Chapter 3

Nitrogen fertilization and time of harvest on rice milling quality

3.1 Introduction

Quality criteria used by rice buyers to determine price were discussed in (Chapter 2). Some of these criteria are likely to be influenced by N supply such as head rice yield (Nangju and De Datta, 1970; Seetanum and De Datta, 1973; Jongkaewwattana *et al.*, 1993). This aspect will be explored in this chapter. Milling quality is defined as the head rice recovery after milling (Brorsen *et al.*, 1984; Jongkaewwattana *et al.*, 1993). Head rice is regularly used to determine rough rice prices in world rice markets. Many studies have been reported to investigate factors affecting milling quality, including genetic (Jongkaewwattana *et al.*, 1993; Nangju and De Datta, 1970), field management (Jongkaewwattana, 1990; Yoshida, 1981) and environmental conditions during the growing period (Henderson, 1954; Yoshida and Hara, 1976).

The timing of N application and grain moisture content at harvest are two field management factors, which can impact on rice yield and milling quality. Applying N fertilizer close to booting stage can enhance photosynthesis during the grain filling period, leading to an increase in the percent of head rice (Japanese Food Agency, 1998). Wopereis-Pura *et al.* (2002) showed that rice grain yield increased with the addition of 30 kg N ha^{-1} at booting by about 0.4 and 1.0 t ha^{-1}, respectively, during the wet and dry seasons. Furthermore, Seetanun and De Datta (1973) indicated that N fertilizer topdressing at flowering increased the percent head rice of IR8, IR20, RD1 and C4-63 and associated positively with high protein content.

Grain moisture content at harvest is considered importantly for head rice recovery. Optimum stage for harvest for maximum grain yield and high percent head rice was 28-34 days after flowering in the dry season and 32-38 days after flowering in the wet season were reported by Nangju and De Datta (1970). Huysmans (1965) and Mores *et al.* (1968) reported that harvesting either immature or over-mature crop decreases the grain yield and milling quality of rice. Dilday (1989) showed that head rice recovery decreased significantly if the moisture content of the grain at harvest decreased. Delay harvesting is the common stresses that affecting milling yield evaluation. Delaying the harvest for 2 weeks with 20-25% grain moisture content, reduced head rice yield about 18% for 16 tested varieties (Berrio and Cuevas-Perez, 1989). This implied that optimum time for harvesting is quite depend on variety and season. However, understanding of N fertilizer application which associate with rice breakage is still not clear in Thai commercial rice. The objectives of this study was to determine the effects of head rice N concentration and grain moisture content at harvest on milling quality of Thai commercial rice varieties.

3.2 Materials and methods

Two paddy rice field experiments, split-split plot in RCB with three replications, were undertaken in the Multiple Cropping Center Experimental Station, Chiang Mai University, Thailand. Nitrogen treatments were assigned to the main plots, rice varieties to sub plots and harvest timing to sub-sub plots.

3.2.1 Experiment 1

Two rice varieties, Khlong Luang 1 (KLG1) and Chainat 1 (CNT1) were grown in the field with five N treatments and three harvests in three replications. The five N treatments were no applied N (0:0:0), applying 60 kg N ha^{-1} at transplanting (60:0:0), at panicle initiation (PI) (0:60:0), at flowering (0:0:60) and 20 kg N ha^{-1} each at transplanting, panicle initiation and flowering (20:20:20). The grain was harvested at three dates, 20, 30 and 40 days after flowering (DAF). The experiment was carried out at Multiple Cropping Center Experiment Station, Chiang Mai University, in the dry seasons 2000. One month old seedlings were transplanted at the spacing of 0.25 x 0.25 m, with three seedlings per hill.

At PI and flowering, the number of tillers $hill^{-1}$ and chlorophyll concentration of the youngest emerged blade (YEB) of five main stem in each plot were measured by a chlorophyll meter, SPAD-502 (Soil-Plant Analysis Development Section, Minonta Camera Co., Osaka, Japan) (Peng *et al*., 1996). The measured YEB and flag leaves were collected for determination of N concentration by Kjeldahl method. At 20, 30 and 40 DAF, 1 m^2 area was harvested from each plot to measure grain yield. Subsamples of 100 g of each harvesting date was milled in order to examine percent unbroken rice recovery and further analyzed for head rice N concentration.

3.2.1 Experiment 2

The experiment was conducted in the wet season 2001 at the Multiple Cropping Center Experiment Station, Chiang Mai University. Four varieties, Khao Dawk Mali 105 (KDML105), Pathum Thani 1 (PTT1), Khlong Luang 1 and Chainat 1, were planted in a split plot design with three replications. Nitrogen treatments were the main plots and varieties were sub plots. Nitrogen treatments were nil (0:0), 60 kg N ha^{-1} at PI (60:0), at flowering (0:60), 30 kg N ha^{-1} each at PI and flowering (30:30), 120 kg N ha^{-1} at PI (120:0), at flowering (0:120) and 60 kg N ha^{-1} each at PI and flowering (60:60). One month old seedlings were transplanted at the spacing of 0.25 x 0.25 m, with three seedlings per hill, in 1.5 x 5 m sub plot.

Plant samples of 0.75 m^2 were harvested weekly beginning at approximately 25 to 30% wb grain moisture content (Riceter series J999 grain moisture tester, Kett Electric Laborator). The final harvest was made about tree weeks after first harvesting date. Samples were threshed by hand and weighed for rough grain yield and dried at room temperature until containing 14% wb. Subsamples (100 g) were dehulled (sheller series P-1, Ngek Seng Huat LTD., Thailand) and polished for 30 seconds (miller series K-1, Ngek Seng Huat LTD., Thailand). Then, milled grain was classified into head (whole grain) and broken rice. All grain types were weighed. The percent milling was calculated by percentage of milled rice per rough rice weight and percent unbroken rice was calculated by percentage of head rice per milled yield weight. The milled rice was analyzed for head rice N concentration.

3.2.3 Statistical analysis

Data were analyzed by analysis of variance (ANOVA), linear and quadratic regression. Significantly different among means were made at $p < 0.05$ by using the least significant difference (LSD). All of statistical analyses were done by using commercial software (Statistix V. 7.1, Analytical Software, Inc.).

3.3 Results

3.3.1 Experiment 1

The interaction effect of N and variety on leaf chlorophyll concentration, measured as SPAD value, was not significant either at PI or flowering stages. At PI, the 60 kg N ha^{-1} applied at transplant, PI or flowering had no effect on the SPAD value (Table 3.1). At flowering, the SPAD values were significantly increased with 0:60:0 and 20:20:20, but not with 60:0:0 or 0:0:60. The chlorophyll concentration (SPAD value) in the YEB at panicle initiation and flowering stages were positive and associated significantly with leaf N concentration in both rice varieties (Figure 3.1). SPAD values increased with increasing leaf N concentration. At PI, it seemed that association between leaf N concentration and SPAD values was greater than flowering stage.

Nitrogen and variety interaction effects on the number of tillers $hill^{-1}$ were not significant (Table 3.2). Nitrogen treatment was not significantly affected number of tillers $hill^{-1}$ at flowering but not in panicle initiation. Applying N fertilizer at 0:60:0 significantly increased number of tillers $hill^{-1}$ and slightly increase at 20:20:20, but not at 60:0:0 or 0:0:60.

The effect of N treatment on grain yield was significantly different between the varieties (Table 3.3). Grain yield of CNT1 increased when applied 60:0:0 or 0:60:0 and even more so with 20:20:20. By contrast, grain yield of KLG1 was not affected by N treatment. However, harvesting times had significantly effect on grain yield in both varieties. For CNT1, high grain yields received from 30 and 40 DAF while KLG1 performed well at 20 and 40 DAF.

Table 3.1 Effect of N treatment on SPAD values of YEB at panicle initiation and flowering stages of two rice varieties

		SPAD values					
Growth stage	Variety	0:0:0	60:0:0	0:60:0	0:0:60	20:20:20	Mean
Panicle initiation							
	KLG1	32.8	34.1	36.3	34.2	33.3	34.1b
	CNT1	27.8	27.6	25.8	25.9	24.9	26.4a
	Mean	30.3	30.8	31.1	30.1	29.1	
Flowering							
	KLG1	39.4	39.0	41.6	39.5	41.1	40.1a
	CNT1	29.9	32.6	36.2	28.4	34.3	32.3b
	Mean	34.6A	35.8AB	38.9B	33.9A	37.7B	
$LSD_{0.05}$							
	Panicle initiation	N^{ns}		V*** = 1.3		$N \times V^{ns}$	
	Flowering	N ** = 2.8		V*** = 1.8		$N \times V^{ns}$	

† The lower case and capital letters are used for comparison between rows and columns, respectively. The different letters are significantly different by $LSD_{(P < 0.05)}$.

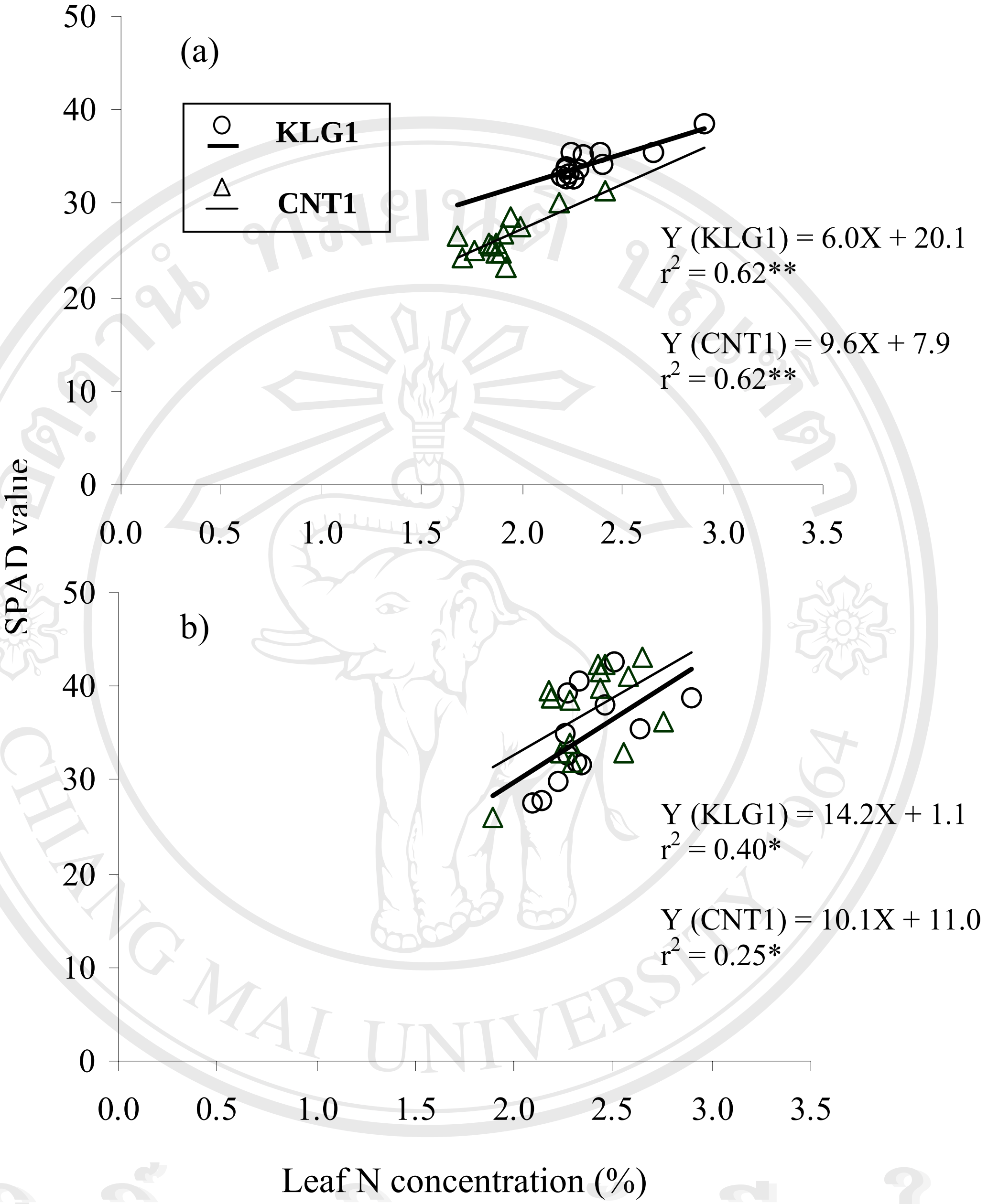

Figure 3.1 Relationship between SPAD values and leaf N concentration (%) of YEB at panicle initiation (a) and flowering (b) stages.

Table 3.2 Effect of N treatment on number of tillers hill^{-1} of two rice varieties at panicle initiation and flowering stages

Growth stage	Variety	Number of tillers hill^{-1}					Mean
		0:0:0	60:0:0	0:60:0	0:0:60	20:20:20	
Panicle initiation							
	KLG1	14.6	17.8	17.9	16.3	17.1	16.7b†
	CNT1	26.0	27.0	24.1	27.3	29.1	26.7a
	Mean	20.3	22.4	21.0	21.8	23.1	
Flowering							
	KLG1	13.7	18.1	24.0	15.5	16.8	17.6b
	CNT1	19.5	21.9	27.8	23.2	24.3	23.4a
	Mean	16.6A	20.0A	25.9B	19.4A	20.5A	
LSD $_{0.05}$							
	Panicle initiation		N ^{ns}		V*** = 2.5	N x V ^{ns}	
	Flowering		N ** = 4.0		V*** = 2.5	N x V ^{ns}	

† The lower case and capital letters are used for comparison between rows and columns, respectively. The different letters are significantly different by LSD $_{(P < 0.05)}$.

There was a highly significant interaction between the effect of nitrogen and variety on head rice N concentration (Table 3.4). When the N fertilizer was applied at 0:60:0, 0:0:60 and 20:20:20, head rice N concentration was increased in both varieties. The strongest effect of N on head rice N concentration was found with 0:0:60 in KLG1.

There was a significant interaction between the effect of N and variety on percent unbroken rice (Table 3.5). Percent unbroken rice of KLG1 was increased significantly when applied at 20:20:20 and even more at 0:0:60, but not at 60:0:0 or 0:60:0. On the other hand, in CNT1 the N fertilizer increased percent unbroken rice when it was applied as 20:20:20 and slightly less with 0:0:60. The effect of harvest time on percent unbroken rice was significantly different between the two rice varieties. When harvested at 20 DAF, the percent unbroken rice in KLG1 was higher than at 30 DAF but it was significantly lower at 40 DAF. Harvesting at 20 DAF, percent unbroken rice of CNT1 was one half of 30 and 40 DAF. There were an interaction among N and harvesting time on percent unbroken rice. In all N treatments, except 60:0:0, the highest percent unbroken rice recovery was obtained when harvested at 30 DAF.

Milled rice N concentration of KLG1 was significantly correlated with percent unbroken rice at three harvests (Figure 3.2). Percent unbroken rice was positively increased with increasing head rice N concentration in KLG1, especially at 40 DAF. Head rice N concentration of CNT1 was correlated with percent unbroken rice only at 40 DAF.

Table 3.3 Effect of N treatment on grain yield (g m^{-2}) of two rice varieties at 3 harvests

		Grain yield (g m^{-2})					
Variety	Harvest	0:0:0	60:0:0	0:60:0	0:0:60	20:20:20	Mean
KLG1	20 DAF	269	242	316	329	295	290c
	30 DAF	267	246	240	204	295	250ca
	40 DAF	250	279	270	271	279	270c
	Mean	262bA†	255bA	275bA	268bA	290bA	
CNT1	20 DAF	334	401	360	323	371	358b
	30 DAF	368	401	427	368	456	404a
	40 DAF	318	459	442	379	473	414a
	Mean	340aA	420aB	410aB	357aAB	433aB	
	N	V	H	N x V	N x H	V x H	N x V x H
F-test	ns	***	ns	*	ns	*	ns
LSD $_{0.05}$		31		69		54	

† The lower case and capital letters are used for comparison between rows and columns, respectively. The different letters are significantly different by LSD $_{(P < 0.05)}$.

Table 3.4 Effect of N treatment on head rice N concentration (%) of two rice varieties at 3 harvests

Variety	Harvest	Head rice N concentration (%)					Mean
		0:0:0	60:0:0	0:60:0	0:0:60	20:20:20	
KLG1	20 DAF	1.23	1.23	1.25	1.75	1.48	1.39
	30 DAF	1.28	1.21	1.38	1.80	1.44	1.42
	40 DAF	1.25	1.22	1.43	1.77	1.48	1.43
	Mean	1.25aC	1.22aC	1.35aBC	1.77aA	1.47aB	
CNT1	20 DAF	0.96	0.96	1.21	1.27	1.16	1.11
	30 DAF	0.94	0.97	1.20	1.39	1.21	1.14
	40 DAF	0.93	1.02	1.18	1.30	1.23	1.13
	Mean	0.94bB	0.98bB	1.20bA	1.32bA	1.20bA	
	N	V	H	N x V	N x H	V x H	N x V x H
F-test	***	***	ns	**	ns	ns	ns
$LSD_{0.05}$	0.08	0.05		0.12			

† The lower case and capital letters are used for comparison between rows and columns, respectively. The different letters are significantly different by $LSD_{(P < 0.05)}$.

Table 3.5 Effect of N treatment on percent unbroken rice of two rice varieties at 3 harvests

Variety	Harvest	Percent unbroken rice						
		0:0:0	60:0:0	0:60:0	0:0:60	20:20:20	Mean	Mean
KLG1	20 DAF	61.8	70.5	64.7	74.2	67.3	67.7a	
	30 DAF	49.5	42.0	59.8	67.0	59.1	55.5b	
	40 DAF	35.9	32.3	40.9	57.4	42.2	41.8c	
	Mean	49.1aA[†]	48.3bA	55.1aAB	66.2aC	56.2aB		55.0
CNT1	20 DAF	28.4	42.5	37.0	32.9	41.8	36.6c	
	30 DAF	64.7	63.5	64.8	68.1	72.5	66.7a	
	40 DAF	59.3	59.3	69.6	72.5	61.6	64.5a	
	Mean	50.8aA	55.1aAB	57.1aAB	57.8bAB	58.7aB		55.9
	20 DAF	45.1bA	56.5aB	50.9bAB	53.6bAB	54.6bB		52.1
	30 DAF	57.1aAB	52.8abA	62.3aB	67.5aB	65.8aB		61.1
	40 DAF	47.6bAB	45.8bA	55.2abB	65.0aC	51.9bAB		53.1
Mean		49.9	51.7	56.1	62.0	57.4		
	N	V	H	N x V	N x H	V x H	N x V x H	
F-test	***	ns	***	*	*	***	ns	
LSD $_{0.05}$	5.3	-	4.1	7.5	9.2	5.8	-	

[†] The lower case and capital letters are used for comparison between rows and columns, respectively. The different letters are significantly different by LSD $_{(P < 0.05)}$.

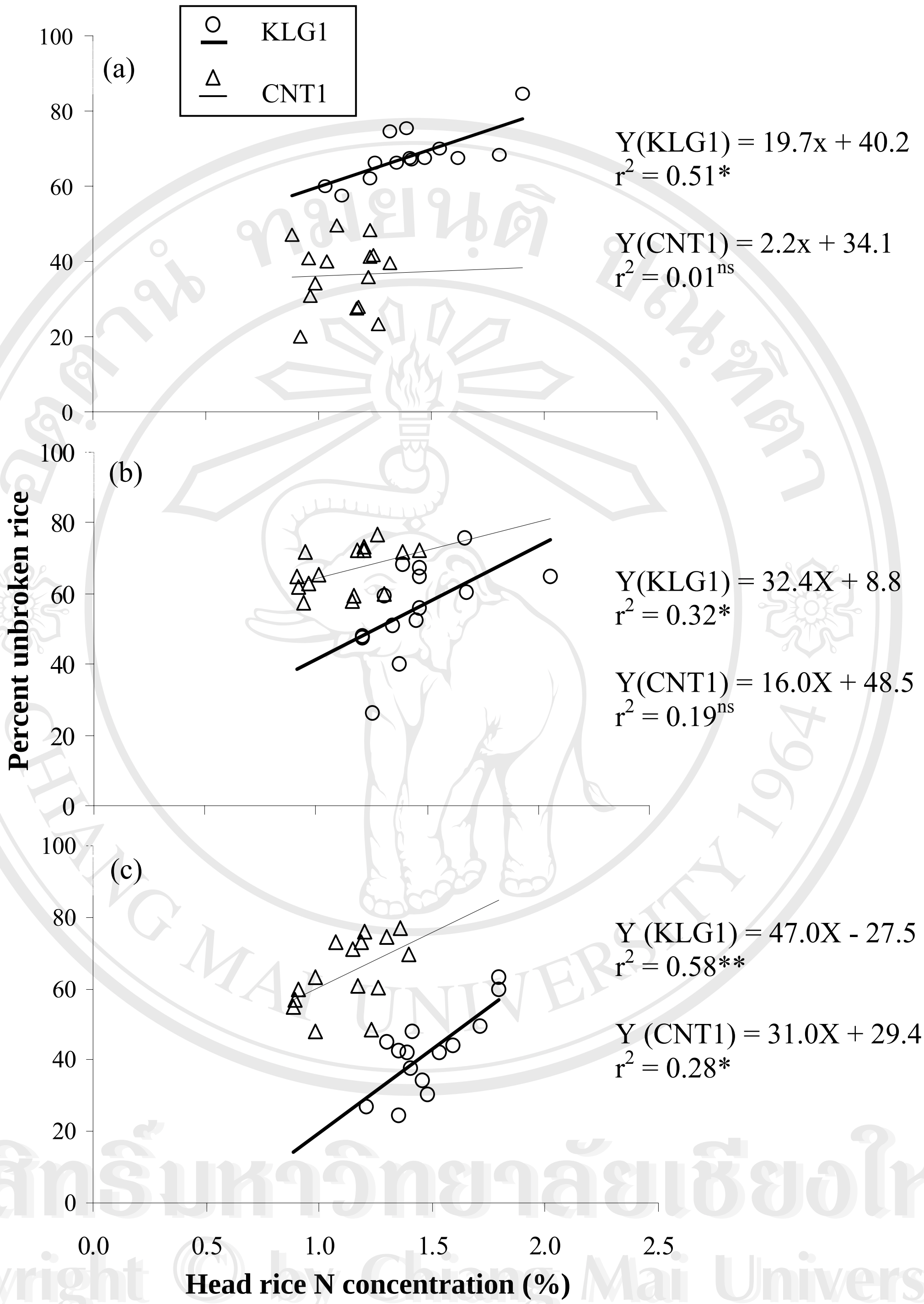

Figure 3.2 Relationship between head rice N concentration (%) and percent unbroken rice at 20 (a), 30 (b) and 40 DAF (c) of two rice varieties.

3.3.2 Experiment 2

Grain yield was not affected by N treatments but it varied between varieties and grain moisture content at harvest (Table 3.6, 3.7). Delaying harvest, at low grain moisture content, increased grain yield in all varieties compared to that of the early harvest at high grain moisture content, but time for harvest was different among varieties. The grain yield was higher in CNT1 than PTT1, KLG1 and KDML105, respectively.

Nitrogen fertilizer application increased head rice N concentration (Figure 3.3). Applying 60 kg N ha^{-1} increased head rice N concentration from 1.4 to 2.0% and even more at 120 kg N ha^{-1}, from 1.4 to 2.2%, in all varieties compared to the no N treatment. Applying N fertilizer at PI and split N application increased head rice N concentration but the maximum effect was achieved by N at flowering. The highest head rice N concentration was obtain using 120 kg N ha^{-1} at flowering, where the grain N concentration was 2.3 % N compared to 1.3% N in the unfertilized rice. Except for KDML105, head rice N concentration was positively correlated with percent unbroken rice (Figure 3.4). Increasing the head rice N concentration of CNT1 from 1.4 to 2.1% increased the head rice per milled rice from 78 to 88%. However, any further increase in grain N did not increase the percent unbroken rice. By contrast, in PTT1 and CNT1, increasing the head rice N concentration above 2.1% was effective in promoting further increases in percent unbroken rice. Percent unbroken rice of PTT1 was insensitive to increasing when head rice N concentration below 1.7%.

Table 3.6 Analysis of variance of head rice N concentration, grain yield, percent unbroken rice and percent milling of KDML105, KLG1, PTT1 and CNT1 in the wet season 2001

Variable[†]	df	Head rice N concentration	Grain yield ($g\ m^{-2}$)	Percent unbroken rice	Percent milling
N	6	***	ns	***	*
V	3	***	***	***	***
H	3	***	***	***	***
N x V	18	ns	ns	*	ns
N x H	18	ns	ns	**	ns
V x H	9	***	***	***	***
N x V x H	54	ns	ns	ns	ns

[†] N = nitrogen treatment, V = variety, H = harvest time

ns Indicates not significant, *, ** and *** Indicates significance at P < 0.05, 0.01 and 0.001, respectively.

Table 3.7 Effect of N treatment and time of harvest on grain yield (g m^{-2}) of four Thai rice varieties

Variety	Harvest[†]	Grain yield (g m^{-2})							Mean
		0:0	60:0	0:60	30:30	120:0	0:120	60:60	
KDML 105	1	221	245	280	273	222	230	247	245i[‡]
	2	224	293	257	296	287	244	243	263hi
	3	259	322	299	324	285	257	274	288fg
	4	256	321	357	319	303	258	287	300efg
	Mean	240	295	298	303	274	247	263	
KLG1	1	280	246	248	257	236	251	271	256i
	2	313	323	269	283	226	230	316	280gh
	3	354	329	320	309	247	270	308	305ef
	4	379	392	331	386	349	377	344	365b
	Mean	332	323	292	309	264	282	310	
PTT1	1	276	226	209	291	285	270	192	250i
	2	319	324	280	358	346	290	321	320de
	3	311	335	303	327	321	302	261	309ef
	4	383	386	348	405	349	297	320	355bc
	Mean	322	318	285	345	325	290	274	
CNT1	1	294	264	262	353	294	293	299	294fg
	2	329	290	290	298	269	259	310	292fg
	3	339	311	346	370	364	333	329	342cd
	4	410	363	424	391	405	359	401	393a
	Mean	343	307	331	353	333	311	335	

	N	V	H	N x V	N x H	V x H	N x V x H
F-test	ns	***	***	ns	ns	***	ns
$LSD_{0.05}$	-	24	11	-	-	22	-

[†] Harvest 1 was started at grain moister about 25-30% wb and then harvested weekly until harvest 4.

[‡] Mean value followed with the different letters indicated significantly different by LSD $_{(P < 0.05)}$.

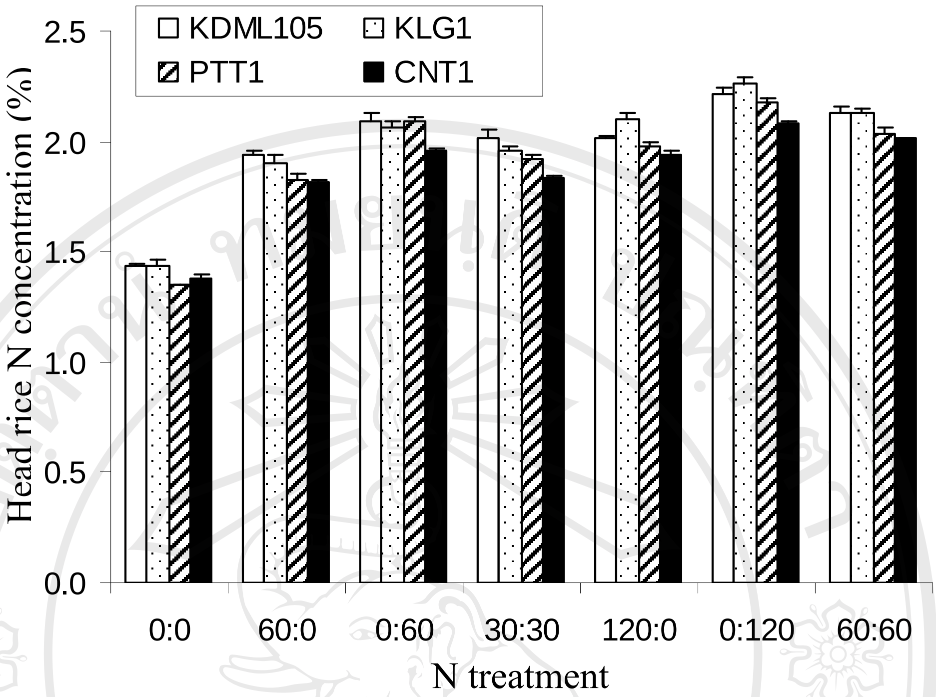

Figure 3.3 Effect of N treatment on head rice N concentration (%) of KDML105, KLG1, PTT1 and CNT1 varieties in the wet season 2001. Vertical bars represent mean and standard errors for comparing between N treatments. The N treatments that nil (0:0); 60 kg N ha^{-1} at PI (60:0), or at flowering (0:60) or split (30:30); 120 kg N ha^{-1} at PI (120:0), at flowering (0:120) or split (60:60).

Percent milling ranged from about 50% in KLG1 to 55% in CNT1. Head rice N concentration and grain moisture content at harvest was correlated with percent unbroken rice of all varieties (equation 3.1).

$$PUB = 56.40 + 7.13HN^{***} + 0.70GM^{***} \quad (r = 0.55^{***}) \quad (3.1)$$

PUB = Percent unbroken rice GM = Grain moisture content at harvest

HN = Head rice N concentration

Percent unbroken rice exhibited a quadratic relationship with grain moisture content at harvest in all varieties, but they had different optimum grain moisture contents (Figure 3.5). The optimum grain moisture contents at harvest of KLG1, PTT1, KDML105 and CNT1 were 26, 25, 23 and 20%, respectively. The maximum percent unbroken rice was about 95% in KDML105 and 90% in KLG1, PTT1 and CNT1. Percent unbroken rice in KDML105 and CNT1 were more sensitive to grain moisture content at harvest than KLG1 and PTT1. Percent milling was affected by grain moisture content at harvest. The optimum grain moisture content at harvest for maximum percent milling of all varieties was 23 to 26%. Furthermore, percent milling in PTT1 was most sensitive to grain moisture content at harvest. KLG1 and KDML105 were moderate sensitive and CNT1 unresponsive. The maximum percent milling was about 53% in KLG1, KDML105 and PTT1, but CNT1 it was about 55%.

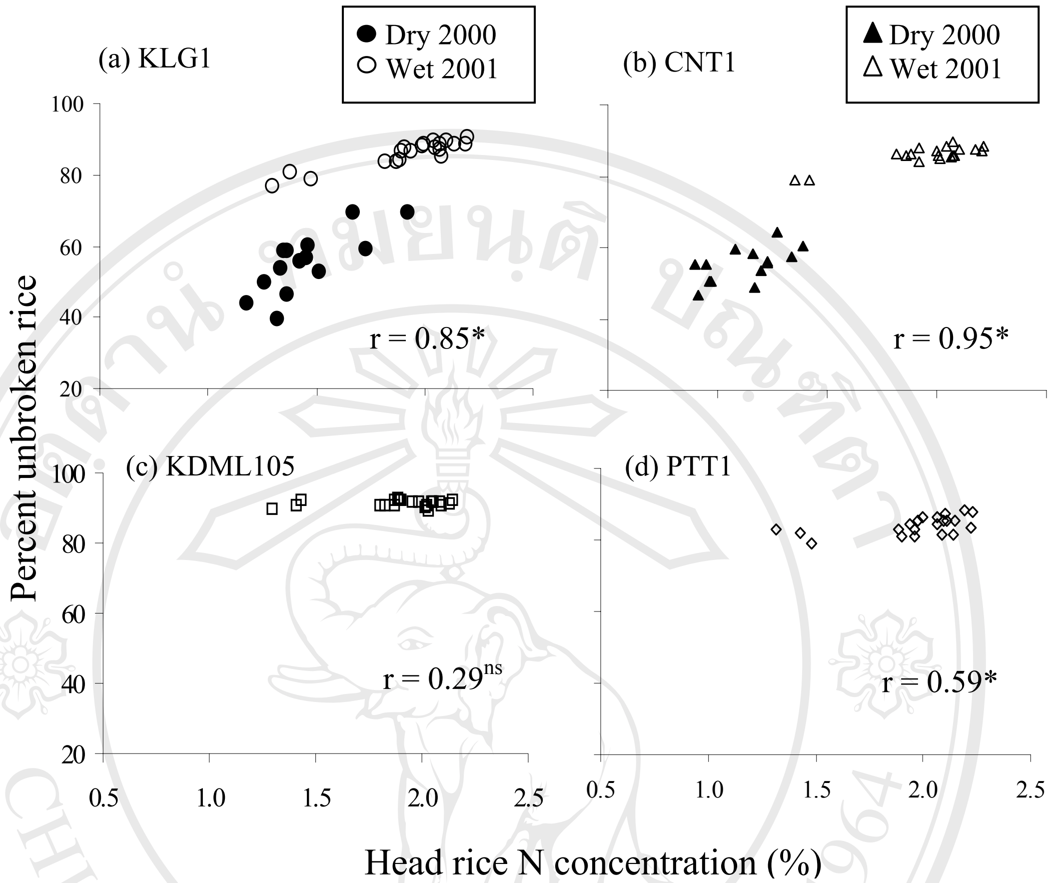

Figure 3.4 Relationship between head rice N concentration and percent unbroken rice of KLG1 (a) and CNT1 (b) varieties in the dry season 2000 and wet season 2001, and KDML105 (c) and PTT1 (d) varieties in the wet season 2001.

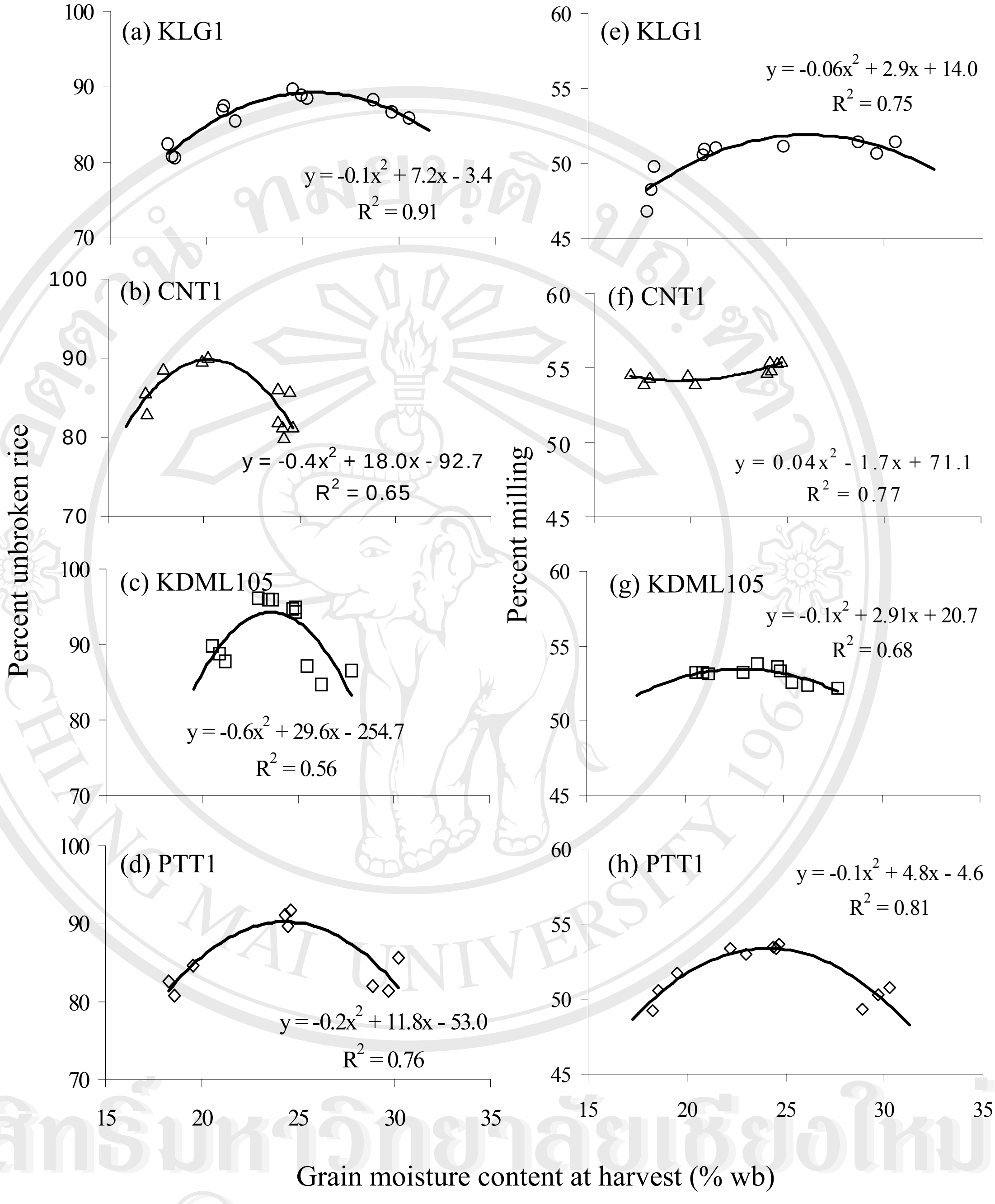

Figure 3.5 Relationship between grain moisture content at harvest and percent unbroken rice (left) and percent milling (right) of KLG1 (a, e), CNT1 (b, f), KDML105 (c, g) and PTT1 (d, h) varieties in the wet season 2001.

3.4 Discussion

Applying N fertilizer increased grain yield of CNT1 but not for KLG1 in 2000 experiment. In 2001 experiment, N rates from 0 to 120 kg N ha^{-1} had no effect on grain yield. By contrast, N had appreciable effects on head rice N concentration and milling quality. For the same total N fertilizer level, applying N at PI and split N increased grain N concentration but late applied N at flowering in both experiments was the most effective treatment for increasing head rice N concentration. Even 20 kg N ha^{-1} applied at flowering appeared to increase head rice N concentration. Japanese Food Agency (1998) reported that applying N fertilizer around booting stage to enhance photosynthesis rate during the grain filling period, led to decrease the immature grain. Nitrogen applied during early reproductive growth is generally more effectively utilized in the grain than N applied during the vegetative lag phase (Sims *et al.*, 1967; Wells and Johnston, 1970; Yoshida, 1981).

Increasing head rice N concentration decreased grain breakage in three varieties but not in KDML105. Nangju and De Datta (1970) and del Rosario *et al.* (1968) found that head rice increased with increasing N fertilizer up to a certain level. They suggested that the effect of N on decreasing breakage might have been because protein bodies occupy the space between unpacked starch granules and may function as a binder for rice starch. In wheat, several studies suggest that the structure of the protein matrix surrounding starch granules (Barlow *et al.*, 1973; Stenvert and Kingswood, 1977) and the interface between the protein matrix and starch granules (Greenblatt *et al.*, 1995; Greenwell and Schofield, 1986) are the physico-chemical base of endosperm hardness. This effect of N can be postulated for KLG1, PTT1 and CNT1 as N fertilizer increased grain N and reduced the milling breakage. As mentioned in Chapter 2, increasing N fertilizer may improve head rice yield. For example, Fagade and Ojo (1977) reported that applying 75 kg N ha^{-1} increased head rice yield of IR8 by 7% when compared with the non-fertilizer treatment. Jongkaewwattana (1990) found that increasing N fertilizer improved head rice in S201, M201 and L202.varieties by 5% compared with no N. The relationship between N concentration and N form in rice endosperm, with respect to breakage during milling, would be a useful area for further investigation. The distinctive behavior of N in grain of KDML105 is of particular interest as increasing grain N concentration did not affect head rice yield, which is similar to results obtained by Seetanun and De Datta (1973) for IR22.

Grain moisture content at harvest was closely correlated to percent unbroken rice and percent milling. The sensitivity of percent unbroken rice and percent milling to grain moisture content at harvest was different between varieties. However it should be noted that sensitivity of percent milling of KDML105 and CNT1 to grain moisture content was not clear because the sampling did not cover the same range of grain moisture content as other varieties. Berrio and Cuevas-Perez (1989) and Dilday (1989) reported that delay in harvest was commonly found to affect milling yield evaluation. The varieties were responsive to delay harvest difference. Delaying the harvest, 2 weeks after 20-25% wb grain moisture content, reduced head rice yield about 18% for 16 tested varieties.

In conclusion, head rice N concentration affected milling quality, head rice and milling yield, of four varieties differently. KLG1, PTT1 and CNT1 showed positive response in term of head rice N concentration and head rice yield, but not KDML105 which was already approaching maximum head rice yield at nil N. By contrast, percent unbroken rice was positively correlated with head rice N concentration in Chapter 2. This may be because the head rice N concentration in Chapter 2 was quite low, 1.2 to 1.4%, but the head rice N concentration of KDML105 in this field experiment ranged from 1.5 to 2.2%. It remains to be further investigated how head rice yield is increased with increasing head rice N concentration in some varieties. Knowledge of any effect of N on the physical properties and internal structure of rice grain may assist in elucidating aspects how N fertilizer can reduce grain breakage during milling in some varieties but not in others. These are explored in Chapter 4.