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Comparison on Grain Quality Between Super Hybrid and Popular Inbred Rice Cultivars Under Two Nitrogen Management Practices

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Abstract

This study was conducted to determine the differences in grain quality traits between super hybrid and popular inbred rice cultivars grown under two nitrogen (N) management practices. Field experiments were done at the Experimental Farm of Guangxi University, Guangxi Province, China in early and late rice-growing seasons in 2014. Two representative super hybrid cultivars Liangyoupeijiu (LYPJ) and Y-liangyou 1 (YLY1) and a popular inbred rice cultivar Huanghuazhan (HHZ) were grown under fixed-time N management (FTNM) and site-specific N management (SSNM) practices in each season. Grain quality traits and N uptake were measured for each cultivar. LYPJ and YLY1 had higher milling efficiency, poorer appearance and palatability, and equal nutritional value than HHZ. The higher milling efficiency and poorer appearance in LYPJ and YLY1 were associated with their higher rice width compared with HHZ. Total N application rate was reduced by 15–20% under SSNM than under FTNM, whereas there was nearly no significant difference in grain quality between SSNM and FTNM. Our results suggest that (1) strategies for grain quality improvement in super hybrid rice should be focused on appearance and palatability, and (2) replacing FTNM with SSNM can reduce N input without sacrificing grain quality in rice production.

Keywords: grain quality, grain shape, nitrogen management, super hybrid rice, temperature

1. Introduction

Rice is the staple food for about 65% of the population of China and therefore rice productivity is critical to the national food security [1]. Although Chinese rice production has increased more than threefold in the past five decades [2], rapid population growth and economic development have been posing a growing pressure for increased food production [3]. It is projected that China will need to produce about 20% more rice by 2030 in order to fulfil its domestic needs [4]. To achieve this goal, great efforts should be made to breed new rice cultivars with higher yield potential [5]. In 1996, China established a nationwide mega-project on the development of super rice based on the ideotype concept [6]. In 1998, Prof. Longping Yuan proposed a strategy for developing super hybrid rice by combining an ideotype approach with the use of inter-subspecific heterosis [7]. The main target of super hybrid rice breeding is to develop high-yielding cultivars. However, the demand for high quality rice increases in China as living standards improve [8]. In 2000, 40% of the rice area was planted with rice cultivars with high grain quality and most of these cultivars were inbreds [9]. Hence, whether the super hybrid rice cultivars can be widely planted in China to some extent depends on their grain quality.

In rice, grain quality is generally classified into four components: milling efficiency, appearance, cooking and eating characteristics and nutritional value [10]. Milling efficiency is typically assessed as brown rice percentage (BRP), milled rice percentage (MRP) and head rice percentage (HRP) [11]. Appearance is often judged by the percentage of chalky rice grains (PCRG) and degree of chalkiness (DC) [12]. Cooking and eating characteristics are mostly determined by gelatinization temperature (GT), amylose content (AC) and gel consistency (GC) of the grain endosperm [13]. A nutritional value is commonly evaluated by protein content (PC) [14]. Among these, milling and appearance traits are highly correlated with grain shape. In general, rice length (RL), rice length-to-width ratio (RLWR), or length-to-thickness ratio are negatively associated with grain milling efficiency, while increased rice width (RW) and thickness tend to result in increased milling efficiency [15] but poorer appearance [16, 17]. In addition, there are strong relationships between some of the grain quality traits. Chalkiness reduces grain resistance to forces applied during the milling process, causing a decrease in HRP [18, 19]. Brown rice with high PC is more resistant to abrasive milling than that with low PC [20].

Rice grain quality depends not only on cultivars but also on crop management practices and environmental conditions [21, 22]. N application has been reported as a common management practice that affects rice grain quality. Leesawatwong et al. [20] observed that the N application increased the milling efficiency and nutritional value in four Thai extra-long grain rice cultivars. Ning et al. [23] found that contents of four proteins (albumin, globulin, prolamin and gutelin) were increased with the increased N level in 31 japonica cultivars. Similarly, Wang et al. [24] reported that PC increased with an increase in N rates in two hybrid rice cultivars and there was a significantly positive relationship between PC and the total N uptake (TNU) for each cultivar. The temperature, especially daily mean temperature during grain-filling period, is one of the dominant climatic factors affecting rice grain quality [25]. High temperature may significantly accelerate the grain-filling rate, but correspondingly shorten its duration, thus resulting in loosely packed starch granules, decreased grain weight and HRP and increased PCRG.

Recently, there has been a report describing the grain quality of a super hybrid rice cultivar Liangyoupeijiu (LYPJ) grown under different N rates [24]. Their results showed that LYPJ had higher HRP, AC and GC but lower PCRG and PC than an ordinary hybrid rice cultivar, Shanyou 63, across a wide range of N rates. However, this study was conducted using only one super hybrid cultivar in comparison with a check cultivar. Furthermore, although rice breeders in China often use Shanyou 63 as a check cultivar because of its superior yield stability, its grain quality is not good enough to suit the preference of consumers. Therefore, it is difficult to conclude whether the grain quality of super hybrid rice is good or not. In our current study, we compared two super hybrid rice cultivars with a popular inbred rice cultivar with good quality under two N management practices in two seasons. The objectives of this study were to (1) determine the differences in grain quality traits between super hybrid and popular inbred rice cultivars and (2) the effects of N management practices on rice grain quality.

2. Materials and methods

2.1. Site and soil

Field experiments were conducted at the Experimental Farm of Guangxi University (22°51' N, 108°17' E, 78 m a.s.l.), Guangxi Province, China in early and late rice-growing seasons in 2014. The soil of the experimental field was an Ultisol (USDA taxonomy) with the following properties: pH 6.75, 32.3 g kg⁻¹ organic matter, 120 mg kg⁻¹ alkali-hydrolysable N, 31.6 mg kg⁻¹ available P and 126 mg kg⁻¹ available K. The soil test was based on samples taken from the 0 to 20 cm soil layer.

Cultivar	Type	Year of release	Female parent	Male parent
Liangyoupeijiu	Indica-japonica hybrid	1999	Peiai64S	9311
Y-liangyou 1	Indica hybrid	2006	Y58S	9311
Huanghuazhan	Indica inbred	2005	Huangxinzhan	Fenghuazhan

Table 1. Information about rice cultivars used in the study.

2.2. Plant and treatments

Three rice cultivars, including Liangyoupeijiu (LYPJ), Y-liangyou 1 (YLY1) and Huanghuazhan (HHZ), were used in this study. LYPJ and YLY1 are two representatives of high-yielding cultivars developed from China's super hybrid rice breeding project [26]. HHZ has been widely grown by rice farmers in southern China because of its good grain quality. Detailed information about rice cultivars is given in **Table 1**. Two N management practices were imposed: fixed-time N management (FTNM) and site-specific N management (SSNM) (**Table 2**). A

N management practice	Season	N application timing and rate (kg ha ⁻¹) ^a				Total N application rate (kg ha ⁻¹)
		Basal	Early tillering	Panicle initiation	Spikelet differentiation	
FTNM	Early and late	112.5	45	45	22.5	225
SSNM ^b	Early	56	60	45	15	176
	Late	56	60	60	15	191

^a Basal was defined as 1 day before transplanting, early tillering as 7 days after transplanting, panicle initiation as the first appearance of differentiated apex and spikelet differentiation as the appearance of glumous flower primordia at the tips of elongating primary rachis-branches [27].

^b A chlorophyll meter (SPAD-502, Soil-Plant Analysis Development Section, Minolta Camera Co., Osaka, Japan) was used to determine top dressings. SPAD value was measured on 10 topmost fully expanded leaves per plot. At panicle initiation, if SPAD < 37, apply 60 kg ha⁻¹; if between 37 and 39, apply 45 kg ha⁻¹; if > 39, apply 30 kg ha⁻¹. At spikelet differentiation, if SPAD < 37, apply 45 kg ha⁻¹; if between 37 and 39, apply 30 kg ha⁻¹; if between 39 and 42, apply 15 kg ha⁻¹; if > 42, apply 0 kg ha⁻¹ [28].

Table 2. N application timing and rate and the total N application rate for fixed-time N management (FTNM) and site-specific N management (SSNM) in early and late seasons.

split-plot design was used with N management practices as main plots and cultivars as subplots. The experiment was replicated three times and subplot size was 20 m².

Pre-germinated seeds were sown in a seedbed. Twenty-two-day-old seedlings were transplanted on 12 April and 31 July in early and late seasons, respectively. Transplanting was carried out at a hill spacing of 20 cm × 27 cm with two seedlings per hill. In addition to the N fertilizer, plants received 112.5 kg P₂O₅ ha⁻¹ and 157.5 kg K₂O ha⁻¹. P fertilizer was applied at basal. K fertilizer was split equally at basal and panicle initiation. The regimen for water management was in the sequence of flooding, midseason drainage, re-flooding and moist intermittent irrigation. Pests and weeds were controlled using chemicals.

2.3. Sampling and measurements

Ten hills were sampled diagonally from a 5 m² harvest area (excluding plants in the borders) for each replication at maturity. These samples were separated into straw and panicles. Panicles were threshed by hand and the filled grains were separated from unfilled grains by submerging them in tap water. Dry weights of straw, rachis and filled and unfilled grains were determined after oven drying at 70°C to constant weight. The N content of straw, rachis and filled and unfilled grains were determined by an autoanalyzer (Integral Futura, Alliance Instruments, Frépillon, France) to calculate N uptake in filled grains (NUFG) and the total N uptake (TNU). Plants were harvested from the 5 m² area and grains were threshed and sun-dried. Filled grains were separated from unfilled grains and debris by winnowing. Around 500 g of the filled grains were taken from each sample and stored at room temperature for 4 months to ensure stable grain quality [29]. A weight of 130 g of the stored grains was dehulled with a roller sheller and polished in a polishing machine according to the National Standard NT 147-88 of China. Brown rice percentage (BRP), milled rice percentage (MRP) and head rice percentage (HRP) were calculated based on the rough rice weight. Percentages

of chalky rice grains (PCRG), degree of chalkiness (DC), gelatinization temperature (GT), gel consistency (GC), amylose content (AC) and protein content (PC) were determined according to the descriptions of Huang et al. [30]. Rice length (RL), rice width (RW) and rice length-to-width ratio (RLWR) were measured on 10 head rice grains using a photoenlarger magnified at 10×. Temperature data were collected from the local weather station.

2.4. Statistical analysis

Data were analyzed following analysis of variance (Statistix 8, Analytical software, Tallahassee, FL, USA). The statistical model used included sources of variation due to replication, cultivar, N management practice, season and interactions of cultivar × N management practice, cultivar × season, N management practice × season and cultivar × N management practice × season. Means of cultivars were compared based on the least significant difference (LSD) test at the 0.05 probability level.

3. Results

Daily mean temperature trended to increase during the early season period, whereas a decrease trend was observed during the late season period (**Figure 1a**). Average daily mean temperatures during the grain-filling period were 28.6°C for HHZ and 29.2°C for LYPJ and YLY1 in early season (**Figure 1b**), as well as 24.0°C for HHZ and 23.3°C for LYPJ and YLY1 in the season (**Figure 1c**).

Significant cultivar effects were observed for all measured grain quality traits except for PC (**Tables 3 and 4**). LYPJ had slightly higher BRP and MRP than HHZ, while the differences were not significant between YLY1 and HHZ. MRP was higher in LYPJ and YLY1 than in HHZ by 13 and 30%, respectively. LYPJ and YLY1 showed 14- and 9-fold, respectively, higher PCRG than HHZ. DC was 20-fold higher in LYPJ and 11-fold higher in YLY1 compared with HHZ. LYPJ showed 12% lower GT than HHZ, while the difference between YLY1 and HHZ was relatively small. AC was 29% higher in LYPJ but 12% lower in YLY1 than in HHZ. GC was 8% higher in LYPJ, but 13% lower in YLY1 than in HHZ. N management practice had no significant effects on any of the grain quality traits except for GT. SSNM showed slightly higher GT than FTNM. Seasonal effects were significant on all the grain quality traits except for BRP. Compared to early season, late season had lower MRP, PCRG, DC and GC but higher HRP, GT, AC and PC. The interactive effects between cultivar and season were significant on all the grain quality traits except for PC, while the other interactive effects were generally insignificant.

There were significant cultivar effects on all three grain shape traits (**Tables 3 and 4**). RL was slightly lower in LYPJ than in YLY1 and HHZ. LYPJ and YLY1 had 12 and 11%, respectively, higher RW than HHZ. RLWR was lower in LYPJ and YLY1 than in HHZ by 13 and 10%, respectively. N management practice showed no significant effects on RL and RLWR, whereas SSNM had a slightly but significantly higher RW than FTNM. A significant seasonal effect was observed for RL but not for either RW or RLWR. RL was slightly lower in early season than in late season.

Cultivar and N management practice had no significant effects on TNU and NUFG (**Figure 2a and b**). Significant seasonal effects were observed for TNU and NUFG. Late season showed higher TNU and NUFG than early season by 5 and 22%, respectively.

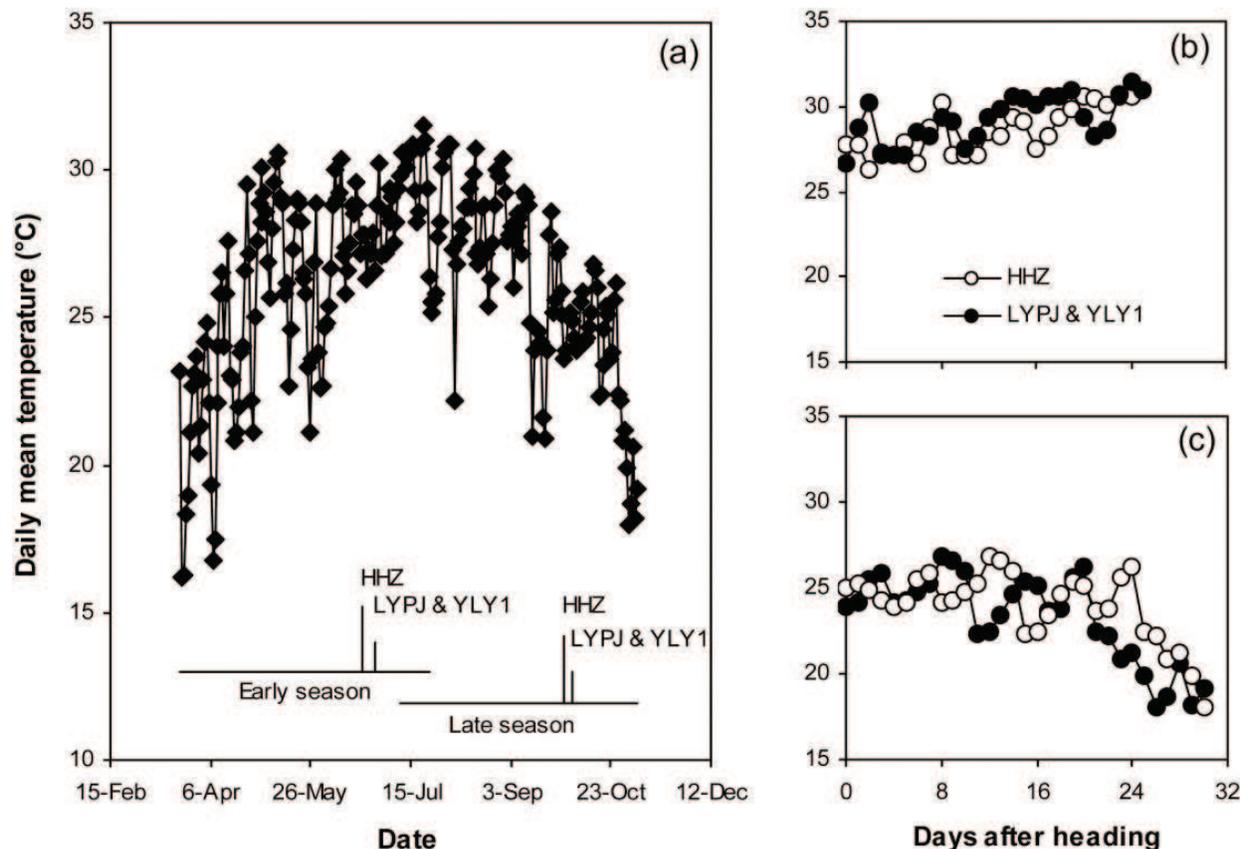


Figure 1. Daily mean temperature during early and late rice-growing seasons (a) and grain-filling period (from heading to maturity) in the early (b) and late (c) seasons. In (a), horizontal lines denote the duration (from sowing to harvesting) of early and late seasons and vertical lines represent the heading dates for three rice cultivars (HHZ, Huanghuazhan; LYPJ, Liangyoupeijiu; and YLY1, Y-liangyou 1).

4. Discussion

Our results indicate that the super hybrid rice cultivars LYPJ and YLY1 had higher milling efficiency, poorer appearance and equal nutritional value compared with the popular inbred rice cultivar HHZ. Wang et al. [24] also observed a higher milling efficiency in LYPJ than in an ordinary hybrid rice cultivar Shanyou 63 and they pointed out that the higher milling efficiency in LYPJ was associated its lower PCRG compared with Shanyou 63. In this regard, it is suggested that chalkiness reduces grain resistance to forces applied during the milling process, causing a decrease in milling efficiency [18, 19]. However, this is not the case in the present study, in which LYPJ and YLY1 had higher PCRG and DC than HHZ. In fact, in addition to the chalkiness, grain shape and PC are also correlated with grain milling efficiency in

Source	Grain quality trait ^a									Grain shape trait ^b		
	BRP	MRP	HRP	PCRG	DC	GT	AC	GC	PC	RL	RW	RLWR
Cultivar (C)	6.02**	7.69**	57.14**	102.48**	116.69**	132.72**	983.19**	85.11**	2.29 ^{ns}	15.40**	307.62**	330.44**
N management practice (N)	0.14 ^{ns}	0.75 ^{ns}	0.19 ^{ns}	2.45 ^{ns}	2.97 ^{ns}	7.98**	2.71 ^{ns}	2.06 ^{ns}	0.07 ^{ns}	0.64 ^{ns}	6.07*	2.35 ^{ns}
Season (S)	4.04 ^{ns}	11.20**	33.85**	12.92**	54.92**	56.15**	55.11**	18.54**	163.28**	5.75*	0.00 ^{ns}	0.59 ^{ns}
C × N	1.27 ^{ns}	0.13 ^{ns}	0.75 ^{ns}	0.38 ^{ns}	0.57 ^{ns}	8.03**	0.05 ^{ns}	0.31 ^{ns}	0.07 ^{ns}	0.64 ^{ns}	2.66 ^{ns}	1.91 ^{ns}
C × S	8.32**	9.32**	19.10**	26.19**	44.71**	13.46**	23.67**	6.72**	1.09 ^{ns}	15.54**	1.14 ^{ns}	5.43*
N × S	2.69 ^{ns}	0.94 ^{ns}	0.74 ^{ns}	1.44 ^{ns}	4.46*	5.45*	0.36 ^{ns}	0.07 ^{ns}	7.60*	1.77 ^{ns}	6.07*	2.35 ^{ns}
C × N × S	0.67 ^{ns}	0.14 ^{ns}	0.81 ^{ns}	0.22 ^{ns}	0.69 ^{ns}	5.49*	0.01 ^{ns}	2.51 ^{ns}	1.40 ^{ns}	0.50 ^{ns}	2.66 ^{ns}	1.91 ^{ns}

^a BRP, brown rice percentage; MRP, milled rice percentage; HRP, head rice percentage; PCRG, percentage of chalky rice grains; DC, degree of chalkiness; GT, gelatinization temperature; AC, amylose content; GC, gel consistency; PC, protein content.
^b RL, rice length; RW, rice width; RLWR, rice length-to-width ratio.
* Significance at the 0.05 probability level.
** Significance at the 0.01 probability level.
^{ns} Non-significance at the 0.05 probability level.

Table 3. F values of analysis of variance for effects of cultivar, N management practice and season on grain quality and shape traits in rice.

Season	N management practice	Cultivar	Grain quality trait ^a								Grain shape trait ^b			
			BRP (%)	MRP (%)	HRP (%)	PCRG (%)	DC (%)	GT	AC (%)	GC (mm)	PC (%)	RL (mm)	RW (mm)	RLWR
Early	FTNM	LYPJ	82.1(0.4) ^c	73.1(0.4)	51.9(1.7)	50.0(3.2)	8.43(0.81)	5.43(0.07)	23.2(0.2)	85.3(1.3)	8.1(0.2)	6.57(0.05)	2.24(0.04)	2.93(0.19)
		YLY1	80.2(0.3)	71.3(0.6)	64.6(0.7)	21.0(2.1)	3.53(0.77)	6.60(0.05)	14.8(0.2)	71.0(1.0)	8.9(0.2)	6.67(0.03)	2.22(0.01)	3.00(0.14)
		HHZ	80.5(0.2)	71.8(0.3)	42.2(2.0)	3.3(0.7)	0.33(0.07)	6.93(0.04)	17.5(0.2)	83.7(2.0)	8.3(0.1)	6.80(0.04)	2.00(0.02)	3.40(0.34)
	SSNM	LYPJ	81.0(0.2)	72.8(0.2)	50.6(1.0)	42.7(2.2)	7.07(0.27)	6.10(0.17)	23.4(0.2)	86.0(2.0)	8.6(0.1)	6.60(0.03)	2.25(0.03)	2.93(0.17)
		YLY1	79.6(0.5)	70.8(0.6)	63.7(0.2)	14.7(4.1)	2.13(0.48)	6.73(0.07)	14.9(0.2)	76.0(0.2)	9.1(0.2)	6.60(0.02)	2.20(0.02)	3.00(0.10)
		HHZ	80.8(0.5)	71.5(0.4)	40.0(1.7)	2.0(0.4)	0.13(0.04)	6.83(0.05)	17.7(0.4)	81.7(1.5)	8.9(0.1)	6.80(0.04)	2.00(0.02)	3.40(0.65)
Late	FTNM	LYPJ	80.4(0.4)	71.1(0.4)	60.0(0.7)	22.7(5.9)	2.43(0.69)	6.37(0.09)	23.0(0.2)	84.7(1.8)	10.5(0.3)	6.63(0.04)	2.21(0.02)	3.00(0.48)
		YLY1	80.5(0.4)	71.5(0.6)	60.7(1.0)	23.3(4.4)	2.27(0.44)	7.00(0.05)	16.9(0.2)	66.0(2.7)	10.6(0.3)	6.80(0.04)	2.19(0.02)	3.11(0.43)
		HHZ	79.5(0.8)	70.9(0.6)	54.5(4.9)	2.3(0.7)	0.23(0.09)	6.93(0.07)	18.4(0.2)	75.0(3.6)	10.9(0.6)	6.67(0.07)	2.00(0.02)	3.34(0.37)
	SSNM	LYPJ	80.5(0.1)	71.4(0.2)	56.6(1.2)	20.7(5.0)	2.37(0.50)	6.47(0.09)	23.4(0.2)	88.3(0.3)	10.3(0.4)	6.67(0.03)	2.30(0.02)	2.90(0.14)
		YLY1	80.8(0.3)	71.6(0.3)	63.1(1.0)	23.7(0.9)	2.57(0.38)	6.90(0.10)	17.2(0.3)	65.0(0.6)	10.4(0.1)	6.83(0.07)	2.25(0.03)	3.04(0.11)
		HHZ	79.9(0.6)	70.6(0.4)	57.0(1.7)	2.0(0.6)	0.30(0.06)	7.00(0.05)	18.8(0.2)	77.7(1.9)	10.2(0.3)	6.73(0.07)	2.00(0.02)	3.37(0.10)
Mean of cultivar														
	LYPJ	81.0a	72.1a	54.8b	34.0a	5.08a	6.09c	23.3a	86.1a	9.4b	6.62b	2.25a	2.94c	
	YLY1	80.3b	71.3b	63.0a	20.7b	2.63b	6.81b	16.0c	69.5c	9.8a	6.73a	2.21b	3.03b	
	HHZ	80.2b	71.2b	48.4c	2.4c	0.25c	6.93a	18.1b	79.5b	9.6ab	6.75a	2.00c	3.38a	

Note: Means of cultivars with the same letters for each parameter are not significantly different according to LSD at the 0.05 probability level.

^a BRP, brown rice percentage; MRP, milled rice percentage; HRP, head rice percentage; PCRG, percentage of chalky rice grains; DC, degree of chalkiness; GT, gelatinization temperature; AC, amylose content; GC, gel consistency; PC, protein content.

^b RL, rice length; RW, rice width; RLWR, rice length-to-width ratio.

^c Values in parenthesis are SE ($n = 3$).

Table 4. Grain quality and shape traits in three rice cultivars, including two super hybrid cultivars Liangyoupeijiu (LYPJ) and Y-liangyou 1 (YLY1) and a popular inbred cultivar Huanghuazhan (HHZ), grown under fixed-time N management (FTNM) and site-specific N management (SSNM) in early and late seasons.

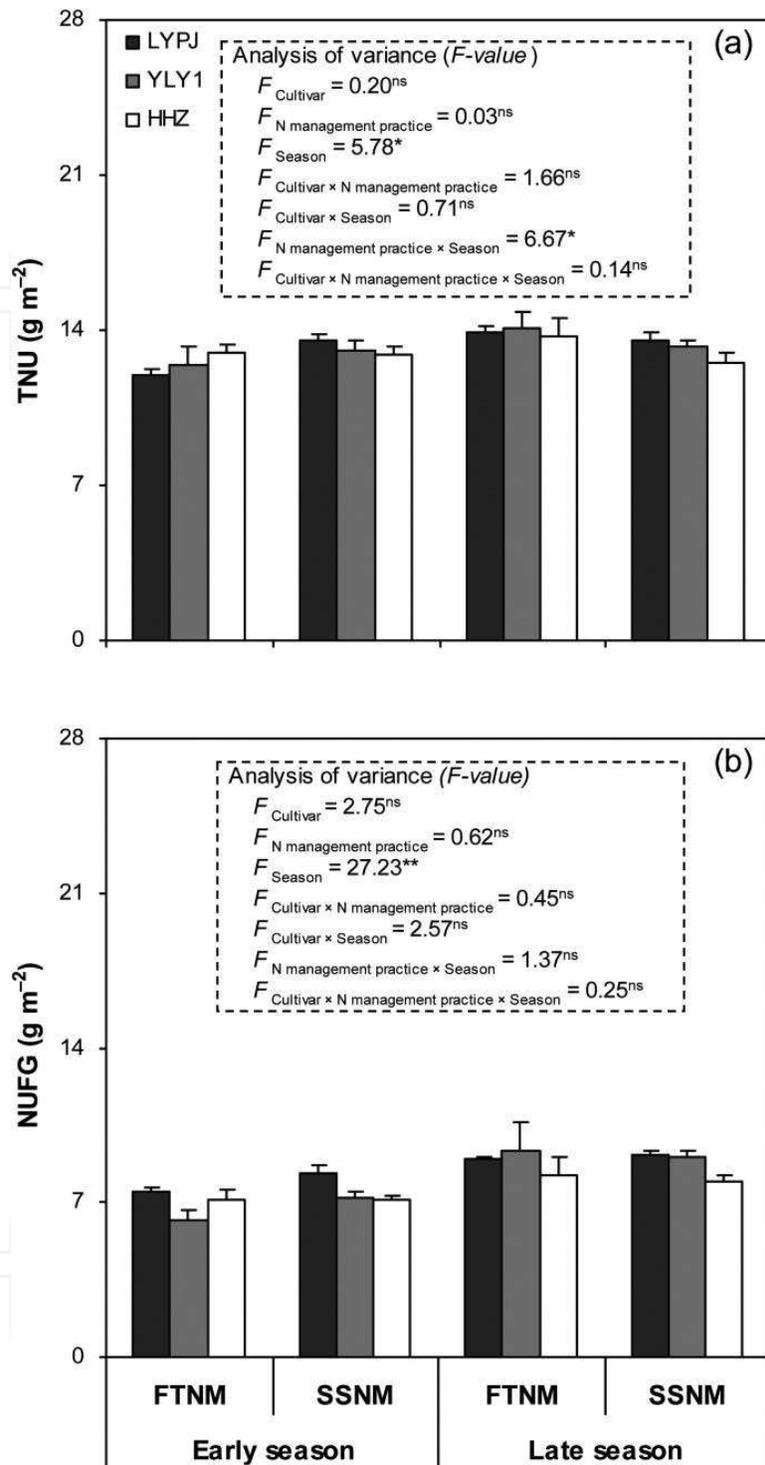


Figure 2. Total N uptake (TNU) and N uptake in filled grains (NUFG) in three rice cultivars, including two super hybrid cultivars Liangyoupeijiu (LYPJ) and Y-liangyou 1 (YLY1) and a popular inbred cultivar Huanghuazhan (HHZ), grown under fixed-time N management (FTNM) and site-specific N management (SSNM). Vertical bars represent SE ($n = 3$). *Significance at the 0.05 probability level. **Significance at the 0.01 probability level. ^{ns}Non-significance at the 0.05 probability level.

rice [15, 20]. Generally, increased RW or PC tends to result in increased milling efficiency. In this study, the former seems to be responsible for the higher milling efficiency in LYPJ and

YLY1 than in HHZ, because LYPJ and YLY1 had equal PC compared with HHZ. Moreover, it has been reported that there are positive relationships between RW with PCRG and DC [16, 17]. Therefore, the poorer appearance (higher PCRG and DC) in LYPJ and YLY1 might also be associated with their higher RW. These results also reveal that it may be difficult to achieve a synchronous improvement in milling efficiency and appearance in super hybrid rice. Among the cooking and eating quality traits, GT is often considered as an indicator affecting the cooking time of rice, for rice with higher GT requires a longer time to cook [31]. This point, however, is uncertain. Bhattacharya and Sowbhagya [32] observed that water uptake and hence the cooking time was strongly influenced by the surface area per unit weight. Other workers have also observed that water uptake of rice at boiling temperature is not related to GT but it is related to grain size and shape [33, 34]. In the present study, significant differences were observed both in GT and in grain shape between LYPJ and YLY1 with HHZ, suggesting that further studies are required to understand the difference in cooking characteristics between them. AC and GC have been considered the key indicators relating to palatability [31, 35]. Generally, consumers, especially in China, favor the rice with moderate AC and GC [25]. HHZ is such a cultivar. In the present study, LYPJ and YLY1 had largely higher or lower AC and GC than HHZ, implying that the palatability of LYPJ and YLY1 was not good enough to suit the preference of consumers. Our study suggests that strategies for grain quality improvement in super hybrid rice should be focused on appearance and palatability.

Previous studies showed that the N application could increase milling efficiency and nutritional value (PC) in rice grains and there was a positive relationship between the PC and N application rate [20, 23, 24]. Furthermore, Wang et al. [24] stated that the increased PC from the higher N application rate depended on increased TNU. However, in the present study, although the total N application rate was lower under SSNM than under FTNM by 20 and 15% in early and late season, respectively (**Table 2**), no significant differences were observed in N uptake (TNU and NUFG) in rice crops as well as milling efficiency and nutritional value in rice grains between SSNM and FTNM. Our results imply that replacing FTNM with SSNM can reduce N input without sacrificing grain quality in rice production.

It is well known that early season rice generally has poorer grain quality than late season rice and the poorer grain quality of early season rice is to a great extent attributed to the higher daily mean temperature during grain-filling period [25]. Consistently, in the present study, average daily mean temperature during grain-filling period across three rice cultivars was about 5°C higher in early season than in late season and grain quality was generally poorer in early season than in late season. More interestingly, we found that TNU and NUFG were significantly lower in early season than in late season. As mentioned above, higher N uptake in rice crops can lead to a higher grain PC, which may consequently result in a higher grain milling efficiency [20, 24]. Therefore, in this study, variation in N uptake was partly responsible for the seasonal differences in milling efficiency and nutritional value. Daily temperature is one of the factors influencing rice N uptake under favorable growth conditions and adequate N supply [36]. In general, higher daily temperature leads to a higher rice N uptake rate. Our previous study showed that daily temperature during the early growth stage was lower in early season than in late season, which resulted in that N uptake was lower in early season than that in late season [37]. This might be one reason why early season had lower TNU and NUFG than late season in the present study. Another reason for the seasonal variation in N

uptake might be the seasonal changes in the N application rate under SSNM, which was 8% lower in early season than in late season (**Table 2**). These results also indicate that SSNM can achieve a good match of N supply with crop demand.

In addition, we observed that the interactive effects between cultivar and season on grain quality traits were generally significant. It is not surprise because (1) the seasonal variation in average daily mean temperature during grain-filling period was different between the super hybrid rice cultivars (5.9°C) and the popular inbred rice cultivar (4.6°C) (**Figure 1b** and **c**) and (2) the temperature effects on grain quality traits are cultivar-dependent [25, 38]. For example, Zhong et al. [25] found that under high temperature, GC decreased or remained little changed for cultivars with higher amylase content and increased for cultivars with lower amylase content. A similar result was also observed in the present study (**Table 4**). Namely, high temperature in early season decreased GC for LYPJ, which had higher amylase content and increased GC for YLY1, which had lower amylase content.

5. Conclusions

It is concluded that (1) strategies for grain quality improvement in super hybrid rice should be focused on appearance and palatability and (2) replacing FTNM with SSNM can reduce N input without sacrificing grain quality in rice production.

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