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Changes in Cooking and Nutrition Qualities of Grains at Different Positions in a Rice Panicle under Different Nitrogen Levels

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Abstract: Cooking and nutrition qualities of grain are two of the most important aspects of rice quality. To understand the difference in cooking and nutrition qualities among the grains at different positions within a rice panicle, the distributions of gel consistency (GC), amylose content (AC) and crude protein content (CPC) of grains in a panicle in association with different nitrogen levels (0, 120 and 240 kg/ha) were investigated by using two rice varieties, Yangdao 6 (indica) and Wuyujing 3 (japonica). In general, the grains at the basal part of a panicle had lower GC and higher AC than those at the upper or middle part of a panicle. The 1st grain on the secondary branch with earlier flowering exhibited the highest GC, whereas the 2nd grain on the primary branch with later flowering showed the highest AC. For Yangdao 6, CPC in the grains on the primary branches was lower at the middle part of a panicle than at the upper or basal part of a panicle. For Wuyujing 3, there were no significant differences in CPCs in the grains among the upper, middle and basal parts of a panicle. GC in the grains was increased, whereas AC was reduced from zero nitrogen application (0N) to low amount of nitrogen application (LN), and the result was reversed from LN to medium amount of nitrogen application (MN). CPC was increased with the increase in the amount of nitrogen application.
Key words: rice; grain position; cooking quality; nutrition quality; nitrogen

Rice quality is an important consideration in production. Much research has showed that rice quality is not only controlled by genetic factors, but also affected by light, temperature, and water and nitrogen managements [1-6]. Cooking and nutrition qualities are two of the most important aspects of rice quality. Some studies [7-9] have investigated the relationship between nitrogen and cooking and nutrition qualities and reported that with increased nitrogen application, crude protein content (CPC) was increased, whereas amylose content (AC) and gel consistency (GC) were reduced. In a panicle of rice, the differences in flowering time and development of spikelets often result in different qualities and weights of grains [10-13]. However, little is known about difference in the cooking and nutrition qualities among the grains at different positions in a panicle of rice, and information on cultivation management and environmental factors regulating the rice quality at different positions in a panicle is unavailable. To find out the mechanism of rice quality of different grains in a panicle, explore the techniques to improve rice quality and consequently offer theoretical basis for rice breeding and cultivation, the distributions of GCs, ACs and CPCs associated with nitrogen application for different grains in a panicle were investigated by using two rice genotypes Yangdao 6 (indica) and Wuyujing 3 (japonica) as materials.

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MATERIALS AND METHODS

Rice materials and experimental design

The experiment was conducted at experimental farm of Yangzhou University, Jiangsu Province, China during May to October of 2003, and repeated in 2004. Two rice genotypes, YD-6 (Yangdao 6, an indica variety) and WYJ-3 (Wuyujing 3, a japonica variety), were grown in paddy field. The soil of the field was sandy loam, with organic matter of 20.2 g/kg, available N of 103.2 mg/kg, available P of 24.5 mg/kg and available K of 85.6 mg/kg.

A split-plot design with nitrogen (N) levels as main plots and genotypes as subplots was adopted. The nitrogen levels included no nitrogen application (0N, 0 kg/ha), low nitrogen application (LN, 120 kg/ha) and medium nitrogen application (MN, 240 kg/ha) with urea as the source (40% as basal fertilizer and 60% as topdressing fertilizer for promoting panicle development). The seeds were sown in the field on 10 May, and rice seedlings were transplanted on 8 June at a hill spacing of 20 cm × 20 cm with 2 seedlings per hill. Plot dimension was in 4 m × 5 m. Each of the genotypes had three plots as repetitions.

Sampling

Five hundred panicles heading on the same day were chosen. For parts of them, the flowering date and the position of every spikelet in the panicle were recorded. Four hundred panicles at maturity were divided into different samples according to different parts and grain positions. YD-6 usually had 11-12 primary branches (PBs) in a panicle, and WYJ-3 usually had 9-10 PBs, all PBs in a panicle were averagely divided into three parts, i.e. the upper (3-4 PBs for YD-6, 3 PBs for WYJ-3), middle (4 PBs for YD-6, 3-4 PBs for WYJ-3) and basal (4 PBs for YD-6, 3 PBs for WYJ-3) parts. The grains were numbered as 1^{st} to 6^{th} on a primary branch and 1^{st} to 3^{rd} or 4^{th} on a secondary branch (SB) from the top to base, and the grains at the same parts or positions were combined as one group. Schematic representation of a rice panicle was shown in Fig. 1. At maturity, grains were harvested, and full-filled grains were selected by using specific gravity method in water and then air-dried for rice quality determination, while empty and partly-filled grains were removed.

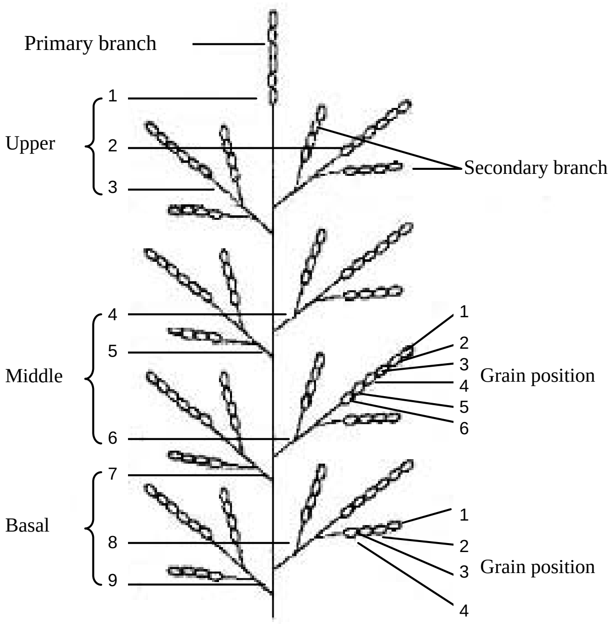

Fig. 1. Schematic representation of a rice panicle.

Measurement methods

AC and GC of rice were determined according to the National Standard of the People's Republic of China (GB/T17891-1999 *High Quality Paddy*). N content of rice was determined using the Kjeldahl method. CPC of rice was calculated from the N content × 5.95.

RESULTS

Distribution of gel consistencies (GCs) of grains in a panicle

The distribution of GCs of grains varied with genotypes and nitrogen levels (Table 1). Under MN, in WYJ-3, grains at the middle part in a panicle exhibited the highest GCs, followed by those at the upper part and those at the basal part showed the lowest. In YD-6, GCs of grains exhibited the order of the upper part > the middle part > the basal part on the primary branch, while the order was the basal part > the upper part > the middle part on the secondary branch. Under LN, GCs of grains were higher at the upper part in a panicle on the primary and secondary branches in WYJ-3 and on the secondary branches in YD-6 than those at the middle and basal parts. On the primary branch in YD-6, GCs of grains exhibited an order of the middle part > the basal part > the upper part. Under 0N, GCs of grains on the primary and secondary branches exhibited the basal part > the upper part > the middle part in YD-6. GCs of grains on the primary branch at the upper part in WYJ-3 were the lowest among the three parts, and those at the middle and basal parts had no significant difference, while GCs of grains were the highest on the secondary branch at the middle part of a panicle, and the differences in GCs between grains at the upper and basal parts were not significant. In general, GCs of grains on the primary branch were greater than those on the secondary branch at the same part in YD-6

Table 1. Gel consistencies of grains at different parts in a panicle of rice under different nitrogen levels.

Treatment	Part of a panicle	Primary branch				Secondary branch			
		YD-6		WYJ-3		YD-6		WYJ-3	
		Mean (mm)	*CV* (%)	Mean (mm)	*CV* (%)	Mean (mm)	*CV* (%)	Mean (mm)	*CV* (%)
MN	All grains	66.3 *b*		67.6 *a*		61.0 *b*		66.1 *b*	
	Upper	71.9 a	12.4	68.5 a	4.8	61.0 a	14.6	69.1 a	12.8
	Middle	65.0 b	3.0	72.6 a	9.3	59.1 a	8.6	70.9 a	13.4
	Basal	62.1 b	9.1	61.8 b	4.8	62.9 a	15.8	58.3 b	11.3
LN	All grains	69.0 *a*		67.5 *a*		65.3 *a*		70.3 *a*	
	Upper	60.3 c	12.2	71.0 a	11.9	67.6 a	13.2	79.5 a	10.5
	Middle	79.1 a	13.7	65.9 b	13.0	64.8 a	6.8	63.1 b	11.2
	Basal	67.7 b	11.8	65.7 b	9.3	63.6 a	11.1	68.3 b	6.6
0N	All grains	60.6 *c*		64.9 *b*		57.4 *b*		69.0 *ab*	
	Upper	61.8 a	10.9	60.0 b	15.2	63.1 a	26.0	67.0 b	12.5
	Middle	55.9 b	7.6	67.1 a	6.9	45.1 b	6.5	72.9 a	3.0
	Basal	64.2 a	6.6	67.5 a	5.5	63.9 a	6.7	67.0 b	5.6

Within a column, data followed by the common Italic and Roman letters indicate no significant difference at 0.05 level for mean of all grains of rice under different nitrogen levels and the grains at different parts under the same nitrogen levels, respectively.

CV, Coefficient of variation.

under different nitrogen levels. GCs of grains on the primary branches in WYJ-3 under MN were higher than those on the secondary branches, whereas GCs of grains on the secondary branch in WYJ-3 were higher than those on primary branch under 0N and LN.

The ordinations of GCs of grains at different parts and positions in a panicle were shown in Table 2. The first grain on the secondary branch in YD-6 showed the highest GC under each nitrogen level. The ordinations of GCs of grains on the primary branch in both YD-6 and WYJ-3 and on the secondary branch in WYJ-3 were changeable. GCs of grains at different positions on the same branch varied with the parts and nitrogen levels, and the ordination was not consistent

Table 2. Gel consistencies of grains (mm) at different positions in a panicle of rice under different nitrogen levels.

Part of a panicle	Grain position	Primary branch						Secondary branch					
		YD-6			WYJ-3			YD-6			WYJ-3		
		MN	LN	0N	MN	LN	0N	MN	LN	0N	MN	LN	0N
Upper	1st	62.5	59.0	61.5	65.0	85.5	51.5	74.5	77.5	88.5	83.0	75.0	74.0
	2nd	81.5	48.5	62.0	69.5	63.5	76.0	52.5	71.0	48.0	64.0	73.5	75.0
	3rd	61.0	65.0	75.0	68.0	65.0	63.5	60.0	66.5	60.0	66.5	77.0	57.5
	4th	76.0	66.0	57.5	67.5	64.5	51.5	57.0	55.5	56.0	63.0	92.5	61.5
	5th	80.5	68.5	58.5	68.5	70.5	55.0						
	6th	70.0	55.0	56.0	72.5	77.0	62.5						
Middle	1st	65.0	67.5	60.0	62.0	82.5	60.5	66.0	70.0	47.5	85.0	54.0	75.0
	2nd	64.5	71.0	56.5	76.0	65.0	70.5	55.5	66.5	45.5	69.5	61.0	72.0
	3rd	67.0	70.5	59.0	-	65.5	69.5	60.5	60.0	41.0	68.0	66.5	73.0
	4th	66.0	82.0	58.0	81.0	56.0	65.5	54.5	62.5	46.5	61.0	71.0	71.5
	5th	65.5	87.5	48.5	72.0	64.0	72.5						
	6th	62.0	96.0	53.5	72.0	62.5	64.0						
Basal	1st	55.0	75.5	63.0	63.5	70.5	71.0	73.0	73.0	67.5	53.0	72.0	64.0
	2nd	68.5	74.5	67.5	63.5	58.5	71.5	71.0	65.0	67.0	55.5	65.5	64.0
	3rd	63.5	75.0	67.0	65.0	60.0	68.0	52.5	61.0	59.5	66.5	72.0	70.0
	4th	62.5	60.0	61.0	58.0	62.0	66.5	55.0	55.5	61.5	-	63.5	70.0
	5th	67.5	58.5	58.5	60.0	73.5	65.5						
	6th	55.5	62.5	68.0	61.0	69.5	62.5						

with the flowering time of spikelets (Table 2).

Both genotypes showed similar responses of GCs of grains to nitrogen (Tables 1 and 2). Generally, GCs of grains were increased with the increasing amount of nitrogen application when the nitrogen level was from zero (0N) to LN. Under such a condition, GCs of grains on the primary and secondary branches were increased by 41.5% and 43.7% for the middle part of a panicle in YD-6, and by 18.3% and 18.7% for the upper part in WYJ-3, respectively. GCs of grains in two rice genotypes, on average, were reduced when the nitrogen levels was from LN to MN, but the values were still higher than those under 0N.

The above results indicated that the amount of nitrogen application affects not only GCs of grains, but also their distributions in a rice panicle.

Distribution of amylose contents (ACs) of grains in a panicle

The average of ACs of grains at different parts in a panicle was presented in Table 3. Under MN, ACs of grains on the primary and secondary branches showed no significant differences among the three parts in a panicle for YD-6. Whereas the differences among grains at the three parts for WYJ-3 was much greater than those for YD-6. ACs of grains at the middle and basal parts had no significant difference, but they were higher than those at the upper part. Under LN, ACs of grains on the primary branch of the two genotypes and on the secondary branch for YD-6 exhibited the order of the upper part > the middle part > the basal part, while those of grains on secondary branch for WYJ-3 showed the order of the upper part > the basal part > the middle part. Under 0N, ACs of grains on the primary and secondary branches in YD-6 presented the order of the upper and basal parts >the middle part, and ACs of grains at the upper and basal parts had no significant difference. But in WYJ-3 it displayed the order of the middle part > the upper part > the basal part. In general, ACs of grains at different parts varied with genotypes and nitrogen levels. For YD-6, ACs of grains on the secondary branch were higher than those on the primary branch under MN, but those on the primary branch were larger than those on the secondary branch under LN and 0N. For WYJ-3, the results were reversed (Table 3).

The ordinations of ACs of grains at different parts and positions were shown in Table 4. Under MN, the 2nd grains on the primary branch at all parts in two rice genotypes showed higher ACs. On the secondary branch, the ordinations of ACs of grains at different parts in YD-6 were variable. In WYJ-3, The 1st grains at the upper and middle parts, and the 3rd grain at the

Table 3. Amylose contents of grains at different parts in a panicle of rice under different nitrogen levels.

Treatment	Part of a panicle	Primary branch				Secondary branch			
		YD-6		WYJ-3		YD-6		WYJ-3	
		Mean (%)	*CV* (%)	Mean (%)	*CV* (%)	Mean (%)	*CV* (%)	Mean (%)	*CV* (%)
MN	All grains	13.6 *c*		15.7 *a*		14.5 *ab*		14.3 *a*	
	Upper	13.5 a	8.2	13.8 b	29.0	14.3 a	3.1	11.3 b	58.4
	Middle	13.4 a	13.6	16.6 a	5.7	14.5 a	8.8	15.6 a	2.2
	Basal	14.0 a	12.3	16.6 a	8.2	14.6 a	1.2	16.0 a	20.9
LN	All grains	15.2 *b*		14.2 *b*		13.5 *b*		15.4 *a*	
	Upper	15.9 a	8.1	14.6 a	23.8	14.9 a	6.4	16.0 a	3.5
	Middle	15.6 a	6.3	14.6 a	13.7	14.4 a	15.1	14.6 a	14.0
	Basal	14.2 b	13.9	13.5 a	12.0	11.3 b	28.3	15.7 a	4.8
0N	All grains	16.8 *a*		15.9 *a*		14.5 *a*		15.9 *a*	
	Upper	17.4 a	9.5	15.4 b	15.4	15.5 a	8.0	15.1 a	4.6
	Middle	15.6 b	10.0	18.5 a	6.3	12.9 b	14.3	17.8 a	2.3
	Basal	17.4 a	9.1	13.7 b	18.3	15.3 a	3.3	14.8 a	17.5

Within a column, data followed by the common Italic and Roman letters indicate no significant difference at 0.05 level for mean of all grains of rice under different nitrogen levels and the grains at different parts under the same nitrogen levels, respectively.

Table 4. Amylose contents (%) of grains at different positions in a panicle of rice under different nitrogen levels.

Part of a panicle	Grain position	Primary branch						Secondary branch					
		YD-6			WYJ-3			YD-6			WYJ-3		
		MN	LN	0N	MN	LN	0N	MN	LN	0N	MN	LN	0N
Upper	1st	12.6	15.2	-	18.8	17.3	17.5	14.5	13.7	14.7	17.7	16.4	
	2nd	14.8	17.6	18.3	15.8	18.6	12.2	14.6	14.9	14.4	16.4	15.6	14.4
	3rd	13.9	15.1	14.5	12.7	16.9	17.6	13.7	16.0	17.1	15.7	-	15.7
	4th	13.8	14.1	18.0	8.0	12.9	17.3	14.6	15.2	15.9	15.5	-	15.2
	5th	13.9	16.7	18.2	-	10.7	13.2						
	6th	11.2	16.5	18.3	13.4	11.0	14.7						
Middle	1st	11.7	15.5	13.3	16.8	13.1	19.4	14.7	15.1	14.2	16.1	-	17.2
	2nd	15.7	15.1	17.2	17.8	12.7	16.5	12.6	16.3	14.0	15.3	12.4	18.1
	3rd	14.5	15.9	15.4	-	14.9	18.8	15.4	14.9	13.0	15.7	15.0	17.9
	4th	10.8	16.9	17.0	15.8	13.2	18.8	15.3	11.3	10.2	15.5	16.4	18.0
	5th	13.9	16.1	14.4	17.2	15.6	17.6						
	6th	13.6	14.0	16.5	15.5	17.9	19.5						
Basal	1st	11.7	14.1	14.4	17.1	12.3	17.9	14.8	14.1	16.0	12.2	15.7	16.4
	2nd	15.2	12.4	18.2	17.8	13.3	12.9	14.5	11.1	14.8	17.9	16.7	18.0
	3rd	15.1	17.2	18.3	16.3	15.5	14.9	14.7	6.9	15.1	18.0	15.6	15.2
	4th	14.8	12.5	17.9	15.5	11.1	12.3	14.5	13.1	15.5	-	14.8	16.5
	5th	11.8	15.9	18.6	14.7	14.1	13.4						
	6th	15.3	13.0	17.0	17.3	14.8	10.7						

basal part showed the highest ACs in their corresponding parts. Under LN, the 2nd grains on the primary branches at the upper part in both genotypes also showed the higher ACs, but ACs of grains at other parts varied with genotypes and grain positions. Under 0N, the 2nd grains on the primary branch at each part in YD-6 had the highest ACs, but those of WYJ-3 had the lowest ACs. Under LN and 0N, ACs in the 3rd grains on the secondary branch at the upper part and in the 1st grains on the secondary branch at middle and basal parts were higher for YD-6, whereas the ordinations varied with nitrogen levels and grain positions for WYJ-3.

Responses of ACs in grains to nitrogen levels varied with genotypes and grain positons (Tables 3 and 4). Generally, for YD-6, ACs in grains on the primary branches were reduced with the increase of N levels from 0N to MN. The reductions of AC under MN and LN were about 19.0% and 9.5% compared with that under 0N, but nitrogen application had no significant effects on AC in grains on the secondary branches. For WYJ-3, the effect of nitrogen application on AC was different in grains at different parts of a panicle. ACs in grains at the upper part had not significant difference when nitrogen levels were from 0N to LN, but they were reduced obviously when nitrogen levels were from LN to MN. ACs in grains at the middle part were reduced obviously when nitrogen level was from 0N to LN, and increased a little when nitrogen level was from LN to MN, but ACs in grains under MN were still lower than those under 0N. At the basal part in a panicle, ACs in grains on the primary branches changed little when nitrogen level ranged from 0N to LN, but increased obviously from LN to MN, while ACs in grains on the secondary branches increased with the increase in the amount of nitrogen application (Tables 3 and 4).

Distribution of crude protein contents (CPCs) of grains in a panicle

The CPCs in grains at different parts in a panicle were shown in Table 5. In YD-6, under MN and LN, grains on the primary branches at the middle part of a panicle had lower CPCs than those at the upper or basal parts, which had no significant difference. Grains on the secondary branches at the basal part of a panicle exhibited the highest CPCs, followed by those at the middle part, and those at the upper part were the lowest. Under 0N, grains on the primary branches at the basal part and on the secondary branches at the upper part all exhibited lower CPCs in comparison with those at other parts. In WYJ-3, CPCs in grains on

Table 5. Crude protein contents (%) of the grains at the different parts in a panicle of rice under different nitrogen levels.

Treatment	Part of a panicle	Primary branch				Secondary branch			
		YD-6		WYJ-3		YD-6		WYJ-3	
		Mean	*CV*	Mean	*CV*	Mean	*CV*	Mean	*CV*
MN	All grain	10.5 *a*		6.4 *a*		8.9 *a*		6.2 *a*	
	Upper	11.8 a	20.92	5.9 b	11.87	8.4 b	31.9	6.1 b	21.0
	Middle	8.5 b	13.92	6.3 b	7.35	8.5 b	9.1	5.7 b	12.6
	Basal	11.2 a	13.32	6.9 a	16.61	9.8 a	4.1	6.7 a	10.3
LN	All grain	8.2 *b*		6.5 *a*		8.0 *b*		6.2 *a*	
	Upper	8.0 a	7.63	6.4 a	5.96	7.4 b	10.3	6.3 a	6.1
	Middle	7.7 a	14.29	6.4 a	7.96	7.7 ab	15.4	6.2 a	3.7
	Basal	8.9 a	22.45	6.6 a	6.24	8.9 a	6.0	6.1 a	7.3
0N	All grain	8.3 *b*		6.5 *a*		8.3 *ab*		5.9 *a*	
	Upper	8.6 a	21.36	6.3 a	8.69	7.6 a	0.9	6.3 a	9.9
	Middle	8.7 a	9.52	6.7 a	10.35	8.9 a	10.0	5.8 ab	11.4
	Basal	7.5 a	5.74	6.5 a	3.05	8.5 a	15.5	5.7 b	8.6

Within a column, data followed by the common Italic and Roman letters indicate significant difference at 0.05 level for mean of all grains of rice under different nitrogen levels and the grains at different parts under the same nitrogen level, respectively.

the primary branches were not significantly different at the three parts of a panicle under the three nitrogen levels, while those on the secondary branches showed the trends of the basal part > the upper part > the middle part under MN, and the upper part > the middle part > the basal part under LN and 0N, but the differences were not significant.

Generally, under the same nitrogen level, grains on the primary branches had higher CPCs than those on the secondary branches for both genotypes. Further analysis showed that the differences in CPCs in grains between the primary and secondary branches in YD-6 was increased with the rising nitrogen levels, with the values of the difference of 0.0%, 2.5% and 18.0% under 0N, LN and MN, respectively. But in WYJ-3, the differences were decreased with the increase of nitrogen application, and values of the differences between the primary and secondary branches were about 10.2%, 4.8% and 3.2% under 0N, LN and MN, respectively.

The distribution of CPCs in grains at different positions varied with genotypes, grain positions and nitrogen levels (Table 6). In YD-6, the distribution of CPCs had no significant difference among the 1st, 3rd, 4th, 5th and 6th grains on the primary branches, even though CPCs in the 5th and 6th grains were a little higher, but in WYJ-3, the ordination of CPCs in grains at different positions was indefinite. Generally, the 1st grain on the secondary branches in both genotypes had the highest CPCs, and those at other positions varied with nitrogen levels and the parts in a panicle.

In YD-6, the averages of CPCs in grains on the primary and secondary branches were increased with increased nitrogen levels, especially those at the upper and basal parts, the increases in the grains on the primary branches were larger than those on the secondary branches. The CPCs in grains at the upper and basal parts under MN were increased by 37.2% and 49.2% than that under 0N, respectively. In WYJ-3, CPCs in grains on the primary branches had no significant response to nitrogen application, but those on the secondary branches, especially at the basal part, were increased with increased nitrogen levels.

DISCUSSION

Our results showed that the grains on the primary and secondary branches at the basal part had the less GC and higher AC, whereas those at the middle and upper parts had higher GC and less AC, indicating the grain quality was related to the development of rachis branches. The grains on the earlier-developed rachis branches (the upper and middle branches of a panicle) had better cooking quality (longer gel consistency and

Table 6. Crude protein contents (%) of grains at the different positions in a rice panicle under different nitrogen levels.

Part of a panicle	Grain position	Primary branch						Secondary branch					
		YD-6			WYJ-3			YD-6			WYJ-3		
		MN	LN	0N	MN	LN	0N	MN	LN	0N	MN	LN	0N
Upper	1st	12.7	7.9	-	6.2	6.2	6.2	9.3	7.3	9.3	4.3	6.7	6.9
	2nd	10.6	7.8	6.9	6.5	6.3	5.9	8.8	8.4	6.7	6.4	6.0	6.1
	3rd	13.2	8.0	10.0	4.7	7.1	6.0	8.8	6.6	6.5	6.4	-	6.8
	4th	15.7	7.2	8.7	6.4	6.1	6.3	6.6	7.4	8.9	7.2	6.1	5.6
	5th	9.3	8.6	9.6	5.5	6.4	6.2						
	6th	11.3	8.6	7.7	6.3	6.2	7.4						
Middle	1st	8.2	9.4	7.5	5.8	6.5	6.1	9.1	7.9	9.4	6.1	-	6.1
	2nd	6.7	7.7	8.0	5.8	6.1	7.4	7.5	9.1	8.4	4.7	6.4	6.6
	3rd	7.8	8.7	8.0	7.1	7.3	7.0	9.2	6.3	7.9	6.3	6.2	5.3
	4th	9.1	7.5	7.4	6.8	6.4	7.4	8.4	7.4	9.9	5.6	5.9	5.2
	5th	9.4	9.3	9.2	6.4	6.4	5.7						
	6th	10.0	9.3	5.8	6.6	5.9	6.5						
Basal	1st	11.3	9.4	8.1	5.8	6.2	6.8	10.1	9.4	7.9	6.9	5.8	6.3
	2nd	8.8	8.7	6.1	6.5	6.7	6.3	9.5	8.9	7.1	6.3	5.4	5.7
	3rd	9.0	8.4	6.3	7.8	7.0	6.6	9.2	8.6	7.3	6.2	6.6	5.1
	4th	10.1	8.9	8.5	7.4	7.2	6.3	10.5	9.3	9.8	7.3	-	5.6
	5th	12.6	8.4	7.9	5.6	6.4	6.4						
	6th	15.4	9.6	7.8	8.5	6.3	6.7						

lower AC), and those on the later-developed branches had worse cooking quality (shorter gel consistency and higher AC). For the grains on the same branches, the 1st grain on the secondary branch with earlier flowering in YD-6 had greater GC. However, GCs of grains on the primary branches in both YD-6 and WYJ-3 and on the same secondary branches in WYJ-3 varied with nitrogen levels. The 2nd grain on the primary branches with later flowering in YD-6 had the highest ACs under the three nitrogen levels (0N, LN, and HN), whereas those in WYJ-3 had the lowest ACs under MN, and the orders of ACs in grains under other nitrogen levels were variable. All these results indicated that the cooking quality of grains was associated with the flowering time of spikelets and varied with genotypes and nitrogen levels. The reason for which the distribution of the cooking quality varies with grain positions in a panicle needs further research.

We found that the grains on the primary branches at the middle part of a panicle in YD-6 had lower CPCs, and those at the upper and basal parts had higher CPCs. But there were no significant differences among the three nitrogen levels for WYJ-3. The difference in the distribution of cooking quality between the two genotypes might be related to the development and filling of endosperms. In YD-6, the plumpnesses of grains on the primary branch at the middle part were good (98.6% in filled-grain percentage), and the grains were heavy (28.6 g in 1000-grain weight), while the plumpnesses of grains on the primary branch at the upper and basal parts were not so good (96.5% and 93.2%, respectively, in filled-grain percentage), and the grain weights were low (27.3 and 26.5 g in 1000-grain weight, respectively). Whereas, in WYJ-3, the differences in the plumpness and grain weight were rather small among the grains at the upper, middle and basal parts (97.5%, 98.1% and 96.9% in filled-grain percentage, and 26.7, 26.9 and 26.4 g in 1000-grain weight respectively). The well-filled grains had higher starch contents but less CPCs, and the results were reversed for those not fully filled grains. It was reported that the differences in grain plumpness and grain weight between the superior and inferior grains were greater for the source-limiting type varieties than for the sink-limiting type ones [15]. We therefore presumed that the difference in CPCs in grains at different parts of a panicle was greater for the source-limiting type than for the sink-limiting type varieties. Minimizing the difference in filled-grain percentage among the grains at different positions would reduce the variation of CPCs in these grains via breeding and cultivation approach.

The results of the present study showed that nitrogen levels had great influence on the cooking and nutrient qualities of rice. GC was increased, whereas AC decreased, when nitrogen levels were from 0N to LN, but GC was decreased and AC increased when nitrogen levels were from LN to MN. The reason for the effects of N application on cooking and nutrient qualities was not clear yet. We had observed that starch branching enzyme (Q-enzyme) activity was increased when nitrogen levels were form 0N to LN, whereas it decreased when nitrogen levels were from LN to MN (data not shown). Moreover, the activity of Q-enzyme was significantly and positively correlated with GC, whereas significantly and negatively correlated with AC, suggesting that nitrogen application could regulate the activity of Q-enzyme and thereby exert actions to physical and chemical properties (GC and AC) of rice. A similar result was reported by Zhao et al [16], they found that CPC was increased with the increase of nitrogen application. A study made by Liu [17] showed that less nitrogen topdressed at the heading stage could increase the activities of glutamine synthetase (GS) and NADH-glutamate synthase (NADHGOGAT), and the activities of GS and NADHGOGAT at the early grain filling stage were significantly and positively correlated with nitrogen translocation efficiency, nitrogen uptake of grains and grain yield. The above results indicated that rice quality could be improved by reasonable management of nitrogen through regulating the activities of enzymes involved in carbon and nitrogen metabolism. The optimized nitrogen application rate for improving rice quality needs to be further analysed.

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