 b	8.2 ± 0.3 c
	HZY 261	262.4 ± 10.5 bc	232.6 ± 7.3 a	82.9 ± 3.7 ab	19.1 ± 0.2 e	9.7 ± 0.3 bc	9.4 ± 0.1 a
	Average	273.9	205.5	75.4	23.7	9.5	8.7
Japonica	NG 46	268.4 ± 11.9 b	117.1 ± 3.1 d	80.7 ± 5.6 b	26.8 ± 0.9 b	6.8 ± 0.2 e	6.1 ± 0.2 f
	SXG 1018	268.4 ± 9.3 b	114.9 ± 3.3 d	86.9 ± 4.0 a	26.5 ± 0.6 b	7.1 ± 0.1 e	6.1 ± 0.1 f
	XS 134	215.9 ± 10.5 d	112.4 ± 4.0 d	83.2 ± 3.9 ab	24.5 ± 2.6 c	4.9 ± 0.2 f	5.1 ± 0.1 g
	CLG	361.3 ± 17.1 a	154.7 ± 6.4 c	74.5 ± 8.4 cd	21.7 ± 2.3 d	9.2 ± 0.4 c	7.0 ± 0.2 d
	Average	278.5	124.8	81.3	24.9	7.0	6.1

The results are expressed as mean ± standard deviation, coefficient of variation, and amplitude of variation. The data in the brackets represent the range measured by the corresponding category of samples. Within a column for each parameter, means followed by different letters are significantly different at a 0.05 probability level according to the least significant difference (LSD) test.

3.2. Rice Quality

Sensory data (e.g., texture, aroma, taste) and chalkiness (a visual/textural defect in grains like rice) directly influence consumer preference and market value. Sensory attributes drive purchasing decisions. For example, sticky rice varieties are preferred in some Asian markets, while non-chalky, translucent grains are associated with higher quality. Chalkiness (opaque spots) correlates with harder, uneven cooking texture, reducing acceptability. Studies show consumers consistently reject chalky rice, associating it with inferior quality [20]. Table 2 presents the comparative analysis of rice quality traits across various indica and japonica rice cultivars: (1) The mean brown rice rate of indica rice (77.6%) was significantly lower than that of japonica rice (79.9%). Among indica cultivars, Zhongzheyu 8 and Huazheyu 261 exhibited the highest brown rice rates (78.7%), whereas Meixiangzhan 2 showed the lowest rate (74.1%). In japonica cultivars, Nangeng 46 demonstrated the highest brown rice rate, contrasting with Changligeng, which displayed the lowest value. (2) The average milled rice rate followed a similar trend, with indica rice (mean value) being inferior to japonica rice. Notably, Zhongzheyu 8 and Huazheyu 261 achieved the highest milled rice rates among indica cultivars (70.5%), while Meixiangzhan 2 recorded the lowest (62.9%). Among japonica cultivars, Nangeng 46 exhibited the highest milled rice rate (71.9%), compared to Xiushui 134 with the lowest rate (67.8%). (3) Head rice rate analysis showed indica rice (35.5%) to be substantially lower than japonica rice (49.7%). Zhongzheyu 8 emerged with the highest head rice rate among indica cultivars (51.6%), while Taoyouxiangzhan showed the lowest (25.8%). In japonica cultivars, Xiushui 134 demonstrated a superior head rice rate (60.5%), contrasting with Nangeng 46 (42.9%), indicating substantial inter-varietal variation. (4) Chalkiness degree analysis revealed indica cultivars (mean value) to be higher than japonica cultivars, though significant intra-group variation was observed. Among indica cultivars, Quanyousimiao exhibited the highest chalkiness degree (5.1), while Meixiangzhan 2 showed the lowest (2.0). In japonica cultivars, Songxianggeng recorded the highest value (4.0), compared to Changligeng with the lowest chalkiness degree (1.1). (5) Sensory evaluation indicated that indica cultivars generally possessed inferior taste quality compared to japonica cultivars. Among indica cultivars, Zhongzheyu 8 achieved the highest taste score, while Taoyouxiangzhan showed the lowest. In japonica cultivars, Songxianggeng 1018 demonstrated superior taste quality (80.3), contrasting with Changligeng (73.6).

Table 2. Variation characteristics of rice quality among different rice varieties.

Types	Cultivars	Brown Rice Ratio (%) BR	Milled Rice Rate (%) MR	Head Rice Rate (%) HR	Chalkiness Degree CD	Eating Quality EQ
Indica	MXZ 2	74.1 ± 0.6 e	62.9 ± 3.0 c	34.4 ± 3.2 e	2.0 ± 0.3 bc	73.4 ± 1.1 cd
	TYXZ	77.6 ± 0.2 d	66.1 ± 2.4 abc	25.8 ± 3.7 f	2.6 ± 1.1 b	72.3 ± 0.8 d
	QYSM	78.6 ± 0.1 c	66.3 ± 0.7 abc	32.6 ± 1.7 e	5.1 ± 0.4 a	74.9 ± 0.8 c
	YXY 2115	78.0 ± 0.5 cd	65.1 ± 1.4 bc	29.2 ± 1.4 ef	4.0 ± 0.4 a	75.1 ± 2.9 cd
	ZZY 8	78.7 ± 0.3 c	70.5 ± 4.8 ab	51.6 ± 2.5 b	2.2 ± 1.0 bc	77.3 ± 1.0 b
	HZY 261	78.7 ± 0.1 c	70.5 ± 3.2 bc	39.3 ± 2.0 d	2.2 ± 0.6 c	74.1 ± 0.8 cd
	Average	77.6	66.9	35.5	3.0	74.5
Japonica	NG 46	82.0 ± 0.5 a	71.9 ± 4.6 a	42.9 ± 3.0 cd	2.8 ± 0.6 b	74.7 ± 1.2 cd
	SXG 1018	80.7 ± 0.2 b	70.2 ± 5.1 ab	47.1 ± 3.4 bc	4.0 ± 0.3 a	80.3 ± 1.8 a
	XS 134	78.7 ± 0.5 c	67.8 ± 0.7 abc	60.5 ± 2.2 a	2.3 ± 0.4 b	78.4 ± 1.7 ab
	CLG	78.2 ± 0.5 cd	68.2 ± 0.3 abc	48.3 ± 1.3 b	1.1 ± 0.3 c	73.6 ± 2.4 cd
	Average	79.9	69.5	49.7	2.6	76.7

The results are expressed as mean ± standard deviation, coefficient of variation, and amplitude of variation. The data in the brackets represent the range measured by the corresponding category of samples. Within a column for each parameter, means followed by different letters are significantly different at a 0.05 probability level according to the least significant difference (LSD) test.

3.3. Dry Matter Accumulation and Distribution

3.3.1. Dry Matter Accumulation at Flowering Stage

The following are shown in Table 3: (1) The stem dry weight of indica rice varieties is higher than that of japonica rice varieties, with values of 48.9 g and 39.4 g, respectively, although considerable variability was observed among individual cultivars. Among indica varieties, Huazheyong 261 has the highest stem dry weight at 68.0 g, while Zhongzheyong 8 has the lowest at 40.7 g. For japonica varieties, Songxianggeng 1018 has the highest stem dry weight at 55.9 g, and Changligeng has the lowest at 34.7 g. (2) The average leaf dry weight of indica varieties is greater than that of japonica varieties, with values of 19.7 g and 16.6 g, respectively. Huazheyong 261 has the highest leaf dry weight at 22.8 g in indica varieties, while Quanyousimiao has the lowest at 16.5 g. Japonica varieties, Songxianggeng 1018 has the highest leaf dry weight at 20.9 g, and Changligeng has the lowest at 15.6 g. (3) The average panicle dry weight of indica varieties is higher than that of japonica varieties, with values of 13.4 g and 11.5 g, respectively. Among indica varieties, Taoyouxiangzhan has the highest panicle dry weight at 15.9 g, while Quanyousimiao and Meixiangzhan 2 have the lowest at 11.2 g. For the Japonica varieties, Songxianggeng 1018 has the highest panicle dry weight at 14.1 g, and Changligeng has the lowest at 8.1 g. (4) The average total dry weight per plant of indica varieties is higher than that of japonica varieties, with values of 82 g and 67.5 g, respectively. Among the indica varieties, Huazheyong 261 has the highest total dry weight at 106.6 g, while Zhongzheyong 8 has the lowest at 70.8 g. For the japonica varieties, Songxianggeng 1018 has the highest total dry weight at 90.8 g, and Changligeng has the lowest at 58.4 g. (5) The average stem dry weight ratio of indica varieties is higher than that of japonica varieties, with values of 59.5% and 58.5%, respectively. The average leaf dry weight ratio of indica varieties is lower than that of japonica varieties, with values of 24.7% and 24.3%, respectively, though there is significant variation among varieties. The average panicle dry weight ratio of indica varieties is slightly lower than that of japonica varieties, with values of 16.3% and 16.9%, respectively, showing a slight difference.

Table 3. Dry matter accumulation and distribution in different rice varieties during the flowering stage.

Types	Cultivars	Stem (g/hill)	Leaf (g/hill)	Panical (g/hill)	Sum (g/hill)	Stem Ratio (%)	Leaf Ratio (%)	Panical Ratio (%)
Indica	MXZ 2	45.1 ± 1.3 de	18.7 ± 1.4 c	11.2 ± 2.4 d	75.0 ± 1.5 c	60.1	24.9	14.9
	TYXZ	52.2 ± 5.0 c	20.1 ± 4.3 b	17.6 ± 1.2 a	89.6 ± 4.0 b	58.3	22.4	19.4
	QYSM	43.8 ± 4.2 e	16.5 ± 0.1 d	11.2 ± 0.8 d	71.5 ± 4.9 cd	61.2	23.1	15.6
	YXY 2115	43.8 ± 5.7 e	21.4 ± 7.7 ab	13.4 ± 4.0 bc	78.5 ± 6.7 c	55.7	27.3	17.0
	ZZY 8	40.7 ± 8.1 ef	18.7 ± 3.0 bc	11.3 ± 0.4 d	70.6 ± 9.7 cd	57.7	26.4	15.9
	HZY 261	68.0 ± 0.8 a	22.8 ± 3.8 a	15.9 ± 1.8 b	106.6 ± 1.6 a	63.8	21.3	14.9
	Average	48.9	19.7	13.4	82.0	59.5	24.3	16.3
Japonica	NG 46	43.8 ± 5.5 e	19.0 ± 0.7 bc	12.3 ± 1.8 cd	75.0 ± 7.8 c	58.3	25.3	16.4
	SXG 1018	55.9 ± 0.5 b	20.9 ± 0.8 ab	14.1 ± 0.3 bc	90.8 ± 1.3 b	61.5	23.0	15.5
	XS 134	49.8 ± 4.6 d	19.9 ± 0.6 bc	13.18 ± 0.6 c	82.9 ± 4.9 bc	60.1	24.0	15.9
	CLG	34.7 ± 2.8 f	15.6 ± 1.8 e	8.1 ± 0.8 e	58.4 ± 3.7 d	59.5	26.7	13.8
	Average	39.4	16.6	11.5	67.5	58.5	24.7	16.9

The results are expressed as mean ± standard deviation, coefficient of variation, and amplitude of variation. The data in the brackets represent the range measured by the corresponding category of samples. Within a column for each parameter, means followed by different letters are significantly different at a 0.05 probability level according to the least significant difference (LSD) test.

3.3.2. Dry Matter Accumulation at Maturity Stage

The following are shown in Table 4: (1) The stem dry weight per hill of indica rice varieties is similar to that of japonica rice varieties, with values of 31.0 g and 30.9 g, respectively. However, there is significant variation among indica varieties. Among them, the indica variety Zhongzheyu 8 has the highest stem dry weight at 37.9 g, while Meixiangzhan 2 has the lowest at 27.8 g. For japonica varieties, Changligeng has the highest stem dry weight at 29.8 g, and Nanjing 46 has the lowest at 26.9 g. (2) The average leaf dry weight of indica varieties is greater than that of japonica varieties, with values of 13.3 g and 12.0 g, respectively. There is considerable variation among varieties. Among indica varieties, Yixiangyou 2115 has the highest leaf dry weight at 15.6 g, while Meixiangzhan 2 has the lowest at 9.1 g. Among japonica varieties, Changligeng has the highest leaf dry weight at 15.8 g, and Xiushui 134 has the lowest at 9.7 g. (3) The average panicle weight of indica varieties is higher than that of japonica varieties, with values of 48.6 g and 36.9 g, respectively. For indica varieties, Huazheyu 261 has the highest panicle weight at 106.6 g, while Quanyousimiao has the lowest at 71.5 g. Among japonica varieties, Songxianggeng 1018 has the highest panicle weight at 126.2 g, and Changligeng has the lowest at 65.8 g. (4) The average total dry weight per plant of indica varieties is higher than that of japonica varieties, with values of 96.6 g and 84.6 g, respectively. (5) In terms of the ratio of panicle dry weight to total dry weight, the average for indica varieties is 50.5%, while for japonica varieties, it is 44.4%. Of the indica varieties, Quanyousimiao has the highest ratio, while among the japonica varieties, Nangeng 46 has the highest.

Table 4. Dry matter weight and distribution of different rice varieties at the maturity stage.

Types	Cultivars	Stem (g/hill)	Leaf (g/hill)	Panical (g/hill)	Sum (g/hill)	Stem Ratio (%)	Leaf Ratio (%)	Panical Ratio (%)
Indica	MXZ 2	27.8 ± 3.9 c	9.1 ± 1.7 d	29.1 ± 3.8 e	66.0 ± 9.4 e	42.1	13.8	44.1
	TYXZ	28.3 ± 4.4 c	14.3 ± 2.2 b	60.0 ± 6.9 a	104.6 ± 13.3 b	27.0	13.7	57.3
	QYSM	20.5 ± 1.8 d	11.4 ± 1.2 c	46.4 ± 1.2 c	78.4 ± 4.2 d	26.2	14.6	59.2
	YXY 2115	37.3 ± 4.4 a	15.6 ± 3.5 ab	52.6 ± 4.2 b	113.1 ± 8.4 ab	33.0	13.7	46.5
	ZZY 8	37.9 ± 6.5 ab	15.4 ± 4.5 ab	52.4 ± 6.5 bc	118.3 ± 12.3 a	32.0	13.1	44.3
	HZY 261	34.2 ± 4.3 b	14.0 ± 2.4 ab	51.0 ± 3.25 b	99.2 ± 15.6 c	34.48	14.1	51.4
	Average	31.0	13.3	48.6	96.6	32.5	13.8	50.5

Table 4. Cont.

Types	Cultivars	Stem (g/hill)	Leaf (g/hill)	Panical (g/hill)	Sum (g/hill)	Stem Ratio (%)	Leaf Ratio (%)	Panical Ratio (%)
Japonica	NG 46	26.9 ± 2.9 cd	10.8 ± 1.3 cd	33.7 ± 3.0 de	71.3 ± 6.1 de	37.7	15.1	47.2
	SXG 1018	27.9 ± 3.8 cd	11.8 ± 0.7 c	35.3 ± 2.9 d	75.0 ± 6.7 de	37.2	15.8	47.1
	XS 134	29.3 ± 3.1 c	9.7 ± 1.2 d	26.8 ± 3.1 e	65.8 ± 6.9 e	44.5	14.8	40.7
	CLG	39.8 ± 7.6 a	15.9 ± 3.9 a	51.8 ± 7.3 b	126.2 ± 13.7 a	31.5	12.3	41.0
	Average	30.9	12.0	36.9	84.6	37.7	14.6	44.0

The results are expressed as mean ± standard deviation, coefficient of variation, and amplitude of variation. The data in the brackets represent the range measured by the corresponding category of samples. Within a column for each parameter, means followed by different letters are significantly different at a 0.05 probability level according to the least significant difference (LSD) test.

3.4. Carbohydrates

3.4.1. Soluble Sugar

Table 5 illustrates the varietal differences in carbohydrate content changes across various rice tissues during the flowering and maturity stages. The data reveal the following key observations: (1) At the flowering stage, indica rice varieties exhibit higher average soluble sugar content in stems, sheaths, leaves, and panicles compared to japonica varieties. Both subspecies demonstrate the highest carbohydrate accumulation in stems, followed by panicles and leaves; (2) during flowering, panicle soluble sugar content varies significantly among varieties, with the indica variety Taoyouxiangzhan showing the maximum concentration (99.7 mg/g) and Zhongzheyong 8 the minimum (40.2 mg/g). For japonica varieties, Xiushui 134 contains the highest level (64.0 mg/g), while Nanjing 46 shows the lowest (31.2 mg/g); (3) at maturity, japonica rice surpasses indica rice in soluble sugar content across all examined tissues (stems, sheaths, leaves, and panicles), with panicles containing the highest concentration, followed by stems and leaves; (4) during the mature phase, indica varieties demonstrate lower panicle soluble sugar content (167.2 mg/g) compared to japonica varieties (186.8 mg/g). Among indica cultivars, Yixiangyou 2115 accumulates the highest concentration (277.7 mg/g), while Meixiangzhan 2 contains the lowest (87.7 mg/g). In japonica varieties, Nanjing 46 exhibits the maximum panicle sugar content (245.1 mg/g), whereas Songxianggeng 1018 shows the minimum (157.3 mg/g).

Table 5. The variation characteristics of soluble sugar in rice leaves, leaf sheaths, and panicles.

Stage	Types	Cultivars	Stem (mg/g)	Leaf (mg/g)	Panicle (mg/g)
Flowering stage	Indica	MXZ 2	172.4 ± 4.6 c	34.7 ± 0.9 e	47.0 ± 4.5 f
		TYXZ	166.7 ± 15.2 cd	27.3 ± 0.6 f	99.7 ± 11.2 a
		QYSM	128.5 ± 3.4 e	42.1 ± 0.3 c	60.4 ± 0.6 d
		YXY 2115	158.5 ± 9.9 cd	38.0 ± 1.2 d	77.7 ± 2.8 b
		ZZY 8	162.3 ± 0.6 c	60.3 ± 0.9 a	40.2 ± 0.9 g
		HZY 261	207.4 ± 15.7 a	39.6 ± 0.4 d	73.7 ± 15.6 bc
		Average	166.0	40.3	66.5
	Japonica	NG 46	128.0 ± 22.6 e	45.18 ± 8.3 bc	31.2 ± 11.1 g
		SXG 1018	101.1 ± 22.3 f	34.3 ± 11.5 ef	39.4 ± 10.7 fg
		XS 134	183.9 ± 10.8 b	48.5 ± 12.5 b	64.0 ± 3.7 c
		CLG	166.6 ± 6.2 c	37.80 ± 8.4 de	57.2 ± 5.7 e
		Average	124.2	37.9	41.78

Table 5. Cont.

Stage	Types	Cultivars	Stem (mg/g)	Leaf (mg/g)	Panicle (mg/g)
Maturity stage	Indica	MXZ 2	141.5 ± 3.7 b	47.2 ± 0.1 c	87.7 ± 4.4 f
		TYXZ	19.0 ± 0.9 g	31.0 ± 0.9 f	106.7 ± 3.1 e
		QYSM	26.5 ± 1.8 f	36.8 ± 1.9 e	106.5 ± 8.8 e
		YXY 2115	99.4 ± 4.9 de	46.1 ± 3.4 c	277.7 ± 41.0 a
		ZZY 8	108.6 ± 1.9 d	56.3 ± 0.9 a	231.1 ± 17.1 bc
		HZY 261	85.8 ± 0.9 e	31.4 ± 4.8 f	193.6 ± 35.8 c
		Average	80.1	41.5	167.2
	Japonica	NG 46	81.7 ± 7.0 e	54.3 ± 1.2 a	245.1 ± 37.1 ab
		SXG 1018	125.4 ± 22.7 c	55.5 ± 14.0 ab	157.3 ± 25.5 d
		XS 134	196.4 ± 20.7 a	49.3 ± 6.3 bc	171.0 ± 21.0 cd
		CLG	95.1 ± 9.5 de	41.1 ± 8.2 d	187.4 ± 23.2 cd
		Average	106.9	51.6	186.8

The results are expressed as mean ± standard deviation, coefficient of variation, and amplitude of variation. The data in the brackets represent the range measured by the corresponding category of samples. Within a column for each parameter, means followed by different letters are significantly different at a 0.05 probability level according to the least significant difference (LSD) test.

3.4.2. Starch

Table 6 displays the variation characteristics of starch content in different parts of various rice varieties during the flowering and maturity stages. Overall, with a few exceptions, the starch moisture content in the stems, leaves, and panicles of japonica rice varieties is higher than that of indica rice varieties. During the flowering stage, both indica and japonica rice varieties have the highest starch content in the stems, followed by the panicles and leaves. At the maturity stage, the panicles have the highest starch content, followed by the stems and leaves. During the flowering stage, the stem and leaf starch content of indica rice is highest in Zhongzheyong 8 and lowest in Taoyouxiangzhan. The panicle starch content is highest in Yixiangyou 2115, reaching 193.5 mg/g, and lowest in Quanyousimiao, at 463.4 mg/g. Among japonica rice varieties, the stem starch content is highest in Xiushui 134 and lowest in Songxianggeng 1018. The leaf starch content is also highest in Xiushui 134 but lowest in Changligeng. The panicle starch content is highest in Yixiangyou 2115 for indica varieties and in Xiushui 134 for japonica varieties. At the maturity stage, the stem starch content of indica rice varieties is highest in Zhongzheyong 8 and lowest in Quanyousimiao. The leaf starch content is highest in Quanyousimiao at 98.6 mg/g and slightly lowest in Huazheyong 261 at 82.9 mg/g. For the panicles, Huazheyong 261 has the highest starch content, while Yixiangyou 2115 has the lowest. Among japonica rice varieties, Xiushui 13 has the highest starch content in the stems, leaves, and panicles, while Changligeng has the lowest in the leaves and stems, and Nangeng 46 has the lowest in the panicles.

Table 6. Variation characteristics of starch content in different parts of various rice varieties.

Stage	Types	Cultivars	Stem (mg/g)	Leaf (mg/g)	Panicle (mg/g)
Flowering stage	Indica	MXZ 2	179.5 ± 16.0 de	94.7 ± 4.8 b	151.4 ± 17.9 bc
		TYXZ	163.4 ± 5.6 f	71.5 ± 4.4 cd	157.4 ± 19.9 bc
		QYSM	208.9 ± 13.3 bc	87.2 ± 11.4 bc	104.6 ± 3.4 e
		YXY 2115	163.4 ± 13.7 f	89.4 ± 6.4 bc	193.5 ± 19.6 a
		ZZY 8	219.1 ± 15.7 bc	103.9 ± 3.5 a	119.8 ± 17.2 d
		HZY 261	171.2 ± 4.3 e	85.5 ± 2.7 bc	132.9 ± 19.6 cd
		Average	184.2	88.7	143.3
	Japonica	NG 46	239.4 ± 14.7 ab	96.4 ± 13.1 bc	136.8 ± 11.1 c
		SXG 1018	156.5 ± 12.8 f	120.2 ± 24.6 ab	117.6 ± 23.8 d
		XS 134	254.2 ± 3.5 a	124.6 ± 20.4 a	153.6 ± 16.1 bc
		CLG	204.2 ± 14.5 bc	90.7 ± 27.5 bcd	139.1 ± 10.9 c
		Average	213.5	107.9	136.8

Table 6. Cont.

Stage	Types	Cultivars	Stem (mg/g)	Leaf (mg/g)	Panicle (mg/g)
Maturity stage	Indica	MXZ 2	176.3 ± 7.6 b	97.4 ± 1.3 cd	295.2 ± 22.2 e
		TYXZ	110.6 ± 27.2 de	92.7 ± 6.4 d	301.2 ± 24.8 e
		QYSM	95.2 ± 4.7 e	98.2 ± 3.4 bcd	261.2 ± 6.7 f
		YXY 2115	140.0 ± 10.4 c	96.9 ± 1.5 cd	185.0 ± 13.2 h
		ZZY 8	140.5 ± 15.3 c	97.4 ± 6.0 cd	221.6 ± 20.1 g
		HZY 261	88.8 ± 4.7 f	82.9 ± 16.3 de	452.2 ± 25.8 b
		Average	125.2	94.2	286.1
	Japonica	NG 46	147.1 ± 27.2 c	109.6 ± 14.4 bc	373.4 ± 57.8 cd
		SXG 1018	161.9 ± 31.1 bc	130.0 ± 3.1 a	459.9 ± 35.8 b
		XS 134	235.0 ± 26.0 a	112.2 ± 17.4 bc	540.8 ± 50.8 a
		CLG	138.9 ± 3.1 c	74.8 ± 20.6 e	400.6 ± 78.3 cd
		Average	170.7	106.7	443.7

The results are expressed as mean ± standard deviation, coefficient of variation, and amplitude of variation. The data in the brackets represent the range measured by the corresponding category of samples. Within a column for each parameter, means followed by different letters are significantly different at a 0.05 probability level according to the least significant difference (LSD) test.

3.4.3. Non-Structural Carbohydrates

As presented in Table 7, the analysis of non-structural carbohydrate (NSC) content revealed significant variations between indica and japonica rice varieties across different plant tissues and developmental stages. At the flowering stage, the mean NSC concentration in stems and sheaths was notably higher in indica varieties (350.2 mg/g) compared to japonica cultivars (337.8 mg/g). Among indica genotypes, Zhongzheyong 8 exhibited the maximum stem NSC accumulation (381.4 mg/g), whereas Taoyouxiangzhan showed the minimum value (330.1 mg/g). In the japonica varieties, Changligeng demonstrated the highest NSC content (370.8 mg/g), contrasting with Songxianggeng 1018, which recorded the lowest concentration (257.6 mg/g).

Contrastingly, the foliar NSC content displayed an inverse pattern, with indica varieties (129.0 mg/g) showing lower values than japonica counterparts (145.8 mg/g). The maximum leaf NSC accumulation in indica varieties was observed in Zhongzheyong 8, while Taoyouxiangzhan exhibited the minimum concentration. Among japonica cultivars, Xiushui 134 possessed the highest foliar NSC content, with Changligeng showing the lowest values.

Regarding panicle NSC content at the flowering stage, indica varieties maintained higher concentrations compared to japonica types. Yixiangyou 2115 demonstrated the maximum panicle NSC accumulation (271.2 mg/g) among indica varieties, while Zhongzheyong 8 showed the minimum value (157.0 mg/g). In japonica cultivars, Changligeng exhibited the highest panicle NSC content, with Songxiangjing displaying the lowest concentration.

At the maturity stage, a distinct pattern emerged, with japonica varieties surpassing indica types in NSC accumulation across all examined tissues (stems, sheaths, leaves, and panicles). Notably, Huazheyong 261 showed the highest panicle NSC content (645.8 mg/g) among indica varieties, while Xiushui 134 exhibited the maximum accumulation (698.1 mg/g) in japonica cultivars. These findings demonstrate substantial interspecific and intraspecific variation in NSC partitioning patterns during critical developmental stages in rice.

Table 7. Variation characteristics of non-structural carbohydrate content in different parts of various rice varieties.

Stage	Types	Cultivars	Stem (mg/g)	Leaf (mg/g)	Panicle (mg/g)
Flowering stage	Indica	MXZ 2	352.0 ± 29.4 abc	129.3 ± 9.9 bc	198.4 ± 20.2 b
		TYXZ	330.1 ± 19.4 bc	98.9 ± 4.5 d	257.0 ± 22.3 a
		QYSM	337.4 ± 21.9 bc	129.3 ± 13.1 bc	165.0 ± 12.0 c
		YXY 2115	321.9 ± 19.6 c	127.5 ± 20.7 bc	271.2 ± 39.2 a
		ZZY 8	381.4 ± 14.2 a	164.2 ± 11.7 a	160.0 ± 31.1 c
		HZY 261	378.7 ± 10.0 ab	125.0 ± 2.7 c	206.6 ± 30.4 b
		Average	350.2	129.0	209.7
	Japonica	NG 46	367.4 ± 32.8 b	141.5 ± 31.2 abc	168.0 ± 20.3 c
		SXG 1018	257.6 ± 17.4 d	154.5 ± 29.6 ab	157.0 ± 29.5 cd
		XS 134	355.3 ± 12.4 b	158.9 ± 8.3 a	193.0 ± 3.6 b
		CLG	370.8 ± 16.3 ab	128.4 ± 19.3 bc	196.3 ± 6.5 b
		Average	337.8	145.8	178.6
Maturity stage	Indica	MXZ 2	317.8 ± 6.9 b	144.6 ± 1.29 c	382.9 ± 35.2 de
		TYXZ	129.6 ± 26.6 e	123.7 ± 6.42 de	407.9 ± 58.4 cde
		QYSM	121.6 ± 5.9 e	134.9 ± 12.73 cd	367.7 ± 9.7 e
		YXY 2115	239.3 ± 13.9 cd	143.0 ± 15.24 d	462.7 ± 20.5 c
		ZZY 8	249.1 ± 34.6 bcd	153.7 ± 11.12 bc	452.7 ± 36.7 c
		HZY 261	174.6 ± 5.0 f	114.3 ± 10.51 de	645.8 ± 53.8 a
		Average	205.3	135.7	453.3
	Japonica	NG 46	228.9 ± 22.3 cd	163.9 ± 15.0 bc	618.5 ± 30.4 ab
		SXG 1018	287.3 ± 41.6 bc	185.5 ± 13.7 a	617.2 ± 37.5 ab
		XS 134	360.4 ± 42.3 a	167.6 ± 26.7 ab	698.1 ± 3.8 a
		CLG	234.0 ± 12.5 d	115.9 ± 29.5 de	588.0 ± 37.2 b
		Average	277.6	158.2	630.4

The results are expressed as mean ± standard deviation, coefficient of variation, and amplitude of variation. The data in the brackets represent the range measured by the corresponding category of samples. Within a column for each parameter, means followed by different letters are significantly different at a 0.05 probability level according to the least significant difference (LSD) test.

3.5. Net Photosynthetic Rate

Table 8 illustrates the variations in the net photosynthetic rate of leaves among different rice varieties. The following observations can be made: (1) The average net photosynthetic rate of indica rice is higher than that of japonica rice during the jointing stage, flowering stage, 10 days after flowering, and 20 days after flowering. The highest rate is observed during the jointing stage, followed by the flowering stage and 10 days after flowering, with the lowest rate occurring 20 days after flowering. (2) The net photosynthetic rate of indica rice varieties does not show a clear trend across different stages. During the jointing stage, Quanyousimiao exhibits the highest rate, while Taoyouxianzhan, Yixiangyou 2115, and Quanyousimiao show the highest rates during the flowering stage, 10 days after flowering, and 20 days after flowering, respectively. (3) For japonica rice, Nangeng 46 has the highest net photosynthetic rate during the jointing stage, 10 days after flowering, and 20 days after flowering. During the flowering stage, it ranks second only to Songxianggeng 1018, reaching 20.1 $\mu\text{mol}/\text{m}^2/\text{s}$. Changligeng, on the other hand, has lower rates during the flowering stage, 10 days after flowering, and 20 days after flowering compared to other varieties.

Table 8. Variation characteristics of net photosynthetic rate in leaves of different rice varieties ($\mu\text{mol}/\text{m}^2/\text{s}$).

Types	Cultivars	Jointing Stage	Flowering Stage	DAF10	DAF20
Indica	MXZ 2	29.7 ± 1.2 ab	19.6 ± 0.5 de	21.0 ± 0.6 c	12.2 ± 0.1 e
	TYXZ	29.7 ± 1.3 ab	25.4 ± 1.0 a	18.1 ± 0.3 e	16.4 ± 1.0 bc
	QYSM	30.9 ± 1.1 a	23.2 ± 0.7 b	23.3 ± 0.1 b	22.2 ± 0.3 a
	YXY 2115	25.5 ± 1.5 cd	22.3 ± 0.4 bc	25.2 ± 0.7 a	15.0 ± 1.0 c
	ZZY 8	26.5 ± 1.1 c	21.6 ± 0.2 c	21.9 ± 0.4 c	16.9 ± 0.8 b
	HZY 261	27.3 ± 0.5 b	23.9 ± 0.5 b	20.1 ± 0.9 cd	21.5 ± 1.3 a
	Average	28.3	22.7	21.6	17.4
Japonica	NG 46	27.2 ± 0.3 b	20.1 ± 0.4 d	19.4 ± 0.9 d	15.6 ± 0.8 bc
	SXG 1018	22.6 ± 0.9 d	20.8 ± 0.7 d	17.4 ± 0.4 ef	13.6 ± 1.1 d
	XS 134	22.4 ± 0.7 d	18.5 ± 0.6 e	18.3 ± 0.7 de	13.2 ± 1.8 d
	CLG	26.6 ± 1.4 c	16.8 ± 0.5 f	16.5 ± 0.6 f	12.5 ± 1.4 e
	Average	24.7	19.0	17.9	13.7

The results are expressed as mean $\pm$ standard deviation, coefficient of variation, and amplitude of variation. The data in the brackets represent the range measured by the corresponding category of samples. Within a column for each parameter, the means followed by different letters are significantly different at a 0.05 probability level according to the least significant difference (LSD) test.

3.6. Correlation Analysis Between Net Photosynthetic Rate and Rice Yield Quality

Table 9 displays the correlation between the net photosynthetic rate at different stages and yield and rice quality. It can be observed that, except for 10 days after flowering, the correlation between the net photosynthetic rate and yield nearly reaches a significant level. In terms of rice quality, no clear patterns are evident. The net photosynthetic rate at the jointing stage shows a significant negative correlation with brown rice rate, milled rice rate, head rice rate, and taste quality. Apart from this, the correlations between the net photosynthetic rate and rice quality do not reach significant levels.

Table 9. Correlation between net photosynthetic rate and rice quality.

	Jointing Stage	Flowering Stage	DAF10	DAF20
GY	0.489 **	0.817 **	0.458	0.823 **
BR	−0.521 **	−0.324	−0.105	−0.123
MR	−0.527 **	−0.293	−0.217	−0.034
HR	−0.424 *	−0.601 **	−0.365 *	−0.239
CD	0.004	0.091	0.318	0.023
EQ	−0.659 *	−0.517	−0.08	−0.197

* and ** represent significant correlation at 0.05 and 0.01 level, respectively. GY = Grain yield, BR = Brown Rice Ratio, MR = milled rice rate, HR = head rice rate, CD = chalkiness degree, EQ = eating quality.

3.7. Correlation Analysis Between Dry Matter Content, Carbohydrates, Yield, and Rice Quality

The following are shown in Table 10: (1) There is no clear pattern in the correlation between carbohydrates, dry matter content, yield, and rice quality during the flowering and maturity stages. The correlations during these two stages almost show opposite trends. (2) At the flowering stage, the correlation between soluble sugars, starch, and yield reached a significant level, but it turned negative at the maturity stage. (3) In terms of head rice rate, soluble sugars and starch showed a significant negative correlation at the flowering stage but a significant positive correlation at the maturity stage. (4) The correlation between chalkiness and soluble sugars or starch dry matter content did not reach a significant level. (5) At the flowering stage, starch and NSCs (non-structural carbohydrates) showed a significant negative correlation with taste quality, while at the maturity stage, soluble sugars and panicle dry matter content showed a significant positive correlation.

Table 10. Correlation between carbohydrates, dry matter content, yeildand rice quality.

		Soluble Sugar	Starch	NSC	Panicle Dry Matter Weight	Panicle/Sum
Flowering stage	GY	0.562 **	0.479 *	0.123	−0.18	0.374 *
	HR	−0.405 *	−0.446 *	−0.33	−0.238	−0.415 *
	CD	−0.069	0.082	−0.088	−0.121	0.111
	EQ	0.032	−0.423 *	−0.482 **	−0.247	−0.055
Maturity stage	GY	−0.15	−0.58 **	−0.532 **	0.561 **	0.374 *
	HR	0.213	0.679 **	0.58 **	−0.111	−0.415
	CD	−0.137	−0.294	−0.268	−0.114	0.111
	EQ	0.521 **	0.039	0.161	0.411 *	−0.055

* and ** represent significant correlation at 0.05 and 0.01 level, respectively. GY = Grain yield, HR = head rice rate, CD = chalkiness degree, EQ = eating quality.

3.8. Membership Comprehensive Function

The evaluation was conducted using the membership comprehensive function based on rice yield, head rice rate, chalkiness degree, and taste quality. From the membership comprehensive function values, it can be observed that Zhongzheyong 8 has the highest value, followed by Huazheyong 261, while Xiushui 134 has the lowest. Additionally, the membership comprehensive function values of indica rice varieties are relatively higher, whereas those of japonica rice varieties are comparatively lower.

Table 11. Membership function values of different varieties.

	GY	HR	CD	EQ	Comprehensive Value
ZZY 8	0.69	0.74	0.73	1.00	0.76
HZY 261	0.96	0.39	0.73	0.37	0.73
QYSM	0.98	0.20	0.00	0.52	0.61
TYXZ	1.00	0.00	0.62	0.00	0.60
YXY 2115	0.79	0.10	0.28	0.56	0.55
CLG	0.43	0.65	1.00	0.26	0.53
MXZ 2	0.32	0.25	0.77	0.22	0.37
NG 46	0.21	0.49	0.57	0.48	0.36
SXG 1018	0.21	0.61	0.27	0.56	0.35
XS 134	0.00	1.00	0.70	0.15	0.31

GY = Grain yield, HR = head rice rate, CD = chalkiness degree, EQ = eating quality.

4. Discussion

Yield-Quality Trade-off. In recent years, with the improvement of living standards, the demand for high-quality rice has been increasing. However, due to China's large population base, high yield of rice remains the primary goal, and the severity of the international situation means that food security is an issue that cannot be overlooked at any time. Therefore, rice varieties and cultivation techniques that synergistically enhance both yield and quality are particularly important. Under the experimental conditions, indica varieties exhibited significantly higher yields but lower overall quality (particularly head rice rate) compared to japonica varieties (Tables 1 and 2). This aligns with prior findings from our laboratory, where high-yielding varieties like Zhongzheyong 1 showed inferior quality to lower-yielding counterparts like Zhongzheyong 8 [21]. The inverse relationship between yield and quality likely stems from energy limitations: photosynthesis in C3 crops like rice generates insufficient energy to simultaneously meet the demands of both processes [22]. However, exceptions exist—e.g., the early indica variety Zhuliangyou 30 achieved superior yield, quality, and heat tolerance, attributed to enhanced ATPase activity,

which improves energy utilization efficiency [15]. While ATPase activity was not measured here, its role in assimilating transport and stress resistance [23] suggests a promising avenue for synergistic improvement.

Photosynthesis: Potential and Limitations. As the foundation of yield and quality, photosynthesis has been a focal point for improvement. While some studies report that increased net photosynthetic rates (P_n) can enhance both traits [24–26], others argue that a higher P_n does not necessarily translate to higher yields [27]. Our data show a generally positive correlation between P_n and yield, supporting the feasibility of yield improvement through photosynthesis. However, P_n exhibited no significant (or even negative) correlation with quality, possibly due to varietal limitations in P_n [22]. Critically, photorespiration in C3 plants remains a bottleneck, underscoring the need for alternative strategies like optimizing energy partitioning.

Dry Matter Partitioning. Dry matter and carbohydrate accumulation are key to yield and quality formation [27], yet their distribution varied widely among varieties in this study, with no consistent correlation to yield or quality. This suggests that stage-specific accumulation patterns may not reliably predict outcomes [28], highlighting the complexity of these relationships.

Varietal Differences and Environmental Adaptation. Indica varieties (e.g., Zhongzheyong 8, Huazheyong 261) demonstrated better yield-quality synergy than japonica (e.g., Nangeng 46, Xiushui 134) (Table 11). This may reflect indica's superior heat tolerance and adaptability to Zhejiang's summer temperatures [29,30], whereas japonica's sensitivity to high temperatures can exacerbate quality deterioration under suboptimal yields [31,32]. Notably, photosynthesis alone did not explain these differences—Zhongzheyong 8's P_n was not the highest, nor was Xiushui 134's the lowest. This implies that photosynthesis, while essential, interacts with other factors (e.g., stress resilience, metabolic efficiency) in complex ways.

Conclusion and Future Directions. Achieving synergistic improvement of yield and quality requires addressing energy allocation constraints, potentially through targeting ATPase activity or other efficiency-related mechanisms [15,21]. Further research should clarify the roles of photosynthesis and dry matter partitioning across environments and genotypes, with an emphasis on heat-tolerant indica varieties as a model for balancing these traits.

5. Conclusions

This study selected 10 major rice cultivars, including 6 indica and 4 japonica varieties, and compared their differences in taste quality, focusing on yield and its components, taste quality, and dry matter accumulation. Among the tested varieties, Songxiangjing 1018 had the best taste quality, but not the highest yield. Zhongzheyong 8, Huazheyong 261, and Quanyousimiao showed both excellent taste quality and high yield. There was no significant correlation between taste quality and yield, suggesting the feasibility of breeding rice varieties with both superior taste and high productivity. Correlation analysis indicated that dry matter mass and net photosynthetic rate were significantly positively correlated with yield, but not with taste quality, highlighting the complexity of taste quality formation. Using a membership function comprehensive evaluation method, a rice variety selection system balancing yield and quality was constructed, and three varieties, Zhongzheyong 8, Huazheyong 261, and Quanyousimiao, were identified as having both high yield and excellent quality.

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Abbreviations

The following abbreviations are used in this manuscript:

NSC	Non-structural carbohydrates
BR	Brown Rice Ratio
MR	Milled rice rate
HR	Head rice rate
CD	Chalkiness degree
EQ	Eating quality
DAF	Day After Flowering
GY	Grain yield

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