Effects of Late Nitrogen Fertilizer Application on Head Rice Yield, Protein Content, and Grain Quality of Rice

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ABSTRACT

Rice yields of 10 and 6 t/ha can be achieved in the humid tropics during the dry and wet seasons, respectively. At these high yield levels, late nitrogen (N) fertilizer application at flowering at the International Rice Research Institute (IRRI) farm often results in increased rough rice yield of IR cultivars and is accompanied by higher milled rice protein and increased total and head-milled rice contents. The combined effects of N application at flowering resulted in a 30–60% increase in head-rice protein yield in three field experiments. In general, milled rice translucency improved, but Kett whiteness decreased with late N fertilizer application. Brown-rice weight was not affected by late N application. In most cases, there was a significant positive correlation between head rice content, milled rice protein, and translucency. Thus, when crop management seeks to achieve yields that approach yield potential levels, late N fertilizer application provides an option to improve milling and nutritional quality of rice grain.

A yield decline has occurred in several long-term experiments where continuous irrigated rice is grown in the Philippines (Flinn and De Datta 1984, Cassman et al 1995). In recent studies to identify the cause of decreasing yield trends at the International Rice Research Institute (IRRI) farm, increased nitrogen (N) fertilizer rates including a top-dressing applied at flowering stage was found to increase the yield of IR rices (Cassman et al 1993, 1994). It was hypothesized that the current low yields at the IRRI farm were partly related to a change in the N supplying capacity of soil which results in low N concentration in the leaf canopy during the grain filling period, early senescence of leaves, and low rates of photosynthesis (Kropff et al 1993; Cassman et al 1995). Consistent with this hypothesis, grain protein content also appears to have decreased. For example, mean protein content of milled rice was typically ≈7% in the 1960's and 1970's at the IRRI farm in plots without applied N (Cagampang et al 1966, Eggum and Juliano 1975, Gomez and De Datta 1975), whereas grain protein from 0-N IRRI field plots (block B4) in the 1991 wet season was only 5.5% for IR72 and 5.0% for IR58109-113-3-3-2 (IRRI, *unpublished data*).

Fertilizer-N application up to panicle initiation stage is known to increase protein content and possibly grain yield of rice (IRRI 1964, Nangju and De Datta 1970, Taira 1970, Taira et al 1970, Seetanum and De Datta 1973, Patrick and Hoskins 1974). Spraying urea (Nishizawa et al 1977) or triazines or substituted ureas (De Datta et al 1972) on the rice leaves at the heading stage also increased grain protein content of rice. High protein content improves the whole-grain or head rice content (Nangju and De Datta 1970, Seetanum and De Datta 1973, Blakeney 1979, Jongkaewwattana et al 1993) and milled-rice translucency (IRRI 1964, Cagampang et al 1966). Protein distribution within the grain becomes more even as protein content increases because the number of protein bodies increase (Juliano et al 1973). High-protein brown rice is more resistant to abrasive milling than low-protein rice of the same variety (Cagampang et al 1966). The increase in protein content in milled rice is reflected mainly in the storage proteins, glutelin, and prolamin (Michael et al 1961, Cagampang et al 1966, Nishizawa et al 1977) located in protein bodies (Juliano et al 1973). An increase in milled rice protein <10% protein only slightly reduces the lysine content of the protein, but has no effect on lysine content when protein is >10% (Cagampang et al 1966, Taira et al 1970, Nishizawa et al 1977). This was confirmed by actual N balance studies of milled rices differing in protein content in rats (Eggum and Juliano 1975, Nishizawa et al 1977) and in humans (Juliano 1993).

Rice is the major source of dietary protein for most people in tropical Asia (Juliano 1993). Head rice is more valuable than brokens, and consumers prefer high head rice content and more translucent rice (Unnevehr et al 1992). The objective of the present study was to determine the effects of increased yield due to higher rates of applied N and application of N fertilizer at flowering on protein content and grain market quality of milled rice.

MATERIALS AND METHODS

Three field experiments were conducted in bunded plots at the IRRI irrigated lowland farm in 1992. Treatments were arranged in a split-plot completely randomized block design in block M10 (Experiment 1) in the dry season. Main plots included 1) a control without applied N; 2) a standard split application of 120 kg of N/ha broadcast and incorporated 1 day before transplanting (basal) and 60 kg N/ha at panicle initiation (total 180 kg of N/ha); and 3) multiple split applications which included 60 kg of N/ha applied basal, mid-tillering, and panicle initiation plus an additional top-dressing of 45 kg of N/ha at flowering (total 225 kg of N/ha). Rice cultivar IR72, line IR58109-113-3-3-2, and hybrid IR64616H were subplots.

Another dry-season experiment in block B4 with IR58109-113-3-3-2 (Experiment 2) had three N fertilizer levels of 0, 150, and 190 kg of N/ha, and three N application timing treatments (basal + panicle initiation, basal + maximum tillering + panicle initiation, and basal + maximum tillering + panicle initiation + flowering) arranged as a completely randomized block design.

In the 1992 wet season (Experiment 3), treatments were arranged in a split-plot design in block K3. Main plots were a factorial combination of four N fertilizer timing treatments applied before panicle initiation and three rices: IR72, line IR58185-23-3-3-2, and hybrid IR64616H. Subplots were without N appli-

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TABLE I
Effect of Rate and Timing of Applied Nitrogen on Rice Characteristics—Experiment 1 (1992 Dry Season)

N Fertilizer Treatment[a] (kg N/ha)										Milled Rice		
B	MT	PI	FL	Total	Rough Rice Yield (t/ha)	Brown Rice 100-Grain Wt (g)	Total Milled Rice (%)	Head Rice (%)	Head Rice Yield (t/ha)	Protein Content (%)	Whiteness (%)	Translucency (%)
0	0	0	0	0	5.26c	2.04b	68.4c	37.5c	1.97c	5.62c	51.1a	58.2c
120	0	60	0	180	9.33b	2.13a	70.2b	47.1b	4.39b	7.58b	44.3b	76.4b
60	60	60	45	225	9.89a	2.13a	70.8a	57.7a	5.69a	9.56a	40.4c	85.5a
Variety												
IR72					7.98b	2.04b	70.3a	38.8b	3.10c	7.63b	45.2a	69.5b
IR58109-113-3-3-2					7.92b	2.23a	69.3b	50.4a	4.00b	7.07c	45.8a	65.5b
IR64616H					8.58a	2.03b	69.8ab	53.0a	4.55a	8.05a	44.8a	85.2a
Significance[b]												
N fertilizer (NF)					***	**	***	**	***	***	***	***
Variety (V)					***	***	*	**	**	***	ns	***
NF × V					**	ns	ns	ns	ns	ns	**	ns
CV (%)					3.3	1.8	1.1	19.4	22.5	4.4	3.0	6.7

[a] B = basal, MT = maximum tillering, PI = panicle initiation, FL = flowering. Means in the same column and heading followed by the same letter are not statistically different ($P < 0.05$) by Duncan's multiple range test.
[b] * = $0.01 < P < 0.05$, ** = $0.001 < P < 0.01$, *** = $P < 0.001$.

cation after panicle initiation or with an additional N topdressing at flowering stage.

Both IR72 and IR64616H are early maturing with a growth duration of 112–115 days. Lines IR58109-113-3-3-2 and IR58185-23-3-3-2 are medium-early maturing with a growth duration of 122–125 days. In all experiments, each treatment had four replicate plots of 19.25 m^2 (7.7 × 2.5 m) each, hill spacing was 20 × 20 cm, and three 13-day-old seedlings were transplanted per hill. Transplanting was done on January 16th in the dry season and July 8th in the wet season. Mean solar radiation was 18.0 mJ/m^2 in the dry season and 16.7 mJ/m^2 in the wet season. Phosphorus (26 kg of P/ha), potassium (50 kg of K/ha), and zinc (7.5 kg of Zn/ha) were applied basal and incorporated during the last harrowing. Nitrogen was added as granular urea. The plots were permanently flooded from 4 days after transplanting up to one week before harvest.

Rough rice samples for quality evaluation were obtained from the center of each plot at harvest (adjacent to the 5-m^2 area for grain yield), at least five rows from the border, threshed, and dried in the laboratory for 24 hr in a forced-air oven at 35°C. Mean daily temperatures during grain ripening were 25–29°C in both seasons. After drying, rough rice samples were stored for three to four months at ambient temperature before processing to ensure stable milling yields. Rough rice for each plot was dehulled with a Satake THU 35A type testing husker, and percent hull was determined. Brown rice 100-grain weight was determined in duplicate per plot. Bulk density was determined in duplicate per plot according to USDA (1982) for test weight. Milled rice length and width were determined on duplicate 10 grains per plot with the aid of a photo-enlarger (10×). Length-to-width (L:W) ratio was calculated. Milled rice thickness was also measured on duplicate 10 grains with the use of a Makino Keisokuki MK-100 caliper.

Brown rice samples of 100 g from each treatment plot were milled in a McGill-type miller no. 2 with the 685 g added weight on the pressure cover for 30 sec, followed by 30 sec without the added weight. Total milled rice weight was determined. Head rice yield was determined by sizing milled rice with a Satake testing rice grader TRG 05A using a 4.75-mm mesh indentation, weighing the brokens and whole grain fractions. Total and head milled rice yields were calculated as percent of rough rice. Head rice yield in kg/ha was calculated from rough rice yields determined at harvest of each experiment from a 5-m^2 area within each plot. Kett whiteness of the milled rice was measured in duplicate with a Kett Model C-3 whiteness meter. Translucency of milled rice was measured in duplicate with a Riken Sanno rice meter (brown rice model). A representative milled rice sample was ground in a Udy cyclone mill with 60-mesh sieve and analyzed for crude protein (wet basis) by the microKjeldahl method using the factor 5.95 (Juliano et al 1973).

Treatment effects on rough rice yield, grain quality parameters and head rice yield were evaluated by analysis of variance and Duncan's (1955) multiple range test. Simple correlation coefficients were calculated for the relationship between head rice content, milled rice protein content, and translucency.

RESULTS AND DISCUSSION

1992 Dry Season Experiments

Experiment 1. Grain yield of three rices in block M10 increased with increasing N fertilizer rates and number of split applications (Table I). Highest rough rice yield was obtained with the hybrid, IR64616H, which gave a yield of 10.7 t/ha with total applied N of 225 kg/ha. Milled rice protein content was lowest in the 0 N treatment and highest with a N rate of 225 kg of N/ha. Protein content and translucency were highest in IR64616H and lowest in the later maturing line IR58109-113-3-3-2. Kett whiteness of milled rice decreased and translucency increased with increasing N fertilizer rate. The decrease in whiteness was not caused by undermilling of the high-protein samples, as the degrees of milling (8.2–8.7% bran-polish in 1991 samples) were similar (*unpublished data*). Thus, the decrease in whiteness was due mainly to the increased protein content and not to undermilling of high-protein samples (Cagampang et al 1966).

Both head-rice milling recovery and head rice yield increased progressively with an increase in N rate (Table I). Head rice yield was more sensitive to N fertilizer regime than rough rice yield. Rough rice yield increased by 6%, head rice yield increased by 30%, and the head-rice protein yield (kg/ha) increased by 63% in the 225 vs. 180 kg of N/ha treatment. Percent hull also was lower in the N-fertilized plots (20.8, 20.7, and 21.9% for 225, 180, and 0 kg of N/ha, respectively).

Bulk density of rough rice (0.55–0.57 g/cm^3) was not affected by N treatment. Brown rice weight was higher in N-fertilized treatments than in the control (0 N), but was unaffected by increasing the N rate from 180 to 225 kg of N/ha. Brown rice bulk density decreased significantly ($P < 0.05$) from 0.762 at 0 N to 0.761 g/cm^3 at 180 kg of N to 0.757 g/cm^3 at 225 kg N, reflecting the lower density of protein relative to starch (1.3 vs. 1.5 g/cm^3).

Experiment 2. The specific effects of N application at flowering on protein content and grain quality were compared to effects of an increased N rate in the vegetative phase up to panicle initiation in a more detailed study with IR58109-113-3-3-2. As in Experiment 1, protein content, total milled rice content, head rice content and yield, and milled rice translucency increased in treatments

TABLE II
Effect of Rate and Timing of Applied Nitrogen on Rice Characteristics—Experiment 2 (1992 Dry Season)

N Fertilizer Treatment[a] (kg N/ha)											Milled Rice		
B	MT	PI	FL	Total	Rough Rice Yield (t/ha)	Brown Rice 100-Grain Wt (g)	Total Milled Rice (%)	Head Rice (%)	Head Rice Yield (t/ha)	Protein Content (%)	Whiteness (%)	Translucency (%)
0	0	0	0	0	3.97d	2.10d	67.7d	37.6c	1.49d	5.63d	52.5a	62.7d
100	0	50	0	150	7.91c	2.20c	68.7c	40.4bc	3.19c	6.59c	47.3b	68.7cd
127	0	63	0	190	8.78a	2.26ab	69.4ab	43.8ab	3.84b	7.04b	45.2c	70.2bc
100	0	50	40	190	8.83a	2.25ab	69.7ab	48.6a	4.29a	8.10a	42.7d	80.0a
50	50	50	0	150	8.50ab	2.27a	69.3bc	43.3ab	3.68bc	6.96bc	45.7bc	71.2bc
37	36	37	40	150	8.23bc	2.21c	69.5ab	47.0ab	3.87b	7.72a	44.2cd	80.7a
50	50	50	40	190	8.71a	2.22bc	70.0a	46.5ab	4.05ab	8.09a	42.2cd	76.5ab
N rate means[b]				150	8.22 b	2.23a	69.2b	43.6b	3.58b	7.09b	45.7a	73.5b
				190	8.78 a	2.24a	69.7a	46.3a	4.06a	7.74a	43.4b	75.6a
FL-N means			0	163	8.40 a	2.24a	69.1 b	42.5b	3.57b	6.86b	46.1a	70.0b
			40	177	8.60 a	2.23a	69.7 a	47.4a	4.07a	7.97a	43.0b	79.1a
Significance[b]												
N fertilizer rate (150 vs. 190)					**	ns	**	**	**	**	*	*
N fertilizer at FL (163 vs. 177)					ns	ns	**	**	**	**	*	**
CV (%)					4.0	1.5	1.0	15.3	0.81	4.6	3.1	5.1

[a] B = basal, MT = maximum tillering, PI = panicle initiation, FL = flowering. Means in the same column and heading followed by the same letter are not statistically different ($P < 0.05$) by Duncan's multiple range test.
[b] Significant difference between N rate or N timing means: * = $0.01 < P < 0.05$, ** $P = < 0.01$.

with higher rates of applied N (150 vs. 190 kg N/ha) (Table II). However, N topdressing at flowering (163 vs. 177 kg of N/ha) had a larger effect on head rice content, protein content, whiteness, and translucency than an increase in the total N rate (150 vs. 190 kg of N/ha). Comparison of treatments with the same total N rate clearly indicate the specific effects of late N application on milling yields and grain quality. For example, the three treatments with a total N rate of 190 kg/ha had similar rough rice yields, but N application at flowering increased head rice content by 12%, protein content by 16%, and head-rice protein yield by 33%.

Milled rice whiteness again decreased as protein increased, and late N application did not consistently affect brown rice weight. Compared to the control without applied N, however, N fertilizer caused a significant increase ($P < 0.05$) in all brown rice dimensions (mm): length from 7.08 to 7.14, width from 2.23 to 2.26, and thickness from 1.73 to 1.76, but had no significant change in length-to-width ratio (3.17 to 3.15). The whiteness and translucency of the higher protein samples were comparable to recorded milled rice properties in Philippine retail markets (Juliano et al 1989), Thai export nonwaxy rice (Juliano et al 1990), and retail markets in Hong Kong, Bonn, and Rome (Kaosa-ard and Juliano 1991), except for the higher translucency of Hong Kong rices. Unpublished data on the 1991 wet season crop showed good correspondence between Kett whiteness and Minolta Chromameter L^* and b^* values: for whiteness values of 46.1, 43.3, and 38.8%, corresponding L^* (whiteness) values were 76.5, 74.6, and 72.4, and b^* (yellowness) values were 10.6, 11.1, and 11.9. Chromameter a^* (greenness) values were similar at –0.9 to –0.5.

1992 Wet Season Experiment

Experiment 3. The beneficial effects of N application at flowering on grain quality observed in the dry season were also evident in Experiment 3 (Table III). Nitrogen application (80 or 110 kg/ha vs. 0 N control) increased grain yield, brown rice weight, total milled rice content, head rice content and yield, milled rice protein content and translucency, and decreased Kett whiteness. Timing of N fertilizer application up to panicle initiation had no significant effect on these properties. In contrast, an additional N application of 30 kg of N/ha at flowering increased rough rice yield by 6%, head rice content by 11%, head rice yield by 17%, protein content of milled rice by 18%, and head rice protein yield by 38%. Corresponding values for brown rice protein content were 8.2% for 0 N, and 8.6–8.8% for N-fertilized treatments. Percentage hull decreased from 20.8% at 0 N to 20.2–20.4% with N fertilizer application. IR58185-23-3-3-2 had much higher head rice yields than the two other rices. The hybrid IR64616H had the highest protein content and the whitest milled rice despite a higher protein content. Translucency values were higher in this experiment than in the 1992 dry season samples (Tables I and II). Highest rough rice yields were obtained with IR58185-23-3-3-2 and IR64616H which gave yields of 5.8–6.3 t/ha with applied N of 110 kg/ha.

Correlation between Protein Content, Head Rice, and Translucency

Linear correlation coefficients (r) between protein content, head rice content, and translucency were positive for all rices in Experiments 1 and 2 and for IR72 in Experiment 3 (Table IV). The pooled correlation that included the three rices in Experiment 1 indicated that these relationships were consistent across genotypes. For IR58185-23-3-3-2 and IR64616H in the Experiment 3, there was also a positive correlation between protein content and head rice. The lower pooled correlation coefficients in the Experiment 3 resulted from genotype differences in the relationship between protein content and head rice, and weak or nonsignificant correlations that involved translucency for two of the three rices.

Unpublished grain-quality studies at IRRI from the 1991 wet season with two rices (IR72 and IR58109-113-3-3-2) in Experiment 2 showed a significant decrease in apparent amylose content from 27.4 to 26.3% dry basis and Rapid Visco-Analyzer peak viscosity from 267 to 252 Rapid Visco Units between the 0 N control and the highest N-rate treatment, probably due to the reduction in starch content. There was no difference in the Instron universal testing machine hardness values of cooked milled rice (0.86–0.87 kg/cm^2). These differences can be attributed to the decrease in starch content in the milled rice with increase in protein content from 5.2 to 7.9%, as starch and protein constitute 98% of milled rice dry matter (Juliano 1993). Matsuzaki et al (1973) reported a decrease in taste quality of cooked rice by sensory test with increase in protein content in a single variety, but varietal differences in taste quality were observed in samples with the same protein content.

The results of our study demonstrate that at rough rice yield levels of 8.7–10.7 t/ha in the dry season and 5.8–6.3 t/ha in the wet season at the IRRI farm, late N fertilizer application at flowering consistently increased head rice content, milled rice protein content, and translucency, while whiteness decreased. These grain yield levels approach the achievable yield potential predicted by the ORYZA1 simulation model for the two cropping seasons

TABLE III
Effect of Rate and Timing of Applied Nitrogen on Rice Characteristics. Experiment 3: (1992 Wet Season)

N Fertilizer Treatment[a] (kg N/ha)										Milled Rice		
B	MT	PI	FL	Total	Rough Rice Yield (t/ha)	Brown Rice 100-Grain Wt (g)	Total Milled Rice (%)	Head Rice (%)	Head Rice Yield (t/ha)	Protein Content (%)	Whiteness (%)	Translucency (%)
0	0	0	0/30	0/30	4.04b	2.16c	71.1b	57.9b	2.34b	7.54b	43.8a	90.0a
80	0	0	0/30	80/110	5.77a	2.21a	71.7a	60.5a	3.49a	8.09a	41.9b	92.7a
40	40	0	0/30	80/110	5.66a	2.21a	71.7a	60.3a	3.41a	8.02a	41.8b	90.5a
27	26	27	0/30	80/110	5.88a	2.19b	71.4ab	60.0a	3.53a	8.14a	41.5b	89.7a
Cultivar												
IR72					5.14b	2.15b	72.2a	53.0c	2.72c	7.79b	41.8b	93.1a
IR58185-23-3-3-2					5.41a	2.34a	71.7b	68.5a	3.71a	7.75b	40.4c	89.4b
IR64616H					5.46a	2.09c	70.5c	57.6b	3.14b	8.29a	44.6a	90.2ab
Late season fertilizer N												
FL-N			0		5.19b	2.19a	71.3b	56.6 b	2.94b	7.29b	43.9a	88.8b
FL-N			30		5.49a	2.19a	71.7a	62.7 a	3.44a	8.60a	40.6b	93.1a
Significance[b]												
N fertilizer (NF)					***	**	*	**	***	**	**	ns
Variety (V)					***	***	***	***	***	***	***	*
NF × V					***	**	***	**	**	ns	ns	**
FL-N					***	ns	***	***	***	***	***	**
NF × FL-N					ns	ns	ns	*	ns	**	*	ns
V × FL-N					ns	ns	**	***	***	ns	ns	**
NF × V × FL-N					ns	ns	ns	ns	ns	ns	ns	ns
CV (%)					3.5	1.3	0.5	3.9	4.6	4.0	2.9	6.6

[a] B = basal, MT = maximum tillering, PI = panicle initiation, FL = flowering. Means in the same column and heading followed by the same letter are not statistically different ($P < 0.05$) by Duncan's multiple range test.
[b] * = $0.01 < P < 0.05$, ** = $0.001 < P < 0.01$, *** = $P < 0.001$.

TABLE IV
Correlation Between Milled Rice Protein (P), Head Rice (HR), and Milled Rice Translucency (T) in Three Nitrogen Fertilizer Experiments

			Correlation Coefficient[b]		
Exp. No. [a]	Variety or Line	*n*	P vs. HR	P vs. T	HR vs. T
1	IR72	12	0.83**	0.98**	0.87**
1	IR58109-113-3-3-2	12	0.55 ns	0.86**	0.78**
1	IR64616H	12	0.76**	0.87**	0.70**
1	All three rices	36	0.63**	0.84**	0.69**
2	IR58109-113-3-3-2	42	0.51**	0.77**	0.55**
3	IR72	32	0.89**	0.84**	0.90**
3	IR58185-23-3-3-2	32	0.49**	0.08ns	0.04ns
3	IR64616H	32	0.70**	0.22ns	0.35*
3	All three rices	96	0.31**	0.34**	0.20*

[a] Experiment 1 for 1992 dry season, Experiment 2 for 1992 dry season, Experiment 3 for 1992 wet season.
[b] ns = not significant, $P > 0.05$, * = $0.05 > P > 0.01$, ** = $P < 0.01$.

(Kropff et al 1993). In two of the three experiments, N applied at flowering was also associated with a 6% increase in rough rice yield. Recent rice shortages in the Philippines highlight the need for increased yields. Present N fertilizer guidelines do not recommend N fertilizer application after panicle initiation. A late N application at flowering provides a management option for increasing protein content and quality of market rice supplies, especially at high yield levels. Such a strategy would result in greater returns to the farmer if the premium for improved quality can be converted into price incentive (Juliano and Duff 1991). Otherwise, only millers would benefit from the improved quality in the Philippines (Umali and Duff 1988). The increased protein in milled rice has been confirmed to have nutritional significance (Juliano 1993), and would increase protein intake of consumers. The effect on eating quality may not be significant but this issue requires further study.

Low mean protein content of milled rice from unfertilized plots of 5.6% (Tables I and II) may reflect the lower available soil N in some fields of the IRRI farm, particularly during the later growth stages (Cassman et al 1995). The low supply of soil N at the reproductive stage relative to the N demand of the rice plant seems to be widespread and not limited to the IRRI farm. For example, the national rice improvement yield trials in the Philippines receive the recommended N fertilizer management, which does not include N application after panicle initiation. In the 1994 dry season trial located at the University of the Philippines Los Baños farm, which is adjacent to the IRRI farm, protein content was low and decreased in germplasm with longer growth duration. Mean protein content of milled rice was 7.8% (range: 5.9–9.2%) for 18 early maturing selections and 6.7% (range: 5.1–8.0%) for 18 medium-early maturing selections (PhilRice 1994). Decreased protein content in genotypes with later maturity has been reported previously (Heu et al 1976, IRRI 1988). Nitrogen topdressing at flowering might be used in germplasm evaluation nurseries to ensure adequate N supply for all rice lines, regardless of growth duration. Based on results from the present study, such a management strategy would help avoid genotype by environment interactions that confound differences in protein content and grain quality among lines tested.

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