agriculture

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Effect of Nitrogen Application Methods on Yield and Grain Quality of an Extremely Early Maturing Rice Variety

Yeotae Yun *, Gyucheol Kim, Giwon Cho , Youngju Lee, Tugsang Yun and Hakhun Kim

Crop Research Department, Chungcheongnamdo Agricultural Research and Extension Services, Yesan 340861, Chungcheongnamdo, Republic of Korea

* Correspondence: yotai@korea.kr; Tel.: +82-41-635-6050

Abstract: This study aimed to investigate the effect of nitrogen application methods on the yield and grain quality of an extremely early maturing rice variety. The experiment was conducted in the rice research field of Chungnam Agricultural Research and Extension Services, South Korea, in 2019 and 2020. Two nitrogen application methods, BD (100% as a basal dressing) and BTD (70% as a basal dressing + 30% as a top dressing), with three different nitrogen levels (70 kg/ha, 90 kg/ha, and 110 kg/ha), were employed. The results showed that BD treatment had comparable or higher head rice yields and improved grain quality compared to BTD treatment at all nitrogen levels. Additionally, the SPAD value at heading date was highly correlated with both the protein content (r^2 = 0.838**) and glossiness of cooked rice (r^2 = 0.630**). Therefore, this study suggests that BD treatment could be an effective approach to improve the productivity and quality of extremely early maturing rice varieties while saving on labor costs, and the SPAD value can be used as an index to infer the taste of rice. In conclusion, this study provides useful insights into nitrogen application methods that can be used to enhance the yield and quality of extremely early maturing rice varieties.

Keywords: rice; nitrogen; yield; quality; extremely early maturing rice

Citation: Yun, Y.; Kim, G.; Cho, G.; Lee, Y.; Yun, T.; Kim, H. Effect of Nitrogen Application Methods on Yield and Grain Quality of an Extremely Early Maturing Rice Variety. *Agriculture* **2023**, *13*, 832. https://doi.org/10.3390/agriculture13040832

Academic Editors: Adrienn Széles, Anikó Nyéki and Safwan Mohammed

Received: 15 March 2023
Revised: 31 March 2023
Accepted: 3 April 2023
Published: 5 April 2023

1. Introduction

Rice (*Oryza sativa* L.) is a vital crop that sustains a significant portion of the world's population, particularly in Asia, where it serves as a staple food. In response to climate change threatening rice production, early maturing rice varieties with short growing periods have emerged as a promising approach to boost productivity and reduce methane emissions. This approach has been supported by several studies which have shown that early maturing rice varieties not only reduce the duration of the anaerobic period but also enable farmers to harvest rice earlier and plant other crops in the same season [1,2]. Recently, Bbareumi, an extremely early maturing rice variety with a substantially shorter growing period than typical early maturing rice, has been developed and selected as a variety in response to climate change [3,4]. This rice variety is being cultivated in agricultural fields to enhance productivity through double cropping.

The protein content of grains, along with the amylose content, is a factor that determines the taste of rice. When the protein content is high, the hardness of rice increases, and the viscosity decreases, resulting in a worse taste. The protein content of rice varies depending on the variety, cultivation environment, and weather conditions [5–7]. Several studies have shown that the protein content of rice grains can be significantly affected by nitrogen levels and that increasing nitrogen levels resulted in a significant increase in the protein content of rice grains [8–10]. Furthermore, nitrogen application has the potential to impact the expression of genes related to grain quality in rice, which includes those that are involved in amino acid and protein metabolism [11–13]. Therefore, standard nitrogen levels have been set to optimize both yield and grain quality in rice production, as the nitrogen level is a critical factor that can largely affect the protein content and other quality characteristics of rice grains.

In addition, other studies suggested that the timing of nitrogen application can have an influence on the protein content of rice grains. Although the specific timing and increase in protein content varied depending on the conditions of the studies, delaying the application of nitrogen fertilizer to rice plants can lead to an increase in the protein content of rice grains [14,15]. Thus, proper management of nitrogen fertilization can help to improve both the protein content and overall quality of rice grains while maintaining optimal yields. In Korea, the recommended nitrogen fertilizer rates vary depending on the desired rice quality, with 70 kg/ha for premium rice, 90 kg/ha for high-quality rice, and 110 kg/ha for regular rice [16]. For mid-late maturing rice in the plains, the standard nitrogen split method involves applying 70% of the fertilizer as basal dressing and 30% as top dressing at the panicle initiation stage (around 60 days after transplanting). However, due to the fewer than 50 days from the transplanting to heading of extremely early maturing rice, there is a need to develop a new fertilization method that can achieve efficient farming and improve rice quality.

As living standards have improved, rice consumption per person has decreased due to the availability and consumption of Western-style convenience foods. Consequently, there has been a growing demand for high-quality rice, driven by consumers who are increasingly seeking rice with certain taste and grain appearance traits [17–19]. Thus, continuous studies have been conducted to enhance the quality of early maturing rice varieties, as these varieties with high protein content and low appearance quality have resulted in poor taste [20–23]. However, there has been little research on the cultivation of extremely early maturing rice varieties.

This study was conducted to investigate the yield and grain quality of an extremely early maturing rice variety according to nitrogen application methods and to develop a cultivation technology that can improve productivity and grain quality while saving on labor.

2. Materials and Methods

2.1. Meteorological Data

To investigate the meteorological conditions during the rice cultivation period in Yesan, South Korea, from 2019 and 2020, weather data from the Korea Meteorological Administration (https://www.weather.go.kr (accessed on 13 February 2023)) were used.

2.2. Experimental Site and Rice Plant Material

This study was carried out from 2019 to 2020 at the rice research field of the Chungcheongnamdo Agricultural Research and Extension Services located in Yesan, Chungcheongnamdo, South Korea (36°44′ N, 126°49′ E). Bbareumi, an extremely early maturing variety with a growing period of less than 100 days from transplanting to harvest, was used. Additionally, soil analysis was performed before the test to determine the appropriate fertilizer based on the characteristics of the soil. Soil samples were obtained at a depth of 0–30 cm, and the collected samples were air-dried, crushed thoroughly, sieved through a 2 mm sieve, and chemically characterized through laboratory analysis (Table 1). The pH and electrical conductivity (EC) of the soil samples were determined using a pH meter (Orion Star A211, Thermo Scientific, Waltham, MA, USA). The other chemical properties of the soil were measured according to the manuals of NIAST [24].

Table 1. Soil chemical properties of the rice research field used in this study.

Property	pH (1:5)	EC (dS/m)	Organic Matter (g/kg)	Available P_2O_5 (g/kg)	Available SiO_2 (g/kg)	Exchangeable Cation ($cmol_c kg^{-1}$)		
						K	Ca	Mg
Data	6.3	0.37	16.2	25	353	0.3	6.6	1.7
Recommendation	6.0–6.5	-	30–50	80–120	>157	0.2–0.3	5.0–6.0	1.5–2.0

2.3. Experimental Treatments

Treatments for nitrogen application methods are summarized in Table 2. The experiment consisted of two nitrogen application methods (BD: 100% as a basal dressing; BTD: 70% as a basal dressing +30% as a top dressing) and three nitrogen levels (70 kg/ha for premium rice, 90 kg/ha for high-quality rice, and 110 kg/ha for regular rice), with three replications over two years. Each plot had a size of 16.5 m^2 (5 m long and 3.3 m wide) and the amount of nitrogen according to the rice quality was calculated using urea as follows [16]:

$$[70\ \text{kg/ha: N (kg/ha)} = 71.0 - 0.85 \times \text{OM (organic matter)} + 0.16 \times SiO_2]$$

$$[90\ \text{kg/ha: N (kg/ha)} = 91.4 - 1.09 \times \text{OM (organic matter)} + 0.20 \times SiO_2]$$

$$[110\ \text{kg/ha: N (kg/ha)} = 111.7 - 1.33 \times \text{OM (organic matter)} + 0.25 \times SiO_2]$$

Table 2. Summary of treatments for nitrogen application methods.

Treatment	Application Method	Total Nitrogen (kg/ha)	Split Application Method (kg/ha)	
			Basal Dressing	Top Dressing
BD70	Basal dressing	70 (100%)	70 (100%)	-
BD90		90 (100%)	90 (100%)	-
BD110		110 (100%)	110 (100%)	-
BTD70	Basal + Top dressing	70 (100%)	49 (70%)	21 (30%)
BTD90		90 (100%)	63 (70%)	27 (30%)
BTD110		110 (100%)	77 (70%)	33 (30%)

Basal dressing was applied during leveling 3 days prior to transplanting and top dressing was applied 24 days prior to heading date.

2.4. Cultivation Methods

To prevent diseases transmitted by rice seeds such as Blast and Bakanae disease, the rice seeds were soaked in 15 °C cold water for 2 days. They were then disinfected with Tebuconazole + Prochloraz copper chloride [25]. The disinfected seeds were sown in nursery boxes and grown in a greenhouse for 3 weeks before being manually transplanted on 3 May. A total of 3–5 seedlings were transplanted hill^{-1} with a spacing of 14 cm between plants and 30 cm between rows. After transplanting, the rice field was immediately flooded, and a depth of 3–5 cm was maintained until 30 days after heading. Afterward, it was dried for harvest. Harvesting was carried out once the accumulated temperature had reached 1000 °C after heading. The accumulated temperature was calculated as the sum of the daily mean temperature after the heading date. Chemical pesticides to control pests and diseases were applied only once immediately after transplanting.

2.5. Traits Evaluation

2.5.1. Agronomic Traits

Heading date was determined when 50% of the panicles were headed, and days to heading was calculated as the number of days from transplanting date to heading date. For panicle length and number hill^{-1}, 10 randomly selected rice plants from each plot were examined at the maturity stage; panicle length was measured from the panicle neck to the panicle tip. For spikelet number and percentage of ripened grain, three rice plants from each plot were harvested before harvest and manually threshed to separate the grains from the straws. Spikelet (unfilled and filled grains) number panicle^{-1} was manually counted and air-dried and then submerged in water to distinguish the unfilled and filled grains. The percentage of ripened grains was determined as the number of filled grains per panicle divided by the total number of grains (unfilled and filled grains) panicle^{-1}. To determine milled rice yield, 50 rice plants in each plot were selected and harvested, threshed, air-dried, and weighed. In addition, 500 g of rough rice was de-hulled for brown rice and polished for milled rice. The milled rice yield was then calculated. The 1000-grain weight was evaluated by measuring the weight of 1000 randomly selected brown rice grains. Additionally, the milled rice yield and the 1000-grain weight were corrected for 15% grain moisture content. Head rice yield was calculated by multiplying the milled rice yield by head rice rate. The SPAD value was measured with a Chlorophyll Meter (SPAD-502, Minolta Camera Co., Tokyo, Japan) at heading date using ten random rice plants selected in each plot and measuring the center of the top second leaf of each plant.

2.5.2. Grain Quality Traits

Appearance traits of milled rice were automatically calculated using a grain inspector (Cervitec 1625, Foss, Höganäs, Sweden) with a sample of approximately 1000 grains. The head rice rate was defined as the percentage of translucent grains that accounted for more than 3/4 of the whole grains, the chalky rice rate was the percentage of grains with an opaque and chalky appearance covering more than half of the grain, and the others were the percentages of broken and damaged rice. The protein content (PC) of milled rice was measured using 100g milled rice samples with a grain analyzer (Infratec 1241, Foss, Höganäs, Sweden), and glossiness of cooked rice (GCR) was measured using 33 g milled rice samples with a Toyo taste meter (MA-90R2, Yakayama, Toyo) in accordance with the manufacturer's instructions.

2.6. Statistical Analysis

Statistical analyses such as *t*-tests, ANOVA (analysis of variance), correlation analysis, and regression analysis were performed using IBM SPSS software (Ver. 20.0.0). The data were arranged into tables and figures, produced using Microsoft Excel 2019.

3. Results

3.1. Meteorological Conditions during Rice Growing Periold

Meteorological data (rainfall and minimum and maximum temperatures) from the transplanting to harvest of Bbareumi rice was organized into 15 days and is shown in Figure 1. The maximum temperature in 2019 was higher than in 2020 during the growth period, except from early June to late June. Notably, the minimum temperature of rice tillering and panicle initiation stage in 2019 was lower than in 2020. Rainfall was higher in 2020 compared to 2019, with the highest amount of rainfall recorded in late July.

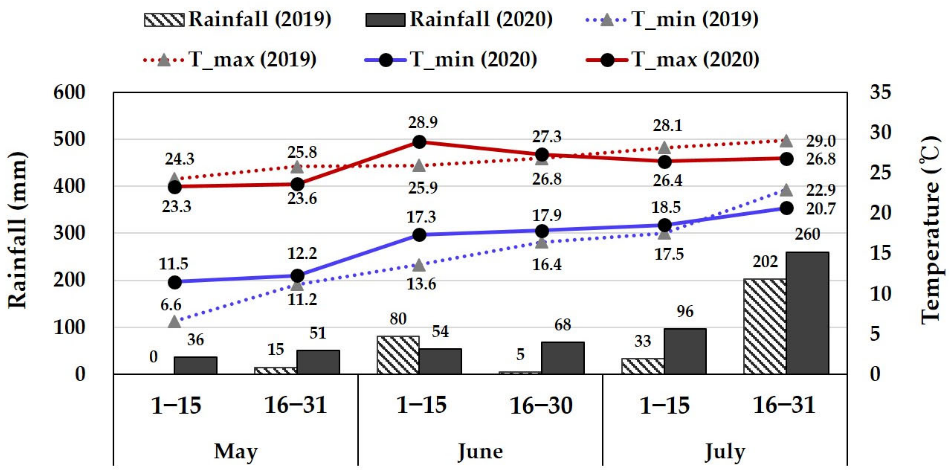


Figure 1. Distribution of rainfall and minimum and maximum temperatures of two years (2019–2020). The data were obtained from the Korean Meteorological Administration.

3.2. Agronomic Traits

The heading date and yield-related traits according to nitrogen application methods are summarized in Table 3. All the traits investigated in this study showed significant differences between years. The heading date in 2020 was two days earlier than that in 2019, indicating that it took 51 days from transplanting to heading. Compared to 2019, longer culm and panicle lengths and a greater panicle number hill^{-1} and m^{-2} were observed in 2020, and all traits showed an increasing trend as the nitrogen fertilizer levels increased. Additionally, the BD treatment (100% basal dressing) resulted in shorter culm and panicle lengths but a greater panicle number hill^{-1} compared to the BTD treatment (70% basal dressing + 30% top dressing). The highest panicle number hill^{-1} was 14.7 and 16.8 in 2019 and 2020, respectively, in the BD110 treatment.

Table 3. Heading date and panicle-related traits according to nitrogen application methods.

Year	Treatment		Heading Date (m.dd)	Days to Heading (Days)	Culm Length (cm)	Panicle Length (cm)	Panicle Number Hill^{-1}
2019	Basal (BD)	BD70	6.26 a	53 a	62.4 d	17.8 c	14.2 c
		BD90	6.26 a	53 a	63.8 c	18.1 bc	14.5 b
		BD110	6.26 a	53 a	65.3 b	18.3 b	14.7 a
	Basal + Top (BTD)	BTD70	6.26 a	53 a	64.5 bc	18.2 b	13.7 d
		BTD90	6.26 a	53 a	65.4 b	18.5 ab	14.2 c
		BTD110	6.26 a	53 a	67.1 a	18.7 a	14.5 b
	Mean	BD	6.26	53	63.8	18.1	14.4
		BTD	6.26	53	65.6	18.5	14.1
		t-test	ns	ns	**	*	**
2020	Basal (BD)	BD70	6.24 a	51 a	70.6 c	19.2 c	15.5 b
		BD90	6.24 a	51 a	71.3 c	19.3 c	16.3 a
		BD110	6.24 a	51 a	72.5 b	19.5 bc	16.8 a
	Basal + Top (BTD)	BTD70	6.24 a	51 a	73.4 ab	19.6 bc	15.1 b
		BTD90	6.24 a	51 a	74.0	19.8 ab	15.4 b
		BTD110	6.24 a	51 a	75.8	20.1 a	15.6 b
	Mean	BD	6.24	51	71.5	19.3	16.2
		BTD	6.24	51	71.0	19.8	15.4
		t-test	ns	ns	**	**	**
Mean		2019	6.26	53	64.7	18.3	14.3
		2020	6.24	51	72.9	19.6	15.8
		t-test	**	**	**	**	**

Means with the same letters in 2019 and 2020 are not significantly different at 5% level as determined by Duncan's multiple range test. *, **: significantly different at $p < 0.05$ and 0.01, respectively. ns: not significant.

The chlorophyll content of the leaves was measured at heading date for two years. The results indicated that the SPAD value increased with higher amounts of fertilizer, and the BTD treatment showed a higher SPAD value than the BD treatment. The BTD110 treatment had the highest SPAD values of 39.1 and 37.9 in 2019 and 2020, respectively. On the other hand, the BD70 treatment had the lowest SPAD values of 34.3 and 33.6 in 2019 and 2020, respectively (Figure 2).

Comparing the data from 2019 and 2020, it was observed that in 2020, the spikelet number hill^{-1}, spikelet number m^{-2}, and the ripened grains number m^{-2} were all higher than the values recorded in 2019 (Table 4). In addition, the 1000-grain weight was 0.1 g heavier in 2020, but there was no statistically significant difference, and the ripening rate was 6.1% higher than in 2019. The spikelet number m^{-2} increased as the nitrogen levels increased under the same nitrogen application method, and those of the BTD treatment were higher than BD. The highest spikelet numbers m^{-2} were observed in the BTD110 treatment, with 29,657 and 32,102 in 2019 and 2020, respectively. The highest ripened grain numbers m^{-2} were 23,904 in the BTD110 treatment in 2019 and 24,507 in the BD110 treatment in 2020. However, the BTD110 treatment exhibited the lowest ripened grain rate, while the BD70 treatment demonstrated the highest. Additionally, the 1000-grain weight showed a slight decrease as the amount of fertilizer applied increased in 2019.

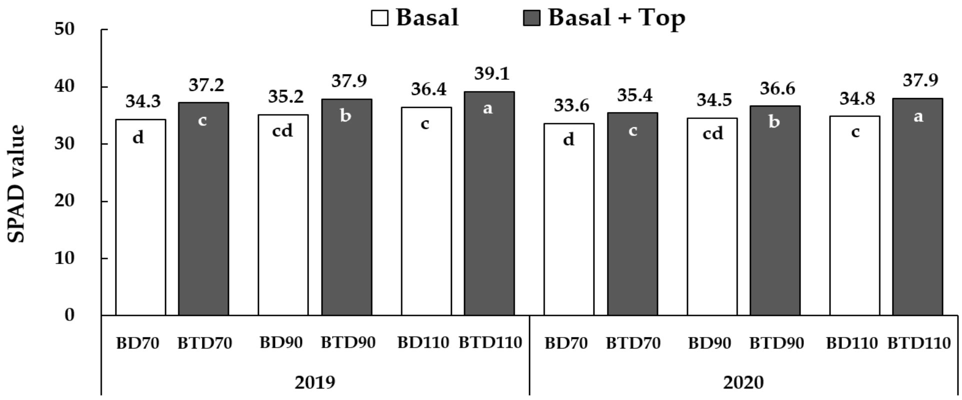


Figure 2. Variation in SPAD value according to nitrogen application methods. Means with the same letters in 2019 and 2020 are not significantly different at 5% level as determined by Duncan's multiple range test.

Table 4. Grain-related traits according to nitrogen application methods.

Year	Treatment		Spikelet No. Panicle^{-1}	Spikelet No. m^{-2}	Ripened Grain (%)	Ripened Grain No. m^{-2}	1000-Grain Weight (g)
2019	Basal (BD)	BD70	75.7 d	25,526 c	85.9 a	21,932 c	20.5 a
		BD90	78.6 c	27,080 b	84.7 b	22,925 b	20.3 ab
		BD110	79.7 bc	27,863 b	82.6 d	23,014 b	20.1 ab
	Basal + Top (BTD)	BTD70	80.4 bc	26,200 c	83.8 bc	21,956 c	20.3 ab
		BTD90	81.5 b	27,657 b	83.4 cd	23,077 b	20.0 b
		BTD110	85.9 a	29,657 a	80.6 e	23,904 a	20.1 ab
	Mean	BD	78.0	26,823	84.4	22,624	20.3
		BTD	82.6	27,838	82.6	22,979	20.1
		t-test	**	**	**	ns	*
2020	Basal (BD)	BD70	76.9 d	28,410 c	79.5 a	22,574 b	20.4 a
		BD90	78.3 d	30,440 b	77.1 bc	23,478 ab	20.3 a
		BD110	80.5 cd	31,966 a	76.7 c	24,507 a	20.1 a
	Basal + Top (BTD)	BTD70	83.1 bc	29,884 b	78.3 ab	23,390 ab	20.5 a
		BTD90	85.0 ab	31,174 ab	77.4 bc	24,135 a	20.3 a
		BTD110	86.4 a	32,102 a	75.2 d	24,154 a	20.3 a
	Mean	BD	78.6	30,322	77.8	23,558	20.3
		BTD	84.9	31,054	77.0	23,893	20.3
		t-test	**	**	**	ns	ns
Mean		2019	80.3	27,331	83.5	22,801	20.2
		2020	81.7	30,663	77.4	23,706	20.3
		t-test	ns	**	**	**	ns

Means with the same letters in 2019 and 2020 are not significantly different at 5% level as determined by Duncan's multiple range test. *, **: significant at $p < 0.05$ and 0.01, respectively. ns: not significant.

3.3. Grain Quality Traits

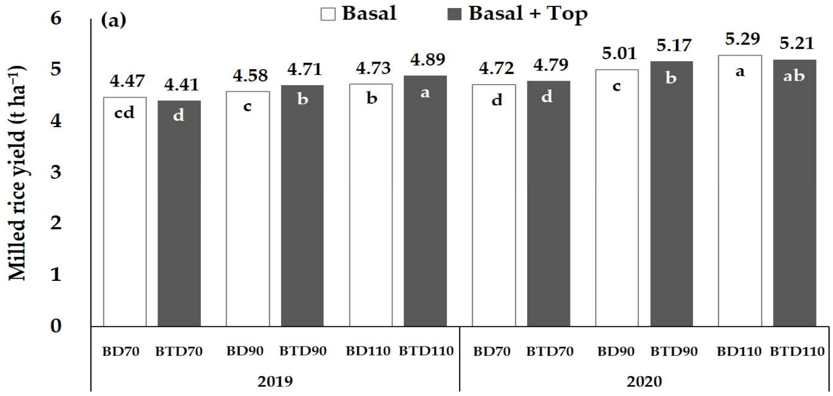
The impact of nitrogen application on grain quality traits was evaluated by examining several factors, such as appearance, protein content, and the glossiness of cooked rice, and the results are presented in Table 5. Compared to 2020, in 2019, the head rice rate was higher, while the GCR (grain chalkiness rate) value was lower. Specifically, the head rice rate was higher in the BD (basal dressing) treatment compared to the BTD (basal and topdressing) treatment. The treatment with the highest head rice rate was BD70, which showed rates of 90.9% and 84.9% in 2019 and 2020, respectively. The protein content of rice grains increased as the nitrogen level increased under the same nitrogen application method. Furthermore, the BTD treatment had a higher protein content than the BD treatment under the same nitrogen level. In particular, the BTD110 treatment showed the highest protein contents of 7.1% and 6.9% in 2019 and 2020, respectively. However, the GCR showed the lowest values in the BTD110 treatment, which was in contrast to the protein content.

Table 5. Grain quality traits according to nitrogen application methods.

Year	Treatment		Appearance Traits				Protein (%)	Glossiness of Cooked Rice
			Head	Chalky	Broken	Damaged		
2019	Basal (BD)	BD70	90.9 a	7.1 d	1.6 b	0.4 a	6.4 e	58.8 a
		BD90	89.4 b	8.2 cd	2.1 a	0.3 a	6.5 d	58.6 a
		BD110	88.6 b	9.1 c	2.2 a	0.1 a	6.7 c	58.3 a
	Basal + Top (BTD)	BTD70	89.3 b	8.9 c	1.5 b	0.3 a	6.8 b	57.4 b
		BTD90	88.4 b	10.2 b	1.2 b	0.2 a	6.9 b	57.1 b
		BTD110	86.2 c	12.2 a	1.2 b	0.4 a	7.1 a	56.1 c
	Mean	BD	89.6	8.1	2.0	0.3	6.5	58.6
		BTD	88.0	10.4	1.3	0.3	6.9	56.9
		t-test	**	**	**	ns	**	**
2020	Basal (BD)	BD70	84.9 a	10.4 b	4.5 d	0.2 a	6.2 c	61.8 a
		BD90	84.0 ab	10.7 b	5.2 c	0.1 a	6.3 c	61.3 ab
		BD110	82.9 b	12.9 a	3.8 d	0.4 a	6.5 b	60.9 b
	Basal + Top (BTD)	BTD70	82.5 b	10.7 b	6.5 b	0.3 a	6.5 b	60.1 c
		BTD90	80.8 d	14.0 a	4.9 c	0.3 a	6.8 a	59.5 c
		BTD110	78.9 e	13.5 a	7.2 a	0.4 a	6.9 a	58.2 d
	Mean	BD	83.9	11.3	4.5	0.2	6.3	61.3
		BTD	80.7	12.7	6.2	0.3	6.7	59.3
		t-test	**	**	*	*	**	**
Mean		2019	88.8	9.3	1.6	0.3	6.7	57.7
		2020	82.3	12.0	5.4	0.3	6.5	60.3
		t-test	**	**	**	ns	*	**

Means with the same letters in 2019 and 2020 are not significantly different at 5% level as determined by Duncan's multiple range test. *, **: significant at $p < 0.05$ and 0.01, respectively. ns: not significant.

We observed an increase in the milled rice yield in 2020 for all treatments compared to 2019 [Figure 3a]. Additionally, the milled rice yield increased as the nitrogen levels applied increased under the same nitrogen application method. The highest milled rice yield was observed in the BD110 treatment in 2020, at 529 t ha^{-1}, while the highest milled rice yield in 2019 was observed in the BTD110 treatment, at 4.89 t ha^{-1}. The head rice yield of the BD treatment was similar to or higher than the BTD treatment [Figure 3b]. Furthermore, the head rice yield did not increase sharply as the nitrogen levels increased. The BD110 treatment showed the highest head rice yield of 4.39 t ha^{-1} in 2020, while in 2019, both the BD110 and the BTD110 treatments had the highest head rice yields of 4.19 t ha^{-1} and 4.22 t ha^{-1}, respectively. Overall, the results suggested that increasing the amount of nitrogen application can increase the milled rice yield, and the BD treatment could be a feasible method to achieve higher head rice yield, as it showed similar or higher yields compared to the BTD treatment under the same nitrogen level.



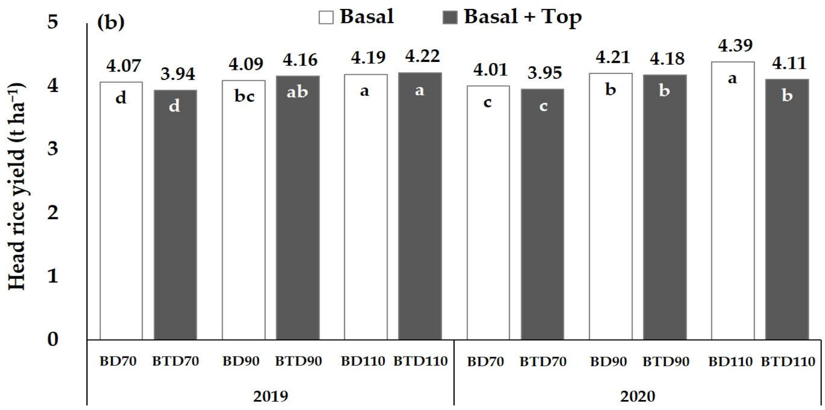


Figure 3. Milled rice yield (**a**) and head rice yield (**b**) according to nitrogen application methods. Means with the same letters in 2019 and 2020 are not significantly different at 5% level as determined by Duncan's multiple range test.

3.4. Relationship among the Traits

Figure 4 illustrates the results of a correlation analysis conducted to examine the relationship between the milled yield and spikelet number m^{-2}. The analysis revealed that milled rice yield had a significant and strong positive correlation with both spikelet number m^{-2} and ripened grain number m^{-2}, with correlation coefficients of $r^2 = 0.865^{**}$ and $r^2 = 0.675^{**}$, respectively. The study found that the correlation between milled rice yield and spikelet number m^{-2} was stronger than that between the milled rice yield and the ripened grain number m^{-2}. Therefore, a regression equation could more accurately predict the milled rice yield based on the spikelet number m^{-2}. However, in contrast to the results for milled rice yield, the head rice yield was more strongly correlated with the ripened grain number m^{-2} ($r^2 = 0.305^{**}$) than with the spikelet number m^{-2} ($r^2 = 0.223^{**}$). Therefore, a regression equation based on the ripened grain number m^{-2} could more effectively estimate the head rice yield (Figure 5).

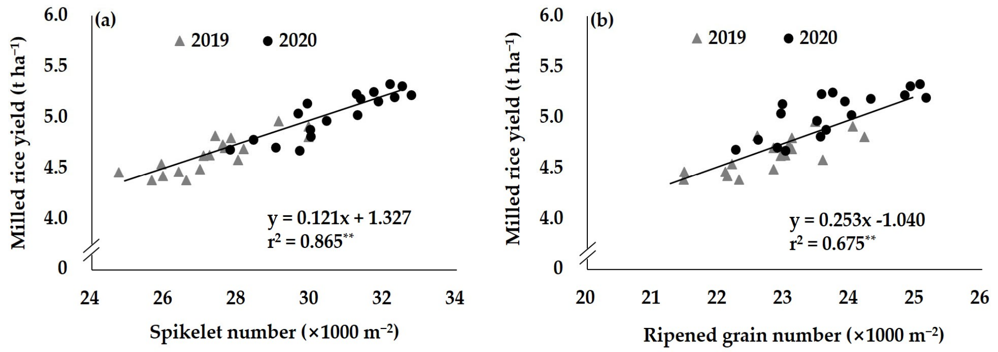


Figure 4. Relationship between the milled rice yield and (**a**) spikelet number m^{-2} and (**b**) ripened grain number m^{-2}. **: significant at $p < 0.01$.

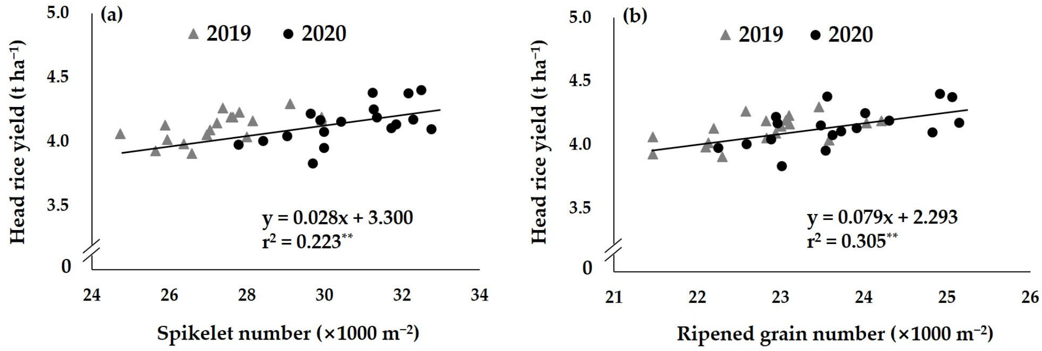


Figure 5. Relationship between the head rice yield and (**a**) spikelet number m^{-2} and (**b**) ripened grain number m^{-2}. **: significant at $p < 0.01$.

A correlation analysis was conducted to investigate the relationship between the SPAD values measured at the heading date and the indirect indicators of rice taste, including the protein content of milled rice and the glossiness of cooked rice. The results are summarized in Figure 6. The findings showed that the SPAD values was positively correlated with protein content (r^2 = 0.838**) and negatively correlated with the glossiness of cooked rice (r^2 = 0.630**). These results suggested that the SPAD values can be employed as an estimator of the indirect indicators of rice taste.

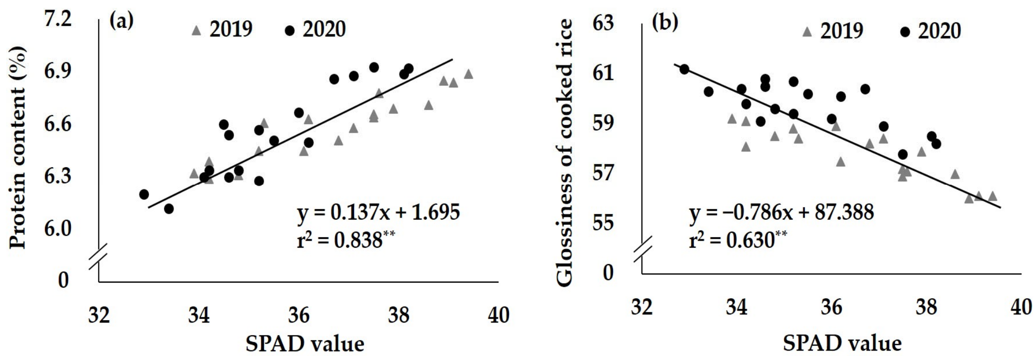


Figure 6. Relationship of SPAD value with (**a**) protein content of milled rice and (**b**) glossiness of cooked rice. **: significant at 0.01.

4. Discussion

An extremely early maturing rice variety has the potential to decrease methane gas emissions and increase grain productivity through double cropping. However, limited research has been conducted on the optimal cultivation techniques for this variety, specifically regarding nitrogen application methods. Therefore, this study aimed to assess the impact of different nitrogen application methods on the yield and grain quality of extremely early maturing rice varieties.

4.1. Importance of Temperature at Vegetative Growth Period

Bbareumi, an extremely early maturing rice variety, has a short vegetative growth period of fewer than 50 days, which emphasizes the importance of early growth. This study found that in 2019, low temperatures during the early growth stage led to reduced growth, resulting in a decrease in the milled rice yield due to a lower number of spikelet m^{-2} compared to 2020. This suggests that temperature during the early growth period plays a critical role in increasing the yield of extremely early maturing rice varieties. Studies have reported that high temperatures increased the nitrogen utilization rate in rice, while low temperatures decreased it, suggesting that high temperatures accelerate plant growth and increase the demand for nitrogen, while low temperatures reduce plant growth and nitrogen demand [26–30]. In addition, this study highlights the importance of considering temperature when growing extremely early maturing rice varieties, as the temperature can significantly influence the growth of rice plants [4].

4.2. Variation in Agronomic Traits and Yield

The results of this study showed that in 2019, the panicle number $hill^{-1}$ and number of spikelet m^{-2} were lower compared to 2020, which led to a decrease in yield across all treatment groups. However, all traits investigated across both years with respect to the nitrogen levels and application methods showed consistent trends. The productivity of rice can be attributed to yield components, which include the number of panicles, the number of spikelets, the rate of ripened grains, and the weight of 1000 grains [31–34]. Panicle and spikelet numbers are determined before the heading date, while the other components are influenced by weather conditions during the grain-filling period. Among them, spikelet number m^{-2} largely explains the variation in yield and is considered as an important factor [35–38]; it is calculated by multiplying the number of panicles by the spikelet number $panicle^{-1}$. To identify which traits have a greater impact on spikelet number m^{-2}, correlation analyses were conducted with the panicle number $hill^{-1}$ and the spikelet number m^{-2}, respectively (Figure 7). The results indicated that both traits showed a highly significant positive correlation with spikelet number m^{-2}, showing that they are important determinants of rice yield. Interestingly, the number of panicles $hill^{-1}$ exhibited a stronger correlation with spikelet number m^{-2} than the number of spikelet $panicle^{-1}$, with r^2 = 0.655** and r^2 = 0.370**, respectively. Furthermore, the study suggested that securing more panicles during the vegetative stage is crucial for achieving stable yield when growing extremely early maturing rice varieties.

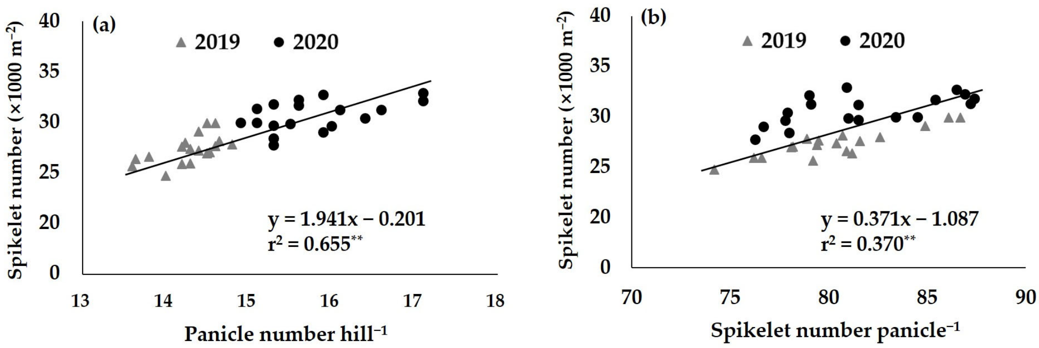


Figure 7. Relationship between spikelet number m^{-2} and (**a**) panicle number $hill^{-1}$ and (**b**) spikelet number $panicle^{-1}$. **: significant at $p < 0.01$.

In this study, it was observed that the panicle number and the spikelet number varied depending on the application methods, even when the same amount of nitrogen fertilizer was used. In the BD treatment (100% nitrogen applied as a basal dressing), a higher panicle number hill^{-1} was observed, while the spikelet number panicle^{-1} was lower. Conversely, the opposite trend was observed in the BTD treatment (70% nitrogen as basal and 30% nitrogen as top-dressing). The observed variation in the traits depending on the application methods of nitrogen fertilizer is likely due to differences in the timing and availability of nitrogen to the rice plants. In the BD treatment, the nitrogen was available to the rice plants early on, allowing for more tiller and ultimately resulting in a higher panicle number hill^{-1}. Conversely, in the BTD treatment, the nitrogen was applied twice, and the top-dressing may have resulted in a larger number of panicles and greater spikelet number panicle^{-1} due to the higher availability of nitrogen during panicle initiation. More nitrogen was absorbed by rice plants or lost from the soil before panicle initiation as the SPAD values were different between the BD and BTD treatments. Overall, the timing and availability of nitrogen appear to be crucial factors in determining the number of panicles and grains of rice, and different application methods can lead to different outcomes. These results were supported by several studies, showing that delaying the application of nitrogen fertilizer to rice plants can lead to an increase in the protein content of rice grains [13–15].

The SPAD values, which indicate chlorophyll content, revealed that the BD treatment had SPAD values ranging from 33.6 to 36.4, while the BTD treatment had slightly higher values from 35.4 to 39.1. Several studies reported that the SPAD values measured at the heading date typically range from 31.7 to 39.2 under different environments and rice varieties [39,40]. These findings suggested that an early maturing rice variety may not experience a nitrogen shortage during the grain-filling stage, even though 100% basal nitrogen is applied. Consequently, there were only small differences in the milled rice yield between the two nitrogen application methods under same nitrogen level (Figure 3).

4.3. Effect of Nitrogen Application on Milled Rice Grain Quality

As the demand for high-quality rice increases, head rice yield is becoming more important than milled rice yield. This is because it indicates the degree of milling efficiency and the level of damage to the rice grains during milling, which ultimately affects the quality of the final product [17–19]. In this study, BD treatment showed similar or higher head rice yield compared to BTD treatment, even under the same nitrogen level. This can be attributed to the negative correlation between the spikelet number panicle^{-1} and the ripened grain rate, as well as the positive correlation between the ripened grain rate and the head rice rate. In this study, BD treatment had fewer spikelet panicle^{-1} than BTD treatment, resulting in higher ripened grain rates and higher head rice rate. Therefore, the head rice yield was similar or higher, even though the milled rice yield was similar or low.

The protein content of rice is a crucial determinant of its quality, as it influences the sensory properties of cooked rice such as texture and taste. Rice with a high protein content tends to have reduced texture and can undergo accelerated aging, which compromises its quality [41,42]. Conversely, rice with a low protein content is generally considered to be of higher quality due to its superior sensory properties. In addition to protein content, the glossiness of cooked rice (GCR) is another important quality attribute used to assess the sensory properties of rice [43]. In this study, we observed significant variations in protein content and GCR based on the nitrogen application methods used, even when the same amount of nitrogen was applied. Specifically, the BTD treatment resulted in a higher protein content and lower GCR value compared to the BD treatment at all nitrogen levels. These findings suggested that the nitrogen application method can affect the quality of extremely early maturing rice. Additionally, the results showed that even when nitrogen is applied as a 100% basal dressing, an extremely early maturing rice variety may not experience nitrogen shortage during the grain-filling stage, as the head rice yield in BD treatment was comparable to or higher than that in the BTD treatment, and it showed a higher GCR with low protein content. These results suggest that the BD treatment could be an effective strategy for improving the yield and grain quality of an extremely early maturing rice variety while saving labor.

In addition, we found that the SPAD value at the heading date was highly correlated with both the protein content and the GCR value. Specifically, a higher chlorophyll content at the heading date resulted in an increased protein content of rice but decreased glossiness, suggesting that the chlorophyll content at the heading date can be used as an index to infer the taste of an extremely early maturing rice. Further research is needed to clarify this relationship.

5. Conclusions

This study found that an extremely early maturing rice variety may not experience a nitrogen shortage during the grain-filling stage, even though 100% nitrogen fertilizer was applied as a basal dressing. The milled rice yield of the BD treatment was similar to the BTD treatment under the same nitrogen level. In addition, the head rice yield in the BD treatment was comparable to or higher than that in the BTD treatment, and the BD treatment showed a higher GCR and a lower protein content. Therefore, the BD treatment could be an effective strategy for improving the yield and quality of an extremely early maturing rice variety while saving labor. This information can be useful for farmers and rice breeders seeking to improve the yields and the quality of rice using extremely early maturing rice varieties in response to climate change.

Author Contributions: Conceptualization, Y.Y.; methodology, Y.Y.; software, Y.Y.; formal analysis, Y.Y.; investigation, Y.L. and G.K.; data curation, Y.Y.; writing—original draft preparation, Y.Y.; writing—review and editing, Y.Y.; visualization, G.C.; supervision, T.Y. and H.K.; project administration, T.Y.; funding acquisition, H.K. All authors have read and agreed to the published version of the manuscript.

Funding: This study was carried out with the support of the Chungcheongnamdo Agricultural Research and Extension Services, South Korea (Project No. LP0042352020) and Rural Development Administration, South Korea (Project No. PJ0158202021).

Data Availability Statement: The corresponding author can be contacted to request the data presented in this study.

Acknowledgments: The author is thankful to Eunmi Lee, Kun Kim, Hyekyun Kim, Misook Lee, Jeongsook Jeon, Heesook Lim, and Jongmi Park for their technical support in the rice research field.

Conflicts of Interest: The authors declare no conflict of interest.

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