CHAPTER 2

Effect of cropping season on rice grain quality

2.1 Introduction

Rice is the staple food for over half of the world's population (Khush, 2005) and it is the major food consumption in Asia. Thailand is one of the biggest rice exporters to the world market. A unique characteristic of Thailand's rice production and trade is the emphasis placed on grain quality compared with the other countries. This has enabled Thailand to capture a major share of the market for high quality rice based on Thai specific rice standards in each type and grade for the domestic and international trades. This has brought benefits to farmers, rice traders and the country's export earnings, in the form of higher prices. Rice grain quality can be defined on many aspects including physical quality such as grain size, shape, head rice yield, grain chalkiness, whiteness and translucency; physico-chemical quality including gelatinization temperature, gel consistency, and amylose content; and nutritional quality defined by the content of nutritional compounds such as proteins, vitamins and metabolites and minerals (Webb, 1991) such as zinc and iron.

Rice grain quality is determined by genetic control and environment conditions during crop production. Global warming and climate change pose a threat to rice yield, but adverse effects on grain quality would also depress farmers' income and export earning of countries that specialize in high quality rice such as Thailand. Temperature is one of the most important factors affecting rice yield and quality. It has been reported that high nighttime temperature has more pronounced negative effects on rice than daytime temperature (Peng *et al.*, 2004). High nighttime temperature during the kernel developing stage caused spikelet infertility (Jagadish *et al.*, 2007; Matsui *et al.*, 1997; Mohammed and Tarpley, 2009; Mohammed and Tarpley, 2010), decreased grain weight and yield (Peng *et al.*, 2004), increased the number of chalky grain (Cooper *et al.*, 2008;

Ishimaru *et al.*, 2009; Tashiro and Wardlaw, 1991; Tsukaguchi and Iida, 2008), decreased head rice yield (Ambardekar *et al.*, 2011; Cooper *et al.*, 2008; Counce *et al.*, 2005) and also affected grain physicochemical attributes including decreasing the amylose content (Cooper *et al.*, 2008). While low temperature extended grain maturity period and decreased ratio of ripened grain whereas, it increased the thousand grain weight. (Funaba *et al.*, 2006). However, most of these results have been obtained on japonica rice grown in temperate regions or on rice grown under controlled conditions. By contrast, information on temperature effects on grain quality of indica rice in the field of tropical regions is limited.

Thailand has two main rice growing seasons, the wet season rice (*Na pee*) and off-season or dry season rice (*Na prang*). However, in irrigated area, e.g. in the Central and Lower North regions, rice may be grown continuously all year round (OAE 2556). Therefore, the rice crop risks facing high or low temperature, depending on the cropping season, particularly at heading and grain filling, growth stages which are the most sensitive stages to temperature. Damages from extreme temperatures may worsen under climate change. To our knowledge, there is no study on the effect of different cropping seasons on grain yield along with grain quality especially milling and nutritional qualities at the field scale. Therefore, this present study aimed to evaluate the effect of different cropping seasons on rice growth, grain yield and grain quality of selected popular Thai rice varieties. This will be achieved by growing crops during the rainy season, summer season and cool season. Understanding effects of cropping season on rice growth and grain quality and variation among rice germplasm will enhance the country's capacity in the production of high quality rice and enable the national rice breeding programs to select for high quality with more precision.

2.2 Materials and methods

2.1.1 Rice variety and culture

Field experimentation was conducted at the Multiple Cropping Center, Faculty of Agriculture, Chiang Mai University, Chiang Mai, Thailand (18º 47' N, 98º 57' E) in 3 cropping seasons: rainy season (August – November 2009), cool season (October 2009– February 2010) and summer (February 2010 – June 2010). These times were chosen in order that temperature conditions during grain filling differed substantially between seasons. Four popular photoperiod insensitive rice varieties were used: Supanburi 1(SPR1), Chai Nat 1 (CNT1) Pathumthani 1 (PTT1) and RD21. Seed were sown in seedbeds for 30 days then transplanted into 4 x 4 m plots, one plant per hill at 0.25 x 0.25 m spacing. The trial designed in each season was a completely randomized block with 4 replicate blocks. Fertilizers were applied to all plots at 15 days after transplanting with 28 kg N/ha, 28 kg P_2O_5/ha and 28 kg K_2O/ha. Top dressing with urea was applied at panicle initiation at the rate 43 kg N/ha. Hand weeding was done at 3 weeks after transplanting and pre-heading stage before applying urea. The experimental plots were flooded 10-15 cm depth and maintained until 7 days before harvesting. Weather data (daily maximum/minimum temperature; relative humidity and radiation) for the whole growing seasons were obtained from The Northern Meteorological Centre, Chiang Mai, Thailand (located about 2.5 km from the experimental area).

2.1.2 Data collection

1) Yield and yield components

Thirty-two plants in two block of 1x1 m^2 block were harvested manually by hand from each replicate plot at physiological maturity to measure grain yield and yield components. Thousand grain weight was evaluated on filled grain only. Grain size distribution was measured by weight individual grain randomly of all grain (filled and unfilled grain).

2) Grain quality

The grain samples were air dried to 11-12 % of moisture content for grain quality evaluation. One-hundred g of paddy rice was dehusked with a laboratory husker machine (model P-1, Ngek Seng Huat, Thailand) to yield brown rice. The husker was Teflon-coated for all containers and handles to avoid Fe contamination during the husking process (Prom-u-thai *et al.*, 2007a; Prom-u-thai *et al.*, 2007b). Thirty g of whole grain brown rice were polished for 30 s with a laboratory milling machine (model K-1, Ngek Seng Huat, Thailand) to yield white rice, then separated into head rice (≥ 4/5 whole grain length) and remainder as broken rice. All grain samples were weighed for head rice yield calculation, broken grain and degree of milling (DOM).

Grain chalkiness was evaluated based on the Standard Evaluation System (SES Scale) (IRRI, 1997). Ten g of head rice were inspected by eye for presence of chalky areas and manually separated into two categories, namely grain with chalky area ≥20% of rice grain area as chalky grain, and grain with chalky area <20% of grain area as non-chalky grain. Percent grain chalkiness was calculated by chalky grain weight per head rice weight.

Gelatinization temperature was assessed with alkali spreading assay (IRRI, 1997). One hundred whole grains of milled rice from each experimental unit were placed individually in Petri dishes containing 10 ml of 1.7% KOH then kept at room temperature for 23 hours. Four milled grains of KDML105 (low gelatinization temperature) and RD4 (high gelatinization temperature) grown in the wet season, 2008 at Multiple Cropping Centre, Faculty of Agriculture, Chiang Mai University were used as checks. The degree of spreading was assessed at the 24th hour, using a seven-point scale of 1 – 7, the lower score indicating higher gelatinization temperature (Table 2.1).

Table 2.1 Grain appearance, disintegration rate and numerical scale for scoring gelatinization temperature.

Description	Score	Gelatinization temperature
Grain not affected	1	High
Grain swollen	2	
Grain swollen, collar incomplete or narrow	3	High intermediate
Grain swollen, collar incomplete or wide	4	Intermediate
Grain split or segmented, collar complete and wide	5	
Grain dispersed, merging with collar	6	Low
Grain completely dispersed and intermingled	7	

IRRI (1997)

An alkali spreading values is inversely indicated the gelatinization temperature; 1-2 are indicators of high gelatinization temperature; 3 is high intermediate; 4-5 are intermediate and 6-7 are low gelatinization temperature.

3) Nutritional quality

The grain samples were analyzed for nitrogen (N), phosphorus (P), iron (Fe) and zinc (Zn). Ten g samples of brown and white rice were oven dried at 75 °C for 72 h then 1 g was dry-ashed in a muffle furnace at 535 °C for 8 h. The ash was dissolved in HCl (1:1; HCl:deionized water and the concentration of P, Fe and Zn were determined using an Hitachi Z-8230 atomic absorption spectrophotometer (AAS) (Allan, 1961). Nitrogen was analyzed by the Kjeldahl method (Jackson, 1967). Soybean leaf powder was used for reference material in all samples to check the quality of N, P, Zn and Fe analyses.

4) Statistical analysis

Analysis of variance was conducted to detect differences in grain yield, yield components and grain quality characteristics using Statistic 8 (analytical software, SXW). Data were analyzed in factorial in randomized complete block design. Data on proportion were arcsine transformed before analysis. The least significant difference (LSD) at $p < 0.05$ was applied to compare the means for significant differences between variety and cropping season.

2.3 Results

2.3.1 Meteorological environment

The summarized data of cropping rice in 3 seasons is shown in Table 2.2 and the climatic data is presented in Figure 2.2-2.6. The rainy season crop was transplanted on August 13th, 2009; cool season crop on October 7th, 2009 and the summer season crop on from February 5th, 2010 to June 2010 (Table 2.2). The rice varieties differed in their rate of development in the different seasons. The varieties all took 102 days in the rainy season, 119-126 days in the cool season and 111-131 days from transplanting to harvest. Climatic data was recorded from June 2009 to July 2010 (Figure 2.1-2.5). From flowering to harvest the average minimum and maximum temperature were 22.4 ºC and 32.3 ºC for the rainy season, 17.1 ºC and 31.1 ºC for the cool season and 25.8 ºC and 37.1 ºC for the summer season (Figure 2.1). The average relative humidity from flowering to harvest was higher in the rainy season (73.6%) followed by the cool season (68.1%) and the summer season (59.4%) (Figure 2.2). The amount of rainfall from flowering to harvesting in the rainy season was 335.6 mm. higher than the cool season (206.3 mm.) and summer season (33.5 mm.), respectively (Figure 2.3). The average sunshine duration from flowering to harvesting was 7.8 hours/day in rainy season, 8.8 hours/day in the cool season and 8.1 hours/day in the summer season (Figure 2.4). The average evaporation rate from flowering to harvesting was similar in the rainy season and the cool season (3.9 and 3.5 mm., respectively) but lower than in the summer season (6.1 mm.) (Figure 2.5).

Table 2.2 The data of rice cropping in 3 season, rainy season, cool season and summer season from August 2009 to June 2010.

Variety	Transplanting[1]	Flowering[2]	Harvest	Flowering to harvest (days)[3]
		Rainy season		
SPR1	Aug 13, 2009	Oct 10, 2009	Nov 23, 2009	44
CNT1	Aug 13, 2009	Oct 10, 2009	Nov 23, 2009	44
PTT1	Aug 13, 2009	Oct 20, 2009	Nov 23, 2009	34
RD21	Aug 13, 2009	Oct 20, 2009	Nov 23, 2009	34
		Cool season		
SPR1	Oct 7, 2009	Dec 10,2009	Feb 3, 2010	55
CNT1	Oct 7, 2009	Dec10,2009	Feb 3, 2010	55
PTT1	Oct 7, 2009	Dec 20,2009	Feb 10, 2010	52
RD21	Oct 7, 2009	Dec 7,2009	Feb 3, 2010	58
		Summer season		
	Planting date	Heading	Harvesting	
SPR1	Feb 5, 2010	April 23, 2010	Jun 3, 2010	41
CNT1	Feb 5, 2010	April 17, 2010	Jun 3, 2010	48
PTT1	Feb 5, 2010	May 4, 2010	Jun 16, 2010	43
RD21	Feb 5, 2010	April 15, 2010	May 27, 2010	43

[1] Transplanting with 30 day old seedlings

[2] Rice flowering at 80% of plot

[3]Rice were harvested at physiological maturity

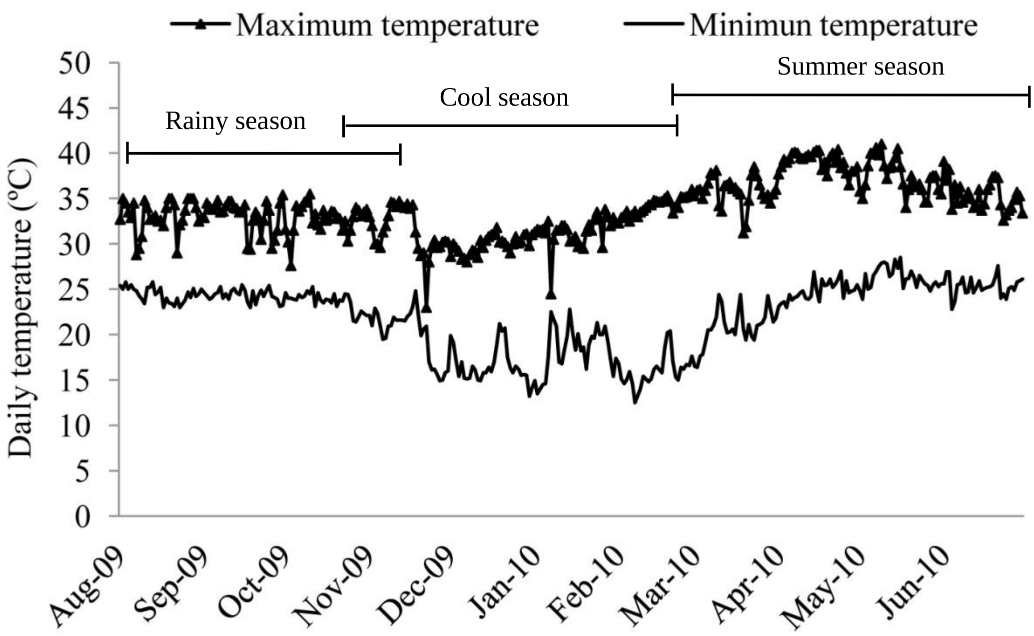

Figure 2.1 Daily maximum and minimum air temperature (ºC) throughout the experimental period from August 2009 to June 2010.

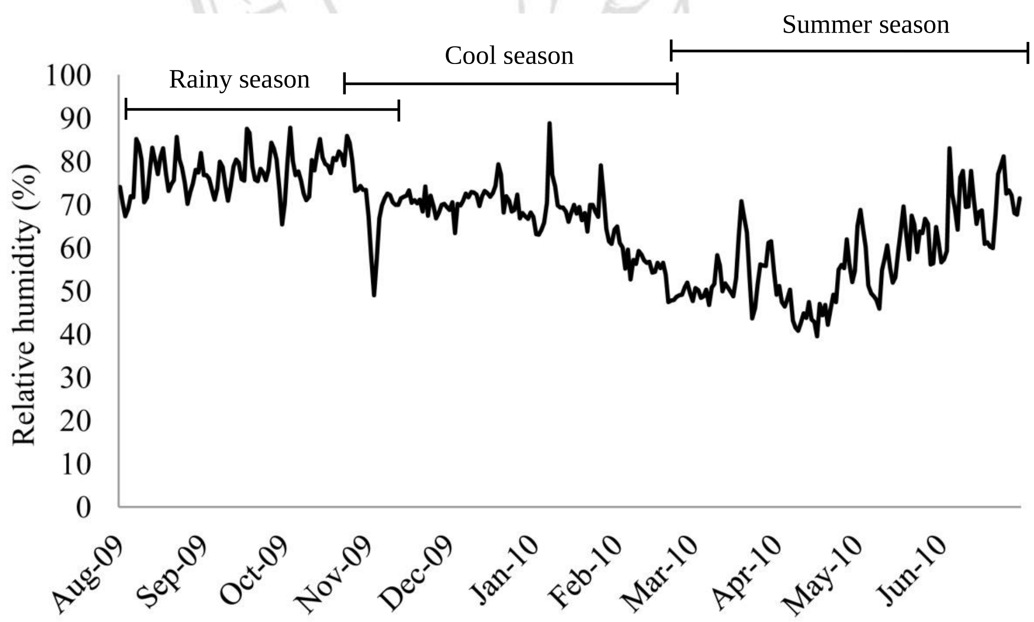

Figure 2.2 Daily relative humidity throughout the experimental period from August 2009 to June 2010.

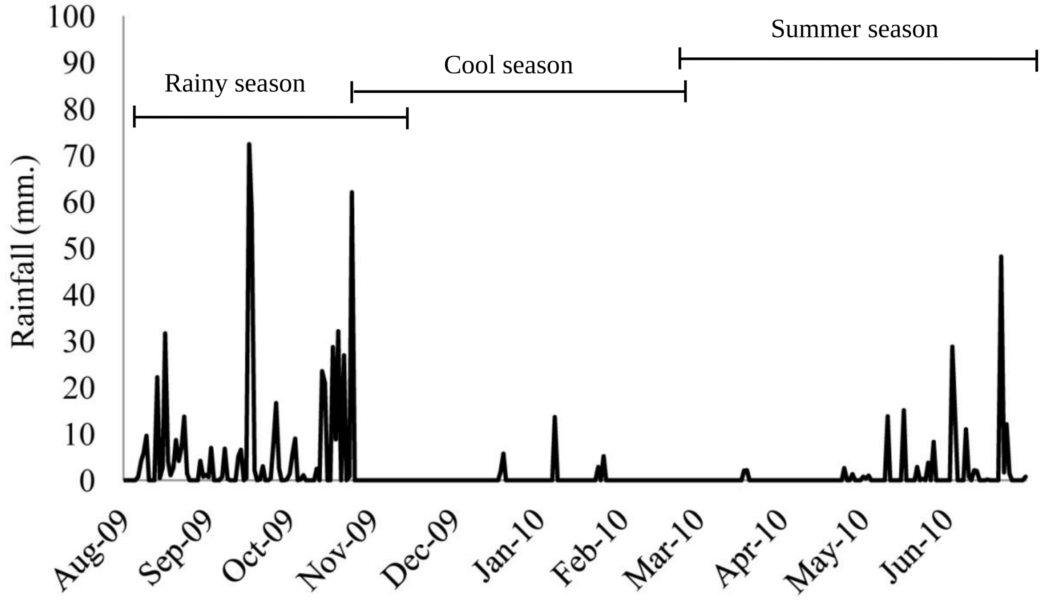

Figure 2.3 Daily rainfall (mm.) throughout the experimental period from August 2009 to June 2010.

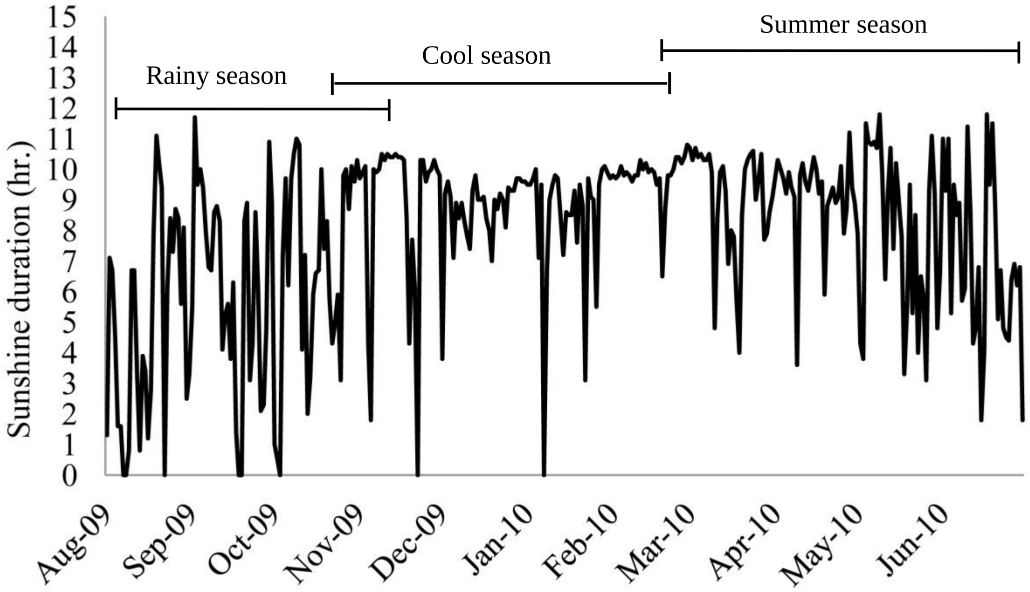

Figure 2.4 Daily sunshine duration (hrs.) throughout the experimental period from August 2009 to June 2010.

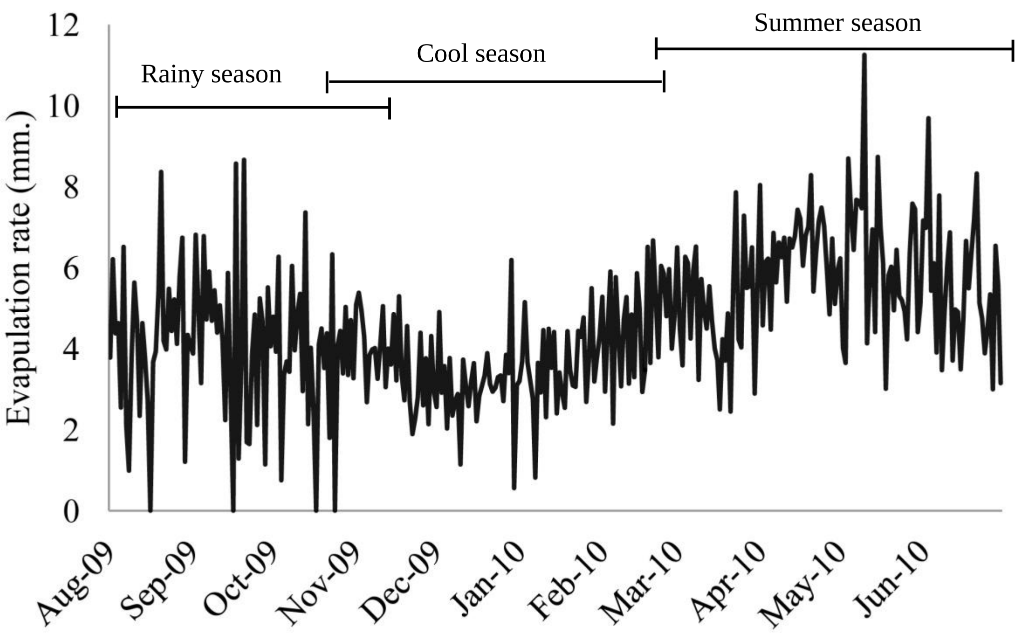

Figure 2.5 Daily evaporation (mm.) throughout the experimental period from August 2009 to June 2010.

2.3.2 Yield and yield components

There were significant effects of rice variety, season and variety x season interactions in rice yield and yield components. All 4 rice varieties produced highest tiller in the cool season (Table 2.3). In the cool season, SPR1was the highest while SPR1 and RD21 were the lowest. In the rainy and summer season, RD 21 was found to have lower tiller number than others three varieties. Overall, the range of tiller was from 8.9 to 47.5 tillers per plant.

Panicle number was also found higher in the cool season than the rainy and summer season which was similar (Table 2.4). In the cool season, CNT1 had the highest panicle number, followed by PTT1, SPR1 and RD21, respectively. In the rainy and summer season, RD21 appears to have lowest panicle number while other 3 varieties were almost the same except SPR1 in the rainy season. The panicle number ranged from 8.1 to 34.8 panicles per plant.

The yield of filled grain in different varieties was affected significantly differently by season (*P<0.01*). In the rainy and summer seasons, filled grain weight of SPR1, CNT1 and RD21 were in similar range from 4.12 to 5.24 t/ha, but were much lower in the cool season, with major differences among the varieties. The variety CNT1 was found to have the most severe depression of filled grain of filled grain weight in the cool season, by 72% from that in the rainy season. Filled grain weight of PTT1, which was highest in the rainy season, was depressed by 13% in the summer season and by 65% in the cool season (Table 2.5).

Total grain weight (filled and unfilled grains) showed a similar response to season and variety as filled grain weight (Table 2.6). SPR1 had the highest total grain weight (4.99 t/ha) compared with the other 3 varieties, which were not different and ranged from 4.30 to 4.68 t/ha. The total grain weight was highest at 5.26 t/ha in the rainy season followed by 4.50 t/ha in summer and 3.15 t/ha in the cool season.

Thousand filled grain weight had similar result as in the total grain weight (Table 2.7). It was highest in the rainy season (from 28.2 to 34.5 g) and lowest in the cool season. Unlike total grain weight, 1000-grain weight was more responsive to variety, being in the order RD21>CNT1>SPR1=PTT1. The varieties RD21 and CNT1 had higher1000-grain weights in the rainy season than in the cool and summer seasons. By contrast, SPR1 and PTT1 had higher 1000-grain weights in the rainy season than in the summer and cool seasons, respectively.

The pattern of individual grain weight distribution of each rice variety was different among cropping seasons. For each rice variety the frequency of the modal grain weight (grain weight with the highest frequency) varied with the season, but the modal grain weight remained constant across the 3 seasons (Figure 3.6). Generally, CNT1, PTT1 and RD21 had higher frequency of the modal grain weight in the rainy and summer seasons than the cool season which had higher unfilled or partially filled grain than other seasons. For CNT1 and PTT1, the modal grain weight was about 28 mg/grain which accounted for 68 to 71% and 74 to79% of the total grain, respectively and it was declined in the cool season to 28% and 27%, respectively. In RD21 the modal grain weight of 35 mg/grain accounted for 63% of the grain in the rainy and 66% in the summer season, declining to 39% of the grain in the cool season. The modal grain weight of 28 mg/grain in SPR1 accounted about 80% of the grain in the rainy season, declining to 69% in the summer and 51% in the cool season.

Table 2.3 Tiller number of 4 rice varieties grown in rainy, cool and summer seasons.

Variety	Tiller number per plant			Mean
	Rainy	Cool	Summer	
SPR1	11.8 ABb	21.1 Ca	14.2 ABb	15.7
CNT1	15.3 Ab	47.5 Aa	15.0 Ab	25.9
PTT1	14.7 Ab	28.8 Ba	15.1 Ab	19.6
RD21	8.9 Bb	17.1 Ca	10.7 Bb	12.2
Mean	12.7	28.6	13.7	
	Variety	Season	Variety x Season	
F-test	***	***	***	
$LSD_{0.05}$	2.4	2.1	4.2	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.4 Panicle number per plant of 4 rice varieties grown in rainy, cool and summer seasons.

Variety	Panicle number per plant			Mean
	Rainy	Cool	Summer	
SPR1	11.3 Bb	16.6 Ca	13.0 Ab	13.8
CNT1	14.5 Ab	38.4 Aa	13.0 Ab	22.0
PTT1	13.5 ABb	19.9 Ba	13.8 Ab	15.7
RD21	8.1 Cb	11.7 Da	9.8 Bab	9.9
Mean	11.8	21.7	12.5	
	Variety	Season	Variety x Season	
F-test	***	***	***	
$LSD_{0.05}$	1.3	1.1	2.3	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.5 Filled grain weight of 4 rice varieties grown in rainy, cool and summer seasons.

Variety	Weight of filled grain (t/ha)			Mean
	Rainy	Cool	Summer	
SPR1	5.30 Aa	3.70 Ab	4.86 Aa	4.62
CNT1	5.24 Aa	1.49 Cb	4.57 Aa	3.76
PTT1	4.72 Aa	1.67 Cc	3.79 Bb	3.39
RD21	4.72 Aa	2.56 Bb	4.12 ABa	3.80
Mean	4.99	2.35	4.33	
	Variety	Season	Variety x Season	
F-test	***	***	**	
$LSD_{0.05}$	0.36	0.42	0.73	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.6 Total grain weight (t/ha) of 4 rice varieties grown in rainy, cool and summer seasons.

Variety	Grain weight (t/ha)			Mean
	Rainy	Cool	Summer	
SPR1	5.51	4.16	4.99	4.99 A
CNT1	5.47	2.60	4.68	4.68 B
PTT1	5.01	2.56	4.03	4.03 B
RD21	5.06	3.28	4.30	4.30 B
Mean	5.26 a	3.15 c	4.50 b	
	Variety	Season	Variety x Season	
F-test	***	***	ns	
$LSD_{0.05}$	0.44	0.39		

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.7 Thousand grain weight (g) of 4 rice varieties grown in rainy, cool and summer seasons.

Variety	Thousand grain weight (g)			Mean
	Rainy	Cool	Summer	
SPR1	28.3 Ca	24.5 Cc	25.4 Cb	26.1
CNT1	29.1 Ba	26.3 Bb	26.4 Bb	27.3
PTT1	28.2 Ca	23.7 Dc	25.5 Cb	25.8
RD21	34.5 Aa	29.8 Ab	30.3 Ab	31.5
Mean	30.0	26.1	26.9	
	Variety	Season	Variety x Season	
F-test	***	***	**	
$LSD_{0.05}$	0.4	0.3	0.7	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

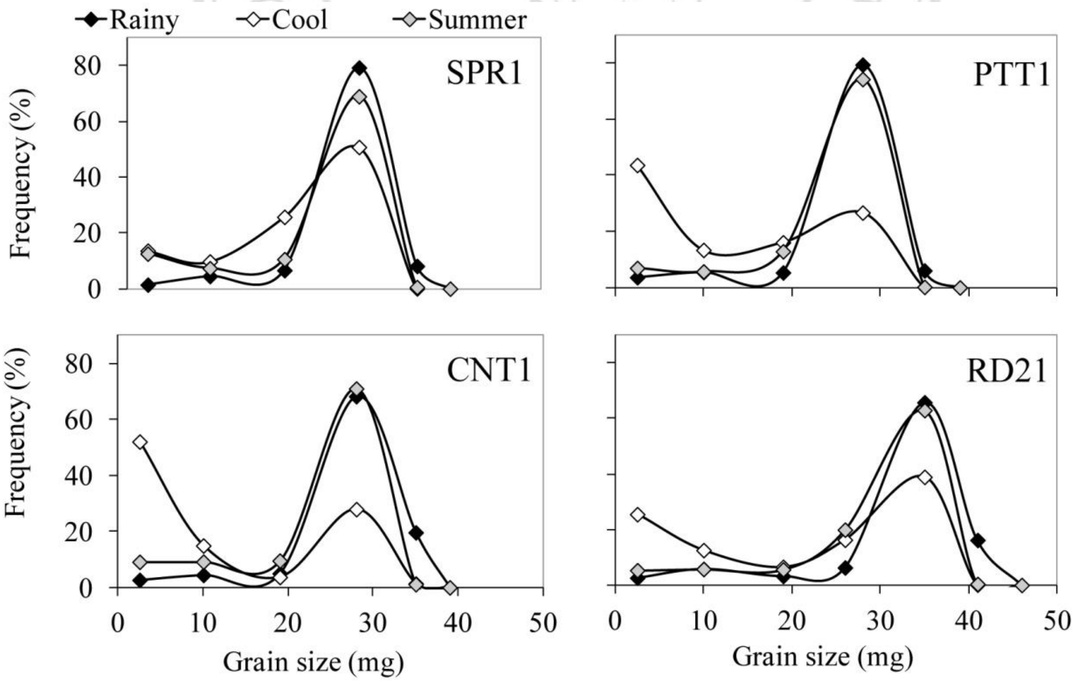

Figure 2.6 Individual grain weight (mg) of 4 rice varieties grown in rainy, cool and summer seasons.

2.3.3 Milling quality

There were significant effects of variety, season and variety x season interactions on head rice yield ($P<0.01$) (Table 2.8), ranging from 37.8 to 70.1%. SPR1 and CNT1 had the highest head rice yield in the rainy season (65.4% and 58.4%, respectively) and lower in the cool and summer seasons (47.9% and 45.0%, respectively for SPR1, and 43.9% and 44.0%, respectively for CNT1). Head rice yield was similar between the rainy and the cool seasons but was lower in summer. Growing season had no effect on head rice yield of RD21 which had consistently higher head rice yield than the other varieties.

Degree of milling was affected by rice variety and season ($P<0.01$) (Table 2.9). It was not differences among CNT1, PTT1 and RD21 (range 13.6 to 14.5%) which were higher than SPR1 (12.5%). The degree of milling was higher in summer (15.6%) than the rainy (12.6%) and the cool (12.7%) seasons.

There were significant difference of variety, season and variety x season interactions in the percent grain chalkiness ($P<0.001$) (Table 2.10). In general, all 4 varieties had the highest grain chalkiness in summer (range 30% to 70%). Grain chalkiness in SPR1 and PTT1 declined by 27.8% and 12.2%, respectively in the rainy season and by 5.3% and 2.4%, respectively, in the cool season compared with summer. By contrast, grain chalkiness of CNT1 and RD21 did not differ between the rainy and cool seasons (means of 43.4 and 55.4%, respectively).

There were significantly different of variety, season and variety x season interaction on alkali spread value, ranging from 2.1 to 7.0 ($P<0.001$) (Table 2.11). The alkali spreading values for CNT1, PTT1 and RD21 were higher than in the summer season (range 2.4 - 4.8) and did not differ between the rainy and cool seasons (range 3.5-7.0). Furthermore, SPR1 had the highest alkali spread value in the cool season (3.1) and it was declined in the rainy (2.8) and summer (2.1) seasons.

Table 2.8 Percentage of head rice yield of 4 rice varieties when grown in rainy, cool and summer seasons.

Varieties	Head rice yield (%)			Mean
	Rainy	Cool	Summer	
SPR1	65.4 ABa	47.9 BCb	45.0 Bb	52.8
CNT1	58.4 Ba	43.9 Cb	44.0 Bb	48.8
PTT1	47.4 Ca	54.6 Ba	37.8 Bb	46.6
RD21	70.1 Aa	64.4 Aa	63.8 Aa	66.1
Mean	60.3	52.7	47.7	
	Variety	Season	Variety x Season	
F-test	***	***	**	
$LSD_{0.05}$	4.6	4.0	8.0	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.9 Degree of milling of 4 rice varieties when grown in rainy, cool and summer seasons.

Varieties	Degree of milling (%)			Mean
	Rainy	Cool	Summer	
SPR1	11.5	11.2	14.8	12.5 B
CNT1	13.7	14.0	15.8	14.5 A
PTT1	12.1	13.2	15.5	13.6 A
RD21	13.4	12.4	16.2	14.0 A
Mean	12.6 b	12.7 b	15.6 a	
	Variety	Season	Variety x Season	
F-test	**	**	ns	
$LSD_{0.05}$	0.9	0.8		

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 3.10 Percentage of grain chalkiness of 4 rice varieties grown in rainy, cool and summer seasons.

Variety	Grain chalkiness (%)			Mean
	Rainy	Cool	Summer	
SPR1	27.0 Ab	5.3 Cc	75.0 Aa	35.7
CNT1	8.2 Bb	14.1 Bb	43.4 Ca	21.9
PTT1	12.4 Bb	2.4 Cc	30.0 Da	14.9
RD21	22.0 Ab	29.5 Ab	55.4 Ba	35.6
Mean	17.4	12.8	50.9	
	Variety	Season	Variety x Season	
F-test	***	***	***	
$LSD_{0.05}$	0.06	0.05	0.10	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.11 Alkali spread value of 4 rice varieties grown in rainy, cool and summer seasons.

Variety	Alkali spreading value			Mean
	Rainy	Cool	Summer	
SPR1	2.8 Db	3.1 Da	2.1 Cc	2.7
CNT1	3.5 Ca	3.8 Ca	2.4 Cb	3.2
PTT1	5.2 Ba	5.6 Ba	3.3 Bb	4.7
RD21	7.0 Aa	7.0 Aa	4.8 Ab	6.3
Mean	4.6	4.9	3.2	
Checked variety				
RD4	2.0	2.0	2.0	2.0
KDML105	7.0	7.0	7.0	7.0
	Variety	Season	Variety x Season	
F-test	***	***	***	
$LSD_{0.05}$	0.30	0.2	0.6	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

2.3.4 Nutritional quality

1) Nitrogen in rice grain

The concentration and content of N in brown and white rice were significant different among variety, season and variety x season interactions in (*P<0.01*) (Table 2.12). The N concentration in brown rice was highest in the cool season, ranging from 2.09 to 2.69%. In the rainy season, all 4 varieties had equal N concentrations than ranging from 1.49% to 1.54% and these were generally higher than the summer season (range 1.20 - 1.28 %) excepted RD21where the N concentration did not differ between the rainy and summer seasons.

The concentration of N in white rice was as similar as in brown rice, being higher in the cool season (range from 1.92 - 2.62%) than in the rainy (range 1.36 - 1.47%) and summer (range 1.13 - 1.22%) seasons (Table 2.13). In addition, milling had no significant effect on the depression of the N concentration (Table 2.14).

The N content in brown rice was highest in the cool season and RD21 had the highest N content (0.59 µg/grain) followed by CNT1 (0.53 µg/grain), PTT1 (0.44 µg/grain) and SPR1 (0.38 µg/grain). Also, the N content declined in the rainy (0.31 to 0.32 µg/grain) and summer seasons (0.23 to 0.33 µg/grain). However, it was found RD21 had higher N content than other three varieties in both rainy and summer seasons (Table 2.15).

The N content in white rice followed the same trend as N concentration in white rice being higher in the cool season ranged from 0.31 to 0.49 µg/grain than in the rainy season (range 0.26 to 0.33 µg/grain) and in the summer season (range 0.18 to 0.24 µg/grain) for the four varieties (Table 2.16).

Table 2.12 The N concentration in brown rice of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	N concentration (%)			Mean
	Rainy	Cool	Summer	
SPR1	1.49 Ab	2.09 Ca	1.23 Bc	1.60
CNT1	1.54 Ab	2.69 Aa	1.28 ABc	1.84
PTT1	1.46 Ab	2.53 ABa	1.20 Bc	1.73
RD21	1.44 Ab	2.42 Ba	1.44 Ab	1.77
Mean	1.48	2.43	1.29	
	Variety	Season	Variety x Season	
F-test	***	**	**	
$LSD_{0.05}$	0.12	0.10	0.20	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.13 The N concentration in white rice of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	N concentration (%)			Mean
	Rainy	Cool	Summer	
SPR1	1.36 Ab	1.92 Ca	1.13 Ac	1.47
CNT1	1.47 Ab	2.62 Aa	1.19 Ac	1.76
PTT1	1.40 Ab	2.47 Ba	1.15 Ac	1.67
RD21	1.40 Ab	2.46 Ba	1.22 Ac	1.69
Mean	1.41	2.37	1.17	
	Variety	Season	Variety x Season	
F-test	***	**	**	
$LSD_{0.05}$	0.08	0.07	0.15	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.14 The milling loss of N of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	Milling loss (%)			Mean
	Rainy	Cool	Summer	
SPR1	8.46	6.70	7.19	7.45
CNT1	4.58	2.47	6.70	4.58
PTT1	4.23	2.79	4.47	3.83
RD21	2.46	1.59	14.76	6.27
Mean	4.93	3.39	8.28	
	Variety	Season	Variety x Season	
F-test	ns	ns	ns	

Table 2.15 The N content in brown rice of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	N content (mg/grain)			Mean
	Rainy	Cool	Summer	
SPR1	0.32 Bb	0.38 Da	0.23 Bc	0.31
CNT1	0.32 Bb	0.53 Ba	0.25 Bc	0.37
PTT1	0.31 Bb	0.44 Ca	0.21 Bc	0.32
RD21	0.38 Ab	0.59 Aa	0.33 Ac	0.43
Mean	0.33	0.49	0.25	
	Variety	Season	Variety x Season	
F-test	***	**	**	
$LSD_{0.05}$	0.03	0.21	0.04	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.16 The N content in white rice of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	N content (mg/grain)			Mean
	Rainy	Cool	Summer	
SPR1	0.26 Bb	0.31 Da	0.18 Bc	0.25
CNT1	0.28 Bb	0.44 Ba	0.20 Bc	0.30
PTT1	0.25 Bb	0.40 Ca	0.18 Bc	0.28
RD21	0.33 Ab	0.49 Aa	0.24 Ac	0.35
Mean	0.28	0.41	0.20	
	Variety	Season	Variety x Season	
F-test	***	**	**	
$LSD_{0.05}$	0.02	0.02	0.03	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

2) Phosphorus in rice grain

The concentration of P in brown rice was significant difference among variety, season and variety x season interactions (*P<0.01*) (Table 2.17). The P concentration in cool season (0.40 to 0.50%) was higher than the rainy and summer season which were not differ (0.34 to 0.38%). In the cool season, SPR1 and RD21 had higher P concentrations than CNT1 and PTT1 while in the rainy and summer seasons, CNT1 and RD21 had higher P concentrations than SPR1 and PTT1.

In white rice, all 4 varieties had higher P concentrations in the cool season than in the summer and rainy seasons. Overall, the P concentration ranged from 0.09 to 0.17 mg/kg. In all three seasons, SPR1 had the lowest P concentration. By contrast PTT1 had the highest P concentration (Table 2.18).

The milling loss of P was significant different among variety, season and variety x season interactions in (*P<0.001*) (Table 2.19). The highest milling loss of P was showed in the rainy season that ranged from 69.2 to 73.4% but declined in cool and summer season. SPR1 and CNT1 had similar percent loss of P in the cool and summer season (69.0 to70.3% and 65.7 to 68.1%, respectively) while PTT1 and RD21 showed different percent milling loss among seasons. PTT1 had higher milling loss of P in the cool season (64.3%) than in the summer (61.1%) and this was contrast to RD21, the milling loss of P in the summer was higher in the summer (96.0%) than in the cool season (57.8%).

The content of P in brown and white rice was significantly affected by rice variety and season and there was a significant variety by season interaction (*P*< 0.001). In brown rice, SPR1 and RD21 had more P in the rainy and cool seasons than in summer. By contrast CNT1 and PTT1 had more P in brown rice in the cool season than in the summer and rainy seasons. Overall, P content in brown rice ranged from 0.062 to 0.098 μg/grain (Table 2.20). In white rice, all four varieties had the higher P content in cool season (0.021 to 0.034 μg/grain) than in the rainy and summer seasons which were similar excepted PTT1 which had more P in the summer season than in the rainy season. Overall, RD21 had the highest P content in all three season (Table 2.21).

Table 2.17 The P concentration in brown rice of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	P concentration (mg/kg)			Mean
	Rainy	Cool	Summer	
SPR1	0.35 Bb	0.41 Ba	0.34 Bb	0.34
CNT1	0.38 Ab	0.50 Aa	0.36 ABb	0.36
PTT1	0.35 Bb	0.48 Aa	0.35 Bb	0.35
RD21	0.36 ABb	0.40 Ba	0.38 Aab	0.38
Mean	0.36	0.45	0.36	
	Variety	Season	Variety x Season	
F-test	***	***	**	
$LSD_{0.05}$	0.02	0.02	0.03	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.18 The P concentration in white rice of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	P concentration (mg/kg)			Mean
	Rainy	Cool	Summer	
SPR1	0.09 Cc	0.13 Ba	0.10 Cb	0.10
CNT1	0.11 Ac	0.17 Aa	0.12 Bb	0.12
PTT1	0.11 Ac	0.17 Aa	0.14 Ab	0.14
RD21	0.10 Bc	0.17 Aa	0.12 Bb	0.12
Mean	0.10	0.16	0.12	
	Variety	Season	Variety x Season	
F-test	***	***	**	
$LSD_{0.05}$	0.01	0.01	0.01	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.19 The milling loss of P of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	Milling loss (%)			Mean
	Rainy	Cool	Summer	
SPR1	73.4 Aa	69.0 Ab	70.3 Aab	70.9
CNT1	72.3 ABa	65.7 ABb	68.1 Ab	68.7
PTT1	69.2 Ba	64.3 Bb	61.1 Bc	64.9
RD21	73.1 Aa	57.8 Cc	69.0 Ab	66.6
Mean	72.0	64.2	67.1	
	Variety	Season	Variety x Season	
F-test	**	***	***	
$LSD_{0.05}$	2.1	1.8	3.6	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.20 The P content in brown rice of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	P content (mg/grain)			Mean
	Rainy	Cool	Summer	
SPR1	0.074 Ca	0.075 Ca	0.064 Cb	0.071
CNT1	0.080 Bb	0.098 Aa	0.070 Bc	0.083
PTT1	0.074 Cb	0.084 Ba	0.062 Cc	0.073
RD21	0.095 Aa	0.097 Aa	0.087 Ab	0.093
Mean	0.081	0.088	0.070	
	Variety	Season	Variety x Season	
F-test	***	***	***	
$LSD_{0.05}$	0.003	0.003	0.003	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 3.21 The P content in white rice of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	P content in white (mg/grain)			Mean
	Rainy	Cool	Summer	
SPR1	0.017 Cb	0.021 Ba	0.016 Db	0.018
CNT1	0.020 Bb	0.021 Ba	0.019 Cb	0.020
PTT1	0.019 Bc	0.028 Ba	0.013 Bb	0.020
RD21	0.023 Ab	0.034 Aa	0.024 Ab	0.027
Mean	0.02	0.03	0.02	
	Variety	Season	Variety x Season	
F-test	***	***	***	
$LSD_{0.05}$	0.001	0.001	0.001	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

3) Zinc in rice grain

The N concentration in both brown and white rice was significant different among variety, season and variety x season interactions (*P<0.05*) (Table 2.22). In general, the concentration of Zn in brown rice was highest in the cool season, being 26.1 mg/kg in RD21, 28.9 mg/kg in SPR1, 35.1 mg/kg in PTT1 and 38.2 mg/kg in CNT1. In the rainy and summer seasons, Zn concentrations were similar and ranged from 20 to 23 mg/kg.

As for brown rice, the highest Zn concentration in white rice occurred in the cool season (range 21.2 - 32.6 mg/ka) (Table 2.23). SPR1, PTT1 and RD21 had similar Zn concentrations in the rainy and summer seasons but CNT1 had a higher Zn concentration in the rainy season than in summer. Overall, the Zn concentration in white rice ranged from 16.0 to 32.1 mg/kg. In addition, percent milling loss of Zn did not differ among rice varieties (18.4 to 22.9%) but it was found higher in the rainy (22.7%) and summer season (25.4%) than in the cool season (14%). In addition, the depression of grain of Zn during milling differed among cropping season, it was found higher loss of Zn the cool season than in the rainy and summer season (Table 2.24).

Following the Zn concentration results, the Zn contents in brown and white rice of the four varieties were highest in the cool season (*P<0.05*) (Table 2.25). In brown rice, SPR1, CNT1 and PTT1 had about the same Zn content in the rainy and summer seasons (0.43 - 0.48 µg/grain). An exception was RD21 which had more Zn than the other three varieties (0.55 µg/grain in the rainy and 0.53 µg/grain in the summer). In white rice, SPR1, PTT1 and RD21 had equal Zn content in the rainy and summer seasons, but lower than that in the cool season (Table 2.26). Whereas, CNT1 had the highest Zn content in the cool season followed by the rainy and summer seasons, respectively. Overall, Zn content in white rice ranged from 0.27 to 0.53 µg/grain.

Table 2.22 The Zn concentration in brown rice of 4 rice varieties grown in rainy, cool and summer seasons.

Variety	Zn concentration (mg/kg)			Mean
	Rainy	Cool	Summer	
SPR1	21.0 Ab	28.9 Ba	23.1 Ab	24.3
CNT1	22.2 Ab	35.1 Aa	22.3 Ab	26.5
PTT1	22.8 Ab	38.2 Aa	24.7 Ab	28.6
RD21	20.7 Ac	26.1 Ba	23.0 Abc	23.3
Mean	21.7	32.1	23.3	
	Variety	Season	Variety x Season	
F-test	**	***	*	
$LSD_{0.05}$	3.0	2.6	5.2	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.23 The Zn concentration in white rice of 4 rice varieties when grown in rainy, cool and summer season

Variety	Zn concentration (mg/kg)			Mean
	Rainy	Cool	Summer	
SPR1	16.0 Bb	21.2 Da	17.6 Bb	18.3
CNT1	18.3 Ab	30.2 Ba	16.1 Bc	21.5
PTT1	18.2 Ab	32.6 Aa	19.5 Ab	23.4
RD21	14.6 Bb	24.2 Ca	16.2 Bb	18.3
Mean	16.8	27.1	17.4	
	Variety	Season	Variety x Season	
F-test	***	***	**	
$LSD_{0.05}$	1.1	0.93	1.86	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.24 The milling loss of Zn of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	Milling loss of Zn (%)			Mean
	Rainy	Cool	Summer	
SPR1	23.7	21.6	23.4	22.9
CNT1	17.4	13.9	27.7	19.6
PTT1	20.2	14.0	21.0	18.4
RD21	29.6	7.0	29.6	22.0
mean	22.7 a	14.1 b	25.4 a	
	Variety	Season	Variety x Season	
F-test	ns	**	ns	
$LSD_{.05}$		6.3		

The lowercase letter is used for comparison between columns, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.25 The Zn content in brown rice of 4 rice varieties when grown in rainy, cool and summer season

Variety	Zn content (μg/grain)			Mean
	Rainy	Cool	Summer	
SPR1	0.45 Bab	0.52 Ba	0.43 Bb	0.47
CNT1	0.46 Bb	0.69 Aa	0.43 Bb	0.53
PTT1	0.48 ABb	0.67 Aa	0.43 Bb	0.53
RD21	0.55 Aab	0.62 Aa	0.53 Ab	0.57
Mean	0.48	0.63	0.45	
	Variety	Season	Variety x Season	
F-test	**	***	*	
$LSD_{0.05}$	0.10	0.04	0.09	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.26 The Zn content in white rice of 4 rice varieties when grown in rainy, cool and summer season

Variety	Zn content (μg/grain)			Mean
	Rainy	Cool	Summer	
SPR1	0.30 Bb	0.34 Ca	0.28 BCb	0.31
CNT1	0.34 Ab	0.51 Aa	0.27 Cc	0.37
PTT1	0.32 ABb	0.53 Aa	0.31 ABb	0.39
RD21	0.34 Ab	0.49 Ba	0.32 Ab	0.39
Mean	0.33	0.47	0.30	
	Variety	Season	Variety x Season	
F-test	***	***	***	
$LSD_{0.05}$	0.02	0.02	0.04	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

4) Iron in rice grain

The concentration of Fe in brown and rice was significantly affected by rice variety and season ($P< 0.01$) (Table 2.27) and there was also a significant variety x season interaction. The concentration of Fe was greater in the summer than in the rainy and cool seasons. In general, SPR1, CNT1 and RD21 (10.5, 9.1 and 9.7 mg/kg) had higher Fe concentration in the summer than in the rainy and cool seasons which were not different from each other. The remaining variety, PTT1 had equal Fe concentrations in the cool and summer seasons and both were higher than that in the rainy season.

Iron concentration in white rice was affected by rice variety and season (Table 2.28). Iron concentration was highest in CNT1 (3.27 mg/kg) followed by PTT1 (3.27 mg/kg), SPR1 (2.96 mg/kg) and RD21 (2.79 mg/kg), respectively. The Fe concentration in the cool season was higher than in the summer and rainy seasons, respectively. The depression in grain Fe concentration on milling differed among rice varieties and was affected by cropping season (Table 2.29). SPR1 had highest loss of Fe in milling (66.8%) followed by PTT1 (62.8%) and RD21 (67.6%) which was similarly and CNT (58.0%), respectively. In addition, rice in rainy and summer seasons had higher loss of Fe concentration in milling than in the cool season.

The Fe content in brown rice was significant different among variety, season and variety x season interactions in (*P<0.01*) (Table 2.30). Generally, the Fe content in brown rice of four varieties was highest in the cool season. SPR1 and RD21 had higher Fe content in summer (0.19 and 0.22 µg/grain, respectively) than in the rainy and cool seasons which had about the same Fe content at 0.17 µg/grain. While Fe content of CNT1 and PTT1 was not different among cropping. Iron content in white rice was different among varieties and season (Table 2.31). CNT1 and RD21 had equal Fe content at 0.06 µg/grain but higher than SPR1 and RD21. The Fe content in the rainy and summer seasons was equal but lower than that in the cool season.

Table 2.27 The Fe concentration in brown rice of 4 rice varieties grown in rainy, cool and summer seasons.

Variety	Fe concentration (mg/kg)			Mean
	Rainy	Cool	Summer	
SPR1	8.0 Ab	8.8 Ab	10.5 Aa	9.1
CNT1	8.0 Ab	8.7 Aab	9.1 Aa	8.6
PTT1	7.6 Ab	9.6 Aa	9.4 Aa	8.8
RD21	6.3 Bb	7.0 Bb	9.7 Aa	7.6
Mean	7.4	8.5	9.7	
	Variety	Season	Variety x Season	
F-test	***	***	**	
$LSD_{0.05}$	0.6	0.5	1.0	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 3.28 The Fe concentration in white rice of 4 rice varieties grown in rainy, cool and summer seasons.

Variety	Fe concentration (mg/kg)			Mean
	Rainy	Cool	Summer	
SPR1	2.7	3.8	2.5	3.0 BC
CNT1	3.2	4.2	3.5	3.6 A
PTT1	2.5	3.8	3.6	3.3 AB
RD21	2.3	3.0	3.1	2.8 C
Mean	2.7 c	3.7 a	3.2 b	
	Variety	Season	Variety x Season	
F-test	**	***	ns	
$LSD_{0.05}$	0.4	0.4		

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.29 The milling loss of Fe of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	Milling loss (%)			Mean
	Rainy	Cool	Summer	
SPR1	66.6	57.5	76.5	66.9 A
CNT1	60.6	51.8	61.6	58.0 B
PTT1	66.2	60.1	62.0	62.8 AB
RD21	63.6	56.5	67.6	62.5 AB
Mean	64.3 a	56.4 b	66.9 a	
	Variety	Season	Variety x Season	
F-test	*	**	ns	
$LSD_{0.05}$	5.2	4.5		

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.30 The Fe content in brown rice of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	Fe content (µg/grain)			Mean
	Rainy	Cool	Summer	
SPR1	0.17 Ab	0.16 Ab	0.19 Ba	0.17
CNT1	0.17 Aa	0.17 Aa	0.18 BCa	0.17
PTT1	0.15 Aa	0.17 Aa	0.17 Ca	0.16
RD21	0.17 Ab	0.17 Ab	0.22 Aa	0.19
Mean	0.16 b	0.17	0.19	
	Variety	Season	Variety x Season	
F-test	**	**	**	
$LSD_{0.05}$	0.01	0.01	0.02	

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

Table 2.31 The Fe content in brown rice of 4 rice varieties when grown in rainy, cool and summer seasons.

Variety	Fe content (µg/grain)			Mean
	Rainy	Cool	Summer	
SPR1	0.05	0.06	0.04	0.05 B
CNT1	0.06	0.07	0.06	0.06 A
PTT1	0.04	0.06	0.06	0.05 B
RD21	0.05	0.06	0.06	0.06 A
Mean	0.05 b	0.06 a	0.05 b	
	Variety	Season	Variety x Season	
F-test	*	**	ns	
$LSD_{0.05}$	0.01	0.01		

The lowercase and uppercase letters are used for comparison between columns and rows, respectively. The different letters are significantly different by LSD (P<0.05).

2.4 Discussion

This present study clearly showed the effect of cropping season on rice growth, yield and grain quality. For growth, tiller numbers and panicle numbers of all rice varieties were found highest in the cool season. Yoshida (1981) suggested that under low temperature and low light temperature, rice may produce more tillers. This results supported by Matsuo and Hoshihawa (1993) who noted number of tillers was greater under low temperature than under high temperature. In addition, it might due to the acclimation of rice plant to survive in the terribly condition. By contrast, total grain yield in the cool season was the lowest due to lowest filled grain number, although, it did not have interaction among genotype by cropping season. It has been reported that the day temperatures below 20 ºC and above 35 ºC (Yoshida, 1981) and night temperatures below 15 ◦C (Rutger and Peterson, 1979) and above 22 ◦C (Peng *et al.*, 2004) could affect the rice crop depending on genotype, duration and intensity of the temperature, and physiological status of the plant. In this present study, the cool season was found to have lower yield than in the rainy and summer seasons. Low temperature (below 20 ºC) during flowering stage induces male sterility (Satake and Hayase, 1970; Shimono *et al.*, 2007) by inducing a shortage of pollen for fertilization which can cause of decreasing fertilized grain. Moreover, the results of the present study shown decreasing number of the standard grain weight in each varieties, by contrast, unfilled grain and partially filled grain were increased. The individual weight of rice grain of all varieties had low frequency in the cool season. Wada *et al*. (1972) noted that lower light intensity increased the level of the sterility induced by low temperature, although the effect of radiation on sterility was smaller than the direct effects of temperature. Rice yield in the summer season was lower when compared to the rainy season, correlated to previous studies reported that high air temperature especially night time temperature affected on rice grain yield (Peng *et al.*, 2004). Yoshida (1981) reported that the expose one or two hours to high temperature during anthesis has a decisive effect on the incidence of sterility in rice, moreover high temperature is shorten grain filling duration and promote grain ripening (Oh-e *et al.*, 2007).

Chalkiness is an undesirable in milling processing because it decreases rice's value in the most of world market because of its appearance and rice grain tend to breakage in milling process. High air temperature during grain filling facilitates the formation of chalky grain (Sato and Inaba, 1973, 1976). Temporal exposure of rice plants to high temperature from 4 days after heading also induced chalky grain (Tashiro and Wardlaw, 1991). Wakamatsu *et al*. (2007) suggested that air temperature above 26 to 27 ºC during 20 days after heading induced can grain chalkiness. Chalkiness was observed in the starchy endosperm, where the development of amyloplasts was deficient (Lisle *et al.*, 2000; Tashiro and Wardlaw, 1991). An insufficient supply of nutrients to the developing endosperm (Sato and Inaba, 1976) may reduced ability to synthesise starch in the endosperm (Jiang *et al.*, 2003; Yamakawa *et al.*, 2007) and the degradation that might cause by shorten grain filling duration in high temperature stress. In this present study, in all varieties, chalky grains were found highest in the summer season that the average air temperature during grain filling rose to 37 ºC in day time and 26 ºC in night time. Moreover, the head rice yield of SPR1, CNT1 and PTT1in the summer season was lower than in the rainy season about 20-30% that might be involved with high number of chalky grains.

Nitrogen fertilizer improved head rice yield (Leesawatwong *et al.*, 2005; Perez *et al.*, 1996) by increased grain N and protein fractions in rice grain especially in peripheral region of rice grain (Leesawatwong *et al.*, 2005) that promoted the resistance to abrasive milling unless that same variety (Cagampang *et al.*, 1966). Protein fractions in rice grain normally positively correlated to grain N. The present study showed that grain N of all four varieties was lowest in the summer season and it correlated to the lower head rice yield in the summer, although the relationship between N content in both brown and white rice and head rice yield quite small (0.33* and 0.32*, data not show)

Gelatinization temperature (GT) indicates the cooking time of rice which the crystalline structure of the starch begin swell (Fitzgerald *et al.*, 2009), therefore rice with high GT requires more time to cook then the low one. Gelatinization temperature is inversely related to alkali spread value, therefore, it can be inferred that CNT1, PTT1 and RD21 had no different gelatinization temperature between the rainy and cool seasons; CNT1 had high intermediated gelatinization temperature in the rainy and cool seasons, and high gelatinization temperature in summer, PTT had intermediated gelatinization temperature in the rainy and cool seasons and high intermediate in the summer, CNT1 had low gelatinization temperature in the rainy and cool seasons and differentiated to intermediate in the summer season. While SPR1 had higher gelatinization temperature in the rainy and summer seasons than the cool season which was intermediated gelatinization temperature in the cool season and became high gelatinization temperature in the rainy and summer seasons. It could be suggested that rice grain in summer season cook more time than rice in other seasons.

It has been reported that nutrients such as Fe in rice grain was a small fraction of that in whole plant (Prom-u-thai., 2003), however, nutrients that taken up by root and transported to rice grain was effected by many factors such as climate, soil properties, amount and fertilizer form that applied to rice plant. In this present study found that the Fe in brown rice of all four varieties was high when growing rice in the summer season. In waterlogged paddy field, Fe^{3+} is reduced into more available Fe^{2+}, results in high level of Fe^{2+} concentration (Matsuo *et al.*, 1995; Ponnamperuma, 1972) for rice uptake. In addition, sunlight intensity and duration during summer season might indirectly affect Fe uptake by rice plant through increase evatranspiration consequently greater uptake Fe into rice plant and transported to rice grain. The Fe was concentrated in the rice bran fraction, however, the removal of bran fraction in polishing process removed most of Fe from rice grain resulted low Fe in white rice. The loss of Fe from brown rice after polishing is an important factor contribute the reduction of Fe concentrations in the white rice (Prom-u-thai *et al.*, 2007a). Prom-u-thai *et al*. (2007) noted that Fe partitioning among the grain husk and caryopsis, bran and endosperm might be the main resistance of Fe partitioning into the endosperm more than the total amount of Fe transported into the grain and the efficiency of Fe intercellular transport in the caryopsis might be an important factor for genotypic variation in Fe concentration of white rice. This might be the causes of no different Fe concentration in white among cropping season in each variety.

Different from grain Fe, grain N, P and Zn were found higher in the cool season than in the rainy and summer seasons. Others climate factors such as temperature, solar radiation, and precipitation during crop growth also impacted on nutrient availability in soil and the ability of rice plant to take up and utilized nutrients (Marschner, 1995). From the results, N content in rice grain which is consistent to grain protein was found greater in the cool season than in wet season and summer, respectively. It has been reported that protein content was affected by high solar radiation occur during grain development (IRRI, 1979), under tropical condition, protein content was generally lower in dry season than in wet season (Gomez and De Datta, 1975). This was supported our resulted that the N or protein in rice grain could be suppress by high solar radiation in summer while in the cool season, lower solar radiation promoted N accumulation. Moreover, temperature during grain ripening was also reported to affected protein content by vary with varietal type. Resurreccion *et al*. (1977) reported that protein content in japonica rice, Fujisaka 5 increased with increasing mean air temperature while indica rice, IR20 was not affected.

Soil temperature can directly affect plant nutrient acquisition by changing root respiration. In general, the nutrient absorption rate becomes higher when temperature rise then reaches a peak at the certain temperature then lowers at higher temperature; the temperature at which the nutrient absorption rate becomes highest varies among plant species (Matsuo *et al.*, 1995). Low temperatures can also decrease root respiratory rate and retard nutrient uptake. It has been reported that high temperature retard the absorption of nutrient such as N and P by rice plant (Yoshida, 1981). In this study, the concentrations of N, P and Zn in rice grain were greater when growing in the cool season. It was possible that the temperature in the cool season of this present study did not lower than the critical temperature for nutrient absorption of *Indica* Thai rice root. From the climate data, day time temperature in the cool season during the grain developing stage was 31.1/17.1 ºC (day/night) that above the critical low temperature for rice growth reported by Yoshida (1981) which was 15 to 22 ºC in the same growth stages. In addition, the availability of nutrients in soil solution might be higher in the cool season than in the rainy and summer. For example, in summer and rainy season, N can be loss by denitrification process that might be stimulated in high air temperature condition and abundant water from raining.

The dilution effects may explain the higher accumulation of nutrients with low yield. In this present study, however, contents of N, P and Zn were still higher than rice of other seasons, therefore, it could be suggested that the dilution effect might be small than the nutrient uptake efficiency of the rice.

In conclusion, cropping season showed affected on rice grain yield and quality, the different of climate factor among season such as temperature play the important role to specify grain yield and quality. Rice in the cool season produced lower grain yield than in the rainy and summer, however, the nutritional quality such as N, P and Zn in rice grain was higher when grown rice in the cool. However, it would be useful if could be improved rice grain quality in every cropping season, especially in the summer that many factors especially air temperature which harm rice plant. So the improvement of grain quality in the summer season will be exploring in Chapter 4.