CHAPTER 4
RESULTS

4.1 Survey

4.1.1 Rice Production Systems in Yunnan

Yunnan province is located in the southeastern part of China. It belongs to a low-latitude plateau ecoenvironment, combining three belts namely cold, temperate and tropical climate. The longitude is between 97°39' to 106°12' E, and latitude is between 21°09' to 29°15' N. It is a mountainous area which an altitude range from 76.4 to 6,740 m above sea level. The total area of Yunnan is about 380,000 KM^2 in which mountainous areas account for 84% of the total area. The annual average temperature range from 4.7 to 21.8°C varying in different regions with the mean temperature about 15°C in majority of rice area. The annual total precipitation amounted to 574 to 2739 mm. The duration of sunshine in the annual crop growing areas range from 966 to 2554 hours (at temperature >10°C) with an annual radiation of 493 to 648 KJ cm^{-2}. Summer drought and autumn cooling and drizzle often occur, especially the autumn cooling (during July to August) is one of the main environmental factors affecting the stability of rice output in the province.

Farming systems of Yunnan is characterized as rice based system in which most of ethnic people take rice as staple food. Rice is considered as one of the most important food crop in terms of crop production and planting area in Yunnan. The archaeological excavation has proved that rice cultivation has more than 4,000 years in Yunnan and the elevation for rice growing is from 76.4 to 2695 m above sea level. Rice growing areas are divided into three belts, which can be further classified into six regions according to topography, soil types, and some other factors (see map: Figure 4.1) (Chen, 1986; Li, 1988; Yang, 1992).

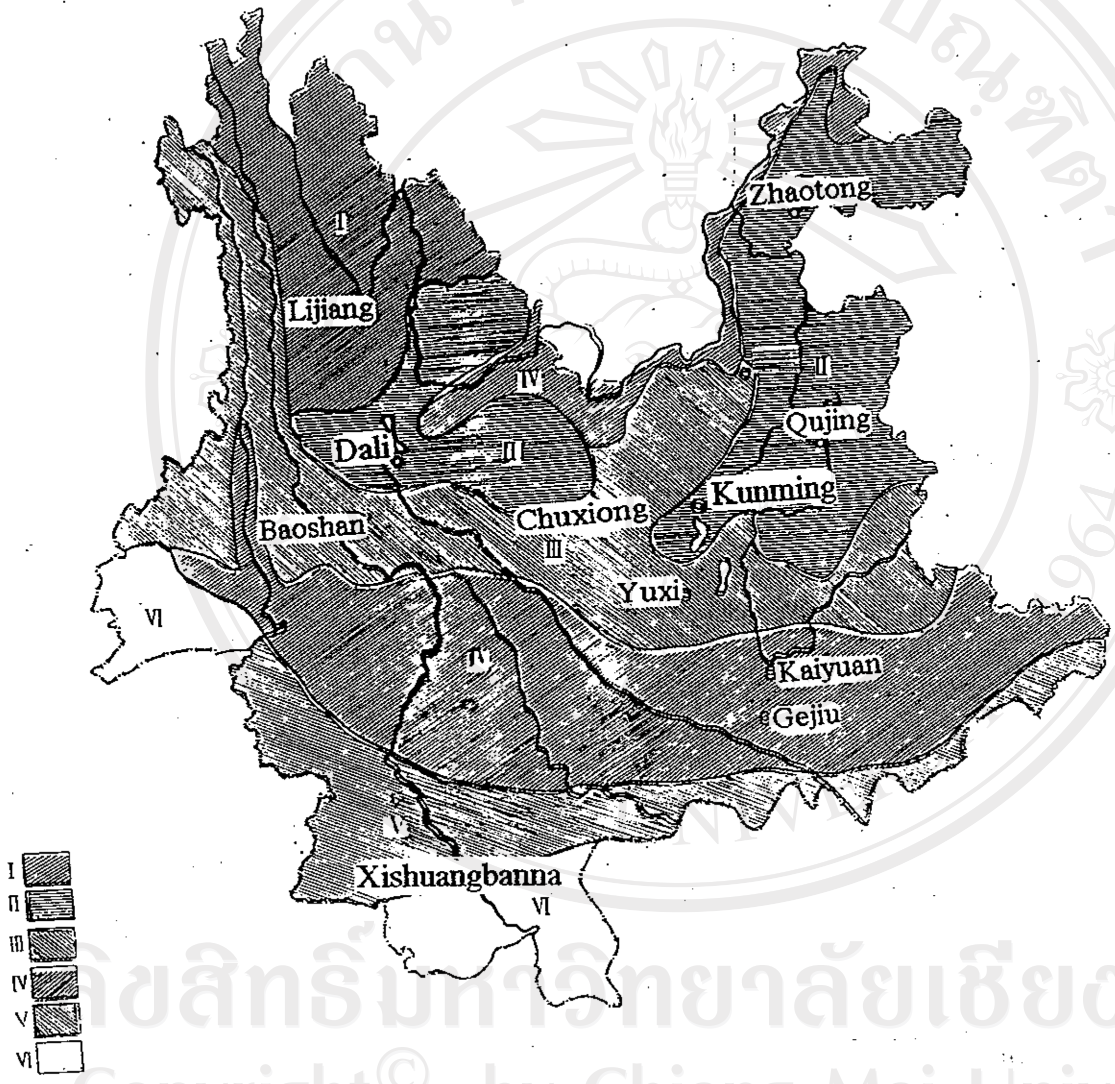

Figure 4.1 Classification of Rice Cropping Regions in Yunnan

The first belt is plateau region of single cropping of japonica rice, including cool-cold (I) warm-cool (II) and warm (III) three sub-regions. The second belt is low-warm region of single and double cropping of indica rice (IV). The last belt is southern marginal region of paddy and upland rice combining cropping, including combined cropping of paddy and upland rice (V) and single late cropping of indica rice (VI) two sub regions. Average grain yield varied from region to region. The highest average yield ranged from 7.5 to 9.2 t/ha in region II and III, and the lowest average yield was 2.2 to 3.4 t/ha in region I. The average grain yield of upland rice was only 1.56 t/ha in region V (Jiang, 1993).

Yunnan consists of about 1.01 million hectares of paddy field, which accounting for 36.7% of the total cultivated area (Yang, 1992). In the last two decades, an average annual planting area covers about 1.05 million hectares (Table 4.1), accounting for 30% of the total food area and 49% of the total grain production. Of which, paddy rice including japonica and indica rice, account for 60% and 28%, and upland rice account for 12%, respectively (Figure 4.2).

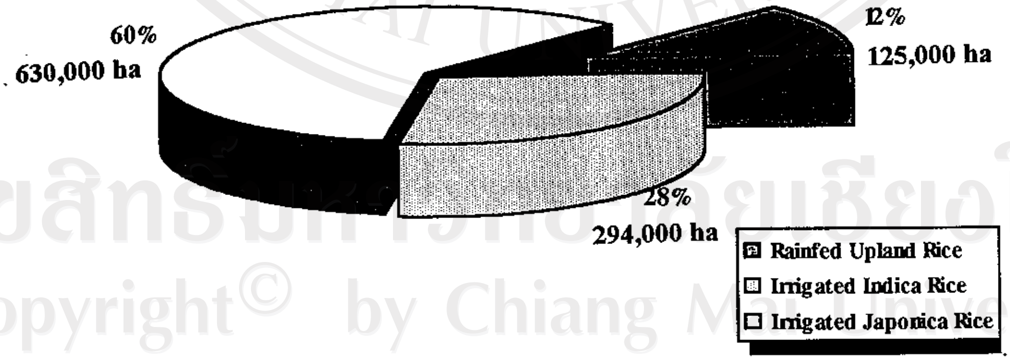

Figure 4.2 Rice Production System in Yunnan (1960's-1990's)
(Data source: Yang, 1992).

Table 4.1 Annual planting area and production output of rice in Yunnan, 1969-1990.

Year	Area (10,000 ha)	Yield (t/ha)	Gross yield (10,000 t/yr)
1969	104.360	3.35	348.45
1970	105.360	3.51	369.65
1971	102.374	3.35	343.00
1972	104.300	3.59	373.35
1973	103.960	3.86	400.40
1974	104.730	3.23	337.80
1975	104.940	3.81	400.00
1976	103.840	3.57	370.30
1977	101.080	3.41	344.40
1978	103.860	3.96	411.60
1979	104.260	3.68	382.50
1980	102.790	3.78	387.60
1981	107.810	4.05	436.20
1982	110.360	4.20	463.90
1983	110.700	4.13	456.90
1984	113.040	4.44	500.90
1985	107.440	4.50	482.95
1986	104.930	4.20	440.00
1987	101.990	4.49	475.96
1988	100.880	4.55	458.31
1989	100.770	4.64	467.54
1990	102.600	4.97	506.94

Source: Yang, 1992.

Yunnan has diversified types of ecoenvironment so does the abundant rice germplasm resources (over 5,000 indigenous cultivars have been collected), which are precious for study on origin, evolution and classification of Asian cultivated rice and its utilization in breeding.

Since the 1980s, comparable improvements have been made in development and popularization of modern varieties (Table 4.2) and cultivation techniques. Noticeably, tremendous achievement has been made in terms of breeding in high yielding variety particularly with respect to hybrid rice. The highest historic yield records of 15 and 16.6 t/ha have been reached successfully in 1984 and late in 1994 by using varieties namely Dianyu 1 and Yuza 29, respectively. The year of 1984 and 1990 witnessed the highest historic average yield records, as the national gross rice production broken through 5 million tons, reaching 4.97 t/ha in 1990.

Apart from yield, Yunnan also concerns a great deal about the improvement of rice quality since 1980's. A series of other good quality varieties were selected which represented the best grade quality rice in China, such as Dianrui 408, Dianlong 201, Diantun 502 and so on. So far, however, the good quality rice production is still unfitful market demands, Table 4.2 demonstrates that the high quality rice mentioned above only covered small area.

In the future, it is clear that there is still a very high potential for increasing yield and good quality rice production in Yunnan.

Table 4.2 Predominantly grown rice cultivars and its area (10,000 ha) in rice production of Yunnan, 1979-1992.

Elevation below 1500 m

Year/Var.	Hybrid	Guichao 2	Aizhongxian	Dianlong 201*	Dianrui 408*
1979	2.35				
1980	1.62		1.02		
1981	1.24	0.07			
1982	1.39	0.40	2.25		
1983	2.87	1.73	1.79		
1984	5.53	4.02	2.33	0.48	0.25
1985	8.56	2.55	0.93	0.94	0.31
1986	10.89	2.57	0.57	0.79	0.53
1987	15.13	2.55	0.44	0.74	0.49
1988	20.15	1.81		0.59	0.31
1989	21.25	2.06	0.23	1.13	
1990	23.99	2.15		0.49	0.25
1991	27.37	2.03	0.18	0.26	
1992	29.18	1.65	0.23	0.75	0.57

* Superior quality varieties.

Table 4.2 (Continued)

Elevation 1500-1800 m

Year/Var.	Xinan 175	Chugeng	65-36	Jingguo 92	Yunyu 1
1979	1.27				
1980	7.90		1.06		
1981	6.33		0.79	0.27	
1982	6.85		1.65	0.65	
1983	7.03		1.67	0.97	0.13
1984	8.35	0.22	1.49	1.20	0.47
1985	5.91	0.79	1.33	1.15	0.59
1986	4.08	2.77	2.55	1.30	0.69
1987	3.83	4.82	2.22	1.40	0.73
1988	3.21	5.61	2.23	1.35	0.78
1989	2.83	7.10	1.78	1.53	0.89
1990	2.09	7.70			0.79
1991	1.81	8.55	1.01	1.01	0.73
1992	0.97	9.00	0.67	0.67	0.38

Table 4.2 (Continued)

Elevation	1800-2100 m				
Year/Var.	8126	Gengdiao 3	Yungeng 9	Yungeng 136	Hexi
1979	2.87	0.53	1.60		
1980	3.89	1.28	2.90	0.09	
1981	3.45	1.91	4.73		
1982	4.89	2.84	3.35	0.39	
1983	3.83	2.21	2.53	0.69	
1984	3.81	1.37	0.80	1.04	
1985	3.79	0.80		1.19	
1986	3.72	0.41	0.99	2.24	
1987	3.10	0.30	0.74	2.47	
1988	2.34	0.35	0.72	2.37	0.07
1989	2.99	0.33	0.28	2.73	0.55
1990	2.70	0.29	0.45	2.19	2.33
1991	2.25	0.25	0.37	2.27	4.00
1992	2.29		0.21	2.49	6.76

Source: Jiang, 1993.

4.1.2 Farmer's Concerns in Rice Production

Rice has long been an important sources of farmers' income in Kunming, Dali and Xishuangbanna. This is because of favorable biophysical environment, applications of innovations in agro-technology, especially with respect to hybrid rice resulted in high productivity (the average grain yield of hybrid rice normally ranged from 8 to 12 t/ha). At present, rice is still a crop adhering to cultural, economic, social activities of farmers who live in studied areas.

In production aspect, farmers are concerned more about the technological components in terms of varieties, chemicals inputs (i.e. fertilizers and pesticides), and crop management strategies. Most of farmers said that their foremost concern in producing rice was how to get the high yield. According to farmers' opinion, low yield means low income.

Economic components such as the cost of input, market and price of rice are receiving much attention by majority of farmers in three survey sites. Grain quality is now being one of the most concerning factor in rice production beside high grain yield, because market price of rice is determined by grain quality.

4.1.3 Rice Experts and Farmers' Opinions on Rice Quality in Relation to Genotypes and Environment

As previously mentioned, people in Yunnan have become more concerned about rice quality since the late 1980's. The survey results confirmed that majority of rice researchers were paying more attention to quality of rice. Presently, most of the breeding programs have considered quality improvement according to the regional consumer preferences for rice. At present, the most concerned quality characteristics in rice breeding included appearance quality, i.e. chalkiness and translucency, cooking-eating quality such as amylose content and aroma, and nutritional quality refers to protein content.

Regarding assessment of rice quality, the rice breeders as well as agronomists paid more attention to genetic effects, hence each newly bred rice variety will be examined on grain quality before released. In contrast, the effects of environmental factors on grain quality were usually ignored or given little attention. On the other hand, according to researchers' opinions, the influences of environmental factors on grain quality of indica rice were more stronger than that of japonica rice. At this point, the preliminary data (see Appendix-A) also provided very similar result, especially with respect to environmental effects on amylose content of rice grain. Despite environmental influences on rice quality have long been recognized, the respondent rice breeders as well as agronomists confessed that they seldom conducted the experimental study in this subject.

The farmers' response indicated that cultivar was one of the most important components which determined either grain yield or grain quality. For their experiences, high quality gave relatively low yield. They said that, quality was determined by variety, and meanwhile production conditions and techniques were important factors for improvement of rice quality. According farmers' ideas, a number of factors including climate, soil type, irrigation management, chemicals application, harvesting time, post harvesting technology, have more or less effects on rice quality, in terms of grain color, percentage of broken rice, milling degree, soft texture etc.

4.1.4 Rice Consumption and Consumers' Preference

Interviews with rice experts and local consumers revealed large variability in level and pattern of rice consumption, consumers' taste, and preferences from region to region as well as culture to culture.

The quantity of rice consumption differed from urban area to rural area. According to the secondary information of survey in major rice producing area of Yunnan, presently, annual per capita rice consumption are around from 120 to 135 kg for urban people and 250 to 280 kg for rural people. It has been estimated that the per capita rice consumption for urban people in general was 180 to 220 kg/yr during 1950's to middle of 1980's, which tended to decline since 1990's (Figure 4.3).

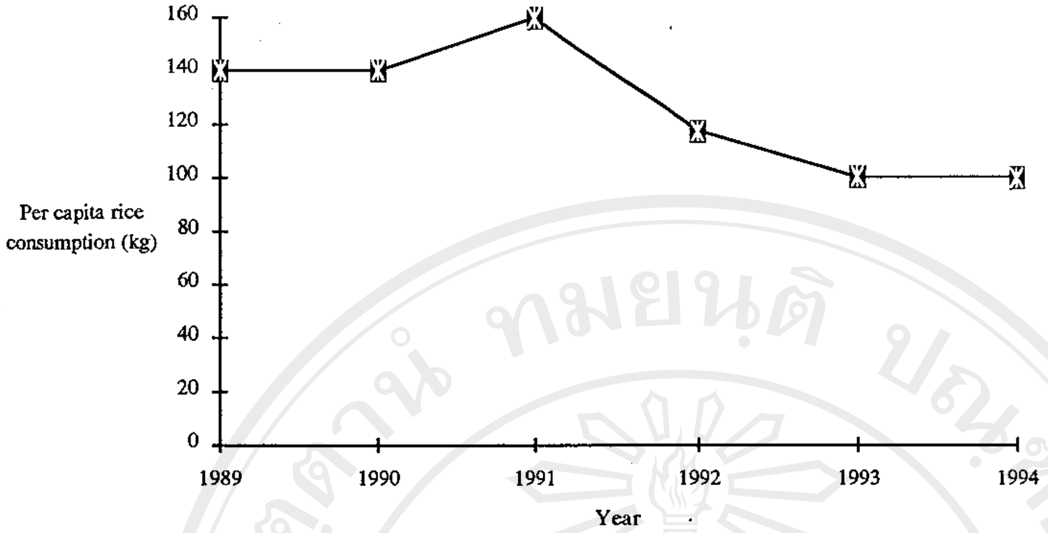

Figure 4.3 Per capita rice consumption of urban people, Yunnan, 1989-1994.
(Data source: Statistic Year Book of Yunnan, 1994).

Consumers' preferences for rice varied from region to region. Local ethnic consumers in the southern region (Xishuangbanna) prefer indica glutinous rice to that of non-glutinous. Purposes of farmers who produced non-glutinous are largely for sale, not much for their own consumption. Normally, consumers of north-western region (Dali) and Central region (Kunming) prefer japonica rice.

Besides the characteristics of rice grain that influence consumers' preferences, market price is also an important factor which determines the consumers' preferences. Generally, rice products which have medium to low prices were commonly accepted by the majority of consumers. However, everywhere it was found that local consumers were willing to pay extra price (if they could afford) for these aromatic rice, glutinous rice, upland rice, and black rice. Most of mentioned consumers who earned income under average level preferred rice with greater volume expansion.

4.1.5 Relationship Between Market Price and Rice Quality

Noticeably, market price of rice has changed drastically since 1989, indicating the price of good quality rice trend to raise more quickly than that of normal rice (Figure 4.4). In 1994, the information gathered from market survey and secondary data showed that there was a large market price variation at provincial level, with a range of 1.6 to 5.0 yuan/kg*, respectively.

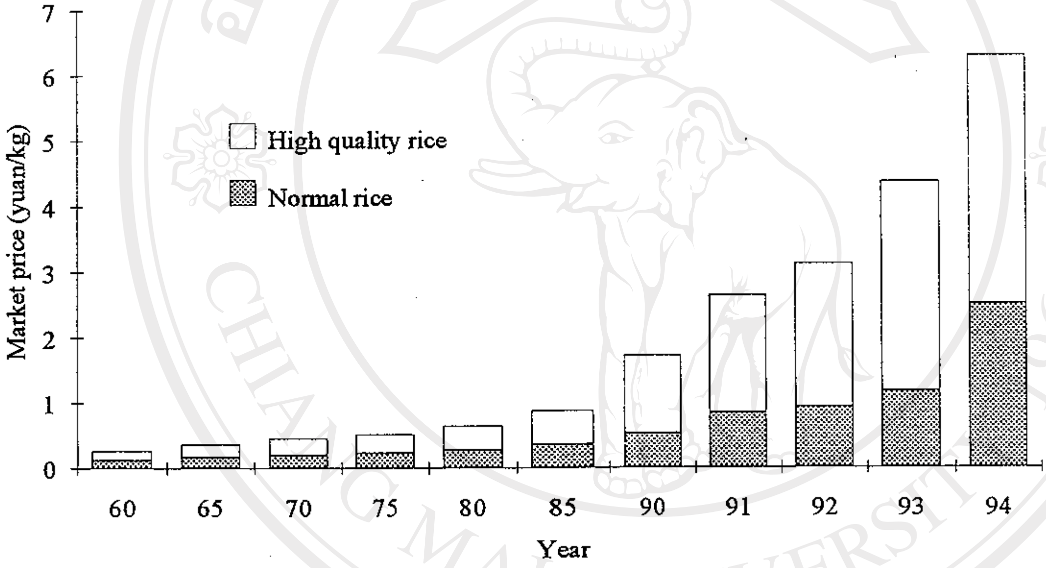

Figure 4.4 Market price of rice in Yunnan, 1960-1994.
(Data source: Statistic Year Book of Yunnan, 1994; IRRI, 1991).

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*Yuan is Chinese Currency, approximately 1US$=8.75 Yuan.

Survey results indicated that market price of rice were affected by a number of factors, i.e. increasing of input costs for rice production, price inflation and other additional socioeconomic factors especially in governmental policies. Most of all, respondents believed that supply of high quality rice products could not meet the recent high demand of rice consumers, which gave a large variation in price of rice.

As a result, grain quality became one of the most important characteristics that accelerate the market prices of rice. At present, rice prices directly reflect the quality characteristics of rice grain as well as the preferences of consumers. In general, the consumers considered that high grain quality related to high price. The price of high quality rice had being 1.8 to 2.5 times higher as that of normal rice since 1990's. Generally, "high quality" rice in consumers' sense referred to good taste, and or with less brokens, slender grains, fewer chalkiness and higher translucency, and higher nutritional value. The most popular high quality rice variety such as Thai rice, Dianlong 201, Daintun 502 were accepted by consumer with high price. In addition, example of high nutritional quality rice was "Babao black rice", people used to take it as nutritious food. Thus, "Babao black rice" was well known as "body strengthening", "drug rice", and " bloody rice".

4.2 Determination of Important Rice Quality Characteristics

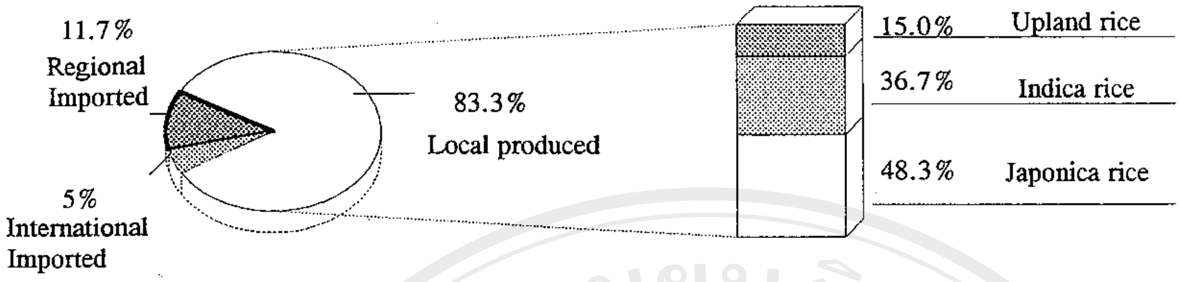
4.2.1 General Descriptions and Statistics of Original Variable Data

Twenty samples of milled rice were collected from markets of each location, namely Kunming, Dali and Xishuangbanna. Total sample of sixty milled rice were collected from selected markets. Among these samples, seven samples were imported from other provinces (Jiangshu, Dongbei, and Hunan), accounting for 11.7%; three samples were imported from other countries (Thailand and Korea), accounting for 5.0%; other fifty samples were produced by Yunnan local farmers, accounting 83.3% (Table 4.3). On an average, the modern rice accounted for 85% of the total samples. Among samples, irrigated indica rice, japonica rice and upland rice accounted for 36.7%, 48.35%, and 15% of the total samples, respectively (Figure 4.5). Of it, the samples collected in Kunming comprised of 80% japonica rice and 20% indica rice; the samples of Dali were about 95% japonica rice and 5% indica rice; and the samples collected in Xishuangbanna consisted 85% indica rice and 15% upland rice, respectively.

Table 4.3 Milled rice samples classifications in three sites.

Region	No. of samples	Sample classification		
		local produced	regional imported*	international imported
Kunming	20	8	3	2
Dali	20	16	4	0
Xishuangbanna	20	19	0	1
Total	60	43	15	3

*samples imported from other provinces.



Sample classification　　Varietal classification

Figure 4.5 Milled rice available in the market and the sample classifications, Yunnan, 1994.

◆ Grain quality of samples

The physicochemical characteristics of milled rice samples at three locations are presented in Table 4.4. In Kunming and Dali, the samples possessed a little higher head rice percentage and lower amylose content comparing to samples of Xishuangbanna. In addition, chalkiness score of the samples collected in Dali and Xishuangbanna were higher than that of Kunming.

The Table 4.5 and Table 4.6 shows the quality characteristics of different types of rice genotypes. One striking difference in the quality of milled rice from different types of rice was nutritional quality. According to the primary data (see Appendix-A), the genotypic variation in protein content of rice grain was more than 5%. The Zn contents of rice grain ranged from 12.98 to 25.98 mg/kg concerning varieties available in the domestic market. Analysis results (Table 4.7-9) indicated that the genotypic variations in Zn contents of rice grain were very significant, upland rice (particularly the black rice) contained relatively high Zn content in milled grain. The results also indicated that waxy rice generally had high nutritional value in terms of protein and Zn content of rice (Table 4.8-9, Figure 4.6 and 4.7).

On the average, the results (Table 4.4-6) indicated that quality characteristics such as chalkiness, amylose content and gel consistency (particularly with waxy rice), and protein content of current predominately rice varieties were still far away from the standards which are required by Agricultural Ministry for high quality rice (see Table 2.1 in Chapter 2). Nevertheless, some quality characteristics including amylose content, gel consistency, and alkali spreading value of milled samples were nearly closed to these high quality criteria, especially with respected to japonica rice.

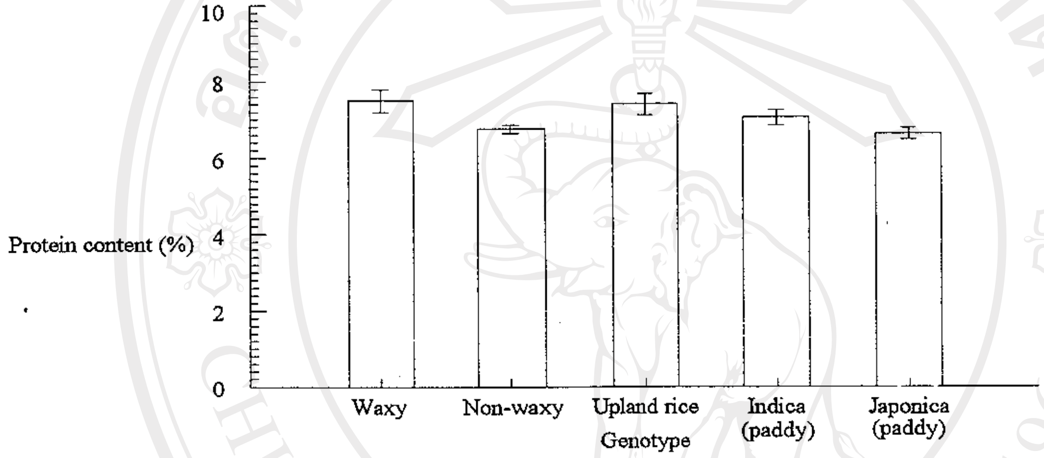


Figure 4.6 Nutritional quality (Zn content of grain) of different rice genotypes (the S.E of groups were showed as small bar in figure).

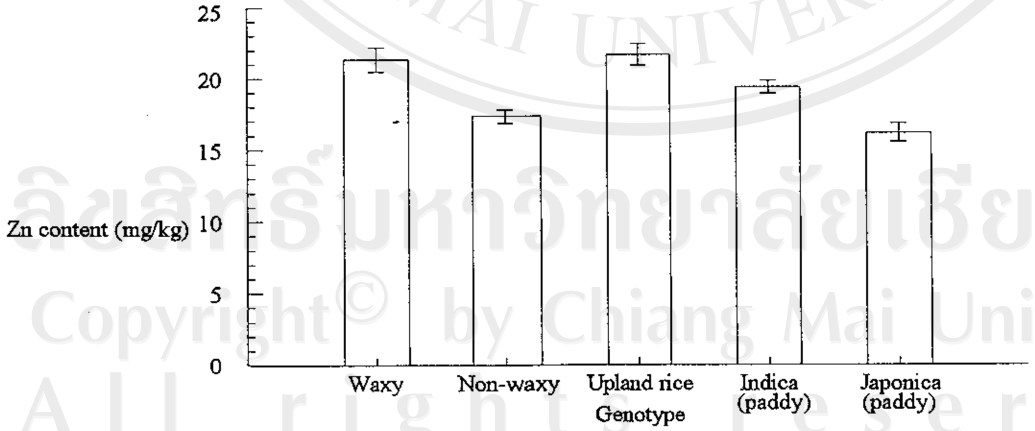


Figure 4.7 Nutritional quality (protein content of grain) of different rice genotypes (the S.E of groups were showed as small bar in figure).

Table 4.4 Average characteristics of rice samples at various locations, Yunnan, 1994 (Standard deviation in parentheses).

Characteristics \ Location	Kunming	Dali	Xishuangbanna	All
Price(yuan/kg)	3.04	2.13	2.24	2.47
	(1.01)	(0.22)	(0.53)	(0.78)
Chalkiness score (%)	17.3	35.85	32.5	28.55
	(20.09)	(25.59)	(28.29)	(25.16)
Shape (L/W)	2.7	2.89	2.61	2.74
	(0.31)	(0.18)	(0.28)	(0.29)
Grain length (mm)	5.87	5.04	6.09	5.67
	(1.18)	(0.59)	(0.69)	(0.95)
Percentage of head rice	87.98	81.07	72.89	80.64
	(7.12)	(9.88)	(14.84)	(12.54)
Amylose content (%)	14.37	13.15	16.38	14.63
	(6.31)	(4.62)	(9.11)	(6.94)
Gel consistency (mm)	80.8	78.05	78.1	78.98
	(18.99)	(8.57)	(16.03)	(14.98)
Alkali spreading value	5.4	6.7	4.1	5.4
	(1.23)	(0.66)	(1.83)	(1.69)
Protein content (%)	6.99	6.62	7.08	6.9
	(1.13)	(0.66)	(0.70)	(0.87)
Zinc content (mg/kg)	19.41	15.8	19.3	18.17
	(3.36)	(3.74)	(2.27)	(3.56)
Phosphorus content (%)	0.164	0.135	0156	0.152
	(0.076)	(0.26)	(0.078)	(0.064)
No. of samples	20	20	20	60

Table 4.5 Average characteristics of the different genotypes of milled rice samples, Yunnan, 1994 (Standard deviation in parentheses).

Characteristics \ Genotypes	Irrigated		Rainfed
	Indica	Japonica	Upland rice
Price(yuan/kg)	2.68 (0.96)	2.14 (0.17)	3.02 (1.04)
Chalkiness score (%)	27.45 (25.93)	29.18 (25.04)	16.78 (26.92)
Shape (L/W)	2.49 (0.28)	2.88 (0.22)	2.68 (0.34)
Grain length (mm)	6.5 (0.88)	5.18 (0.59)	6.07 (0.60)
Percentage of head rice	77.61 (14.92)	81.92 (11.55)	78.37 (17.19)
Amylose content (%)	16.31 (8.14)	13.18 (6.24)	9.92 (9.35)
Gel consistency (mm)	71.59 (18.79)	83.26 (10.29)	87 (13.70)
Alkali spreading value	4.18 (1.76)	6.1 (1.18)	4.78 (1.30)
Protein content (%)	7.05 (0.92)	6.63 (0.74)	7.4 (0.87)
Zinc content (mg/kg)	19.36 (2.15)	16.18 (3.55)	21.67 (2.30)
Phosphorus content (%)	0.149 (0.077)	0.153 (0.057)	0.21 (0.086)
No. of samples	22	29	9

Table 4.6 Average characteristics of the waxy and non-waxy milled rice samples, Yunnan, 1994 (Standard deviation in parentheses).

Characteristics \ Genotypes*	Waxy	Non-waxy
Price(yuan/kg)	3.11 (1.01)	2.31 (0.62)
Chalkiness score (%)		35.44 (23.51)
Shape (L/W)	2.63 (0.37)	2.67 (0.27)
Grain length (mm)	5.89 (0.82)	5.61 (0.98)
Percentage of head rice	78.98 (15.84)	80.68 (12.28)
Amylose content (%)	2.34 (0.90)	17.33 (4.14)
Gel consistency (mm)	89.00 (16.72)	76.48 (13.57)
Alkali spreading value	5.08 (1.24)	5.48 (1.79)
Protein content (%)	7.50 (1.03)	6.75 (0.76)
Zinc content (mg/kg)	21.35 (2.98)	17.37 (3.25)
Phosphorus content (%)	0.211 (0.117)	0.137 (0.029)
No. of samples	12	48

*Percent amylose, milled rice dry weight basis. Waxy 0-5%, non-waxy >5%.

Table 4.7 Descriptive statistics for characteristics of milled rice samples (n=60), Yunnan, 1994.

	PI	ZN	P	PR	AMY	HEA	GEL	CHK	ALK	GL	GW
Case	60	60	60	60	60	60	60	60	60	60	60
Lower 95.0% C.I.	2.27	17.25	0.135	6.67	12.84	77.41	75.11	22.05	4.96	5.42	1.98
Mean	2.47	18.17	0.152	6.90	14.63	80.64	78.98	28.55	5.40	5.67	2.13
Upper 95.0% C.I.	2.67	19.09	0.168	7.12	16.43	83.88	82.85	35.05	5.84	5.91	2.28
S.D.	0.78	3.56	0.064	0.866	6.95	12.54	14.98	25.16	1.69	0.95	0.59
S.E. (Mean)	0.10	0.46	0.008	0.118	0.90	1.62	1.93	3.25	0.22	0.12	0.08
C.V.	31.4	19.6	42.5	12.6	47.5	15.6	19.0	88.1	31.3	16.8	27.9
Minimum	1.80	9.96	0.072	5.27	1.33	41.10	39.00	0.00	2.00	4.50	1.43
Median	2.20	18.25	0.133	6.89	15.95	83.95	80.50	25.00	6.00	5.21	1.83
Maximum	4.80	25.98	0.400	9.82	25.70	99.70	100.0	100.0	7.00	8.68	3.48

Note: PI=price of rice, ZN=zinc content, P=phosphorous content, PR=Protein content, AMY=amylose content, HEA=percentage of head rice of total milled rice, GEL=gel consistency, ALK=alkali spreading value, CHK=chalkiness score, GL=grain length, GW=grain width.

Table 4.8 Descriptive statistics for Zn content of milled rice samples.

Genotype	Case	Mean	Min.	Med.	Max.	S.D.	S.E	C.V.
Waxy	12	21.35	15.94	21.13	25.98	2.98	0.86	13.98
Non-waxy	48	17.37	9.96	17.96	24.14	3.25	0.47	18.72
Upland rice	9	21.67	18.54	21.00	25.98	2.30	0.76	10.59
Indica (paddy)	22	19.36	15.14	19.18	25.05	2.15	0.46	11.09
Japonica (paddy)	29	16.18	9.96	15.27	24.14	3.55	0.66	21.92

Table 4.9 Descriptive statistics for protein content of milled rice samples.

Genotype	Case	Mean	Min.	Med.	Max.	S.D.	S.E	C.V.
Waxy	12	7.50	5.50	7.39	9.82	1.03	0.30	13.74
Non-waxy	48	6.75	5.27	6.81	8.92	0.76	0.11	11.25
Upland rice	9	7.40	5.50	7.40	8.92	0.87	0.29	11.78
Indica (paddy)	22	7.05	6.07	6.87	9.82	0.92	0.20	13.12
Japonica (paddy)	29	6.63	5.27	6.78	8.00	0.74	0.14	11.19

As summarized in Table 4.10, in consumers' sense, so-called "high quality" rice varieties with high price were associated with their quality characteristics of aromatic (i.e. Diantun 502), low-to-medium amylose content (i.e. Dianrui 456, Dianlong 201, and Hunan softy rice), less brokens (i.e. Thai rice), and higher protein and Zn content (i.e. Babao black rice).

Table 4.10 Quality characteristics of rice varieties with high price (>3.50 yuan/kg), Yunnan, 1994.

Charact.\ Varieties	Dianlong 201*	Diantun 502	Dianrui 456	Hunan rice	Baoxiu black rice	Babao black rice	Thai rice
Case	1	3	1	1	1	1	2
Genotypes	Indica	Indica	Indica	Indica	Upland	Upland	Indica
Price(yuan/kg)	2.30	3.50	3.50	3.80	4.50	4.80	4.80
Chalkiness score (%)	10.0	25	15.0	-	-	-	5.0
Shape (L/W)	2.36	2.43	2.21	2.42	2.44	2.26	2.19
Grain length (mm)	7.38	7.30	7.15	7.01	6.59	6.48	7.29
Percentage of head rice	61.0	84.7	95.0	90.0	85.4	96.5	99.2
Amylose content (%)	14.90	14.52	13.95	3.22	1.38	20.28	18.69
Gel consistency (mm)	69.0	46.0	51.0	100	100	39.0	77.0
Alkali spreading value	6.0	6.0	6.0	5.0	5.0	2.0	4.0
Protein content (%)	6.22	7.92	6.78	7.68	7.50	9.82	7.20
Zinc content (mg/kg)	19.39	22.00	18.00	24.52	20.83	25.05	19.30
Phosphorus content (%)	0.103	0.166	0.136	0.176	0.278	0.400	0.112

* One of superior rice variety in Yunnan.

With overview of the total samples, in Kunming and Dali, low amylose rice was predominant, whereas waxy and low-and-intermediate amylose rice predominated in Xishuangbanna. Very low amylose rice were identified only in Dali, and high amylose rice were found only in Xishuangbanna (Table 4.11). Amylose content in these milled rice samples ranged from 1.33-25.7%, and overall mean amylose content was 14.63%.

Table 4.11 Amylose scattergram of milled rice samples of varieties grown in various regions in Yunnan, 1994.

Location	No. of sample	Amylose type*				
		waxy	very low	low	mediate	high
Kunming	8	1	4	7	0	0
Dali	16	1	0	11	0	0
Xishuangbanna	19	5	0	6	7	2
Total	43	7	4	24	7	2

*Percent amylose, milled rice dry weight basis (Juliano et al., 1991).
waxy 0-5%, very low 5.1-12.0%, low 12.1-20.0%, (inter)mediate 20.0-25.0%, high>25.0%, respectively.

In addition, analysis results (Table 4.12) showed that quality characteristics of the same variety was different when grown rice under different biophysical conditions. Accordingly, environmental conditions including crop management showed some effects on rice quality.

Table 4.12 Quality characteristics of rice variety under different biophysical conditions in Yunnan.

Characteristics \ Varieties	Shangyou 63[a]		Diantun 502[b]			Hexi 17[c]	
	1	2	1	2	3	1	2
Price(yuan/kg)	1.90	1.90	2.40	3.50	3.60	2.04	2.00
Chalkiness score (%)	35	40	25	25	15	60	80
Shape (L/W)	2.62	2.61	2.36	2.43	2.35	3.05	2.83
Grain length (mm)	5.94	6.08	7.36	7.30	6.99	4.97	4.89
Percentage of head rice	79.3	64.0	58.2	84.7	82.0	81.0	78.0
Amylose content (%)	22.65	24.14	15.59	14.52	12.99	17.21	15.95
Gel consistency (mm)	100	90	48	46	51	74	77
Alkali spreading value	2.0	2.0	6.0	6.0	5.0	7.0	7.0
Protein content (%)	7.38	6.48	7.38	7.92	6.25	6.13	5.91
Zinc content (mg/kg)	18.19	17.35	18.19	22.00	22.51	15.83	12.98
Phosphorus content (%)	0.152	0.125	0.152	0.166	0.120	0.126	0.118

Source of samples: [a] from the same farmer with different soil;
[b] from different locations with diversified environmental conditions;
[c] from the same location with different farmer practice.

◆ Correlation analysis

Correlation analysis results (Table 4.13) indicated that there were some particularly strong correlation among quality characteristics of milled rice. As expected, the rice price showed significant positive relationship with head rice percentage of total milled rice, Zn and protein content of grain, and grain size, but there was a negative relationship between amylose content, chalkiness score and price of milled rice.

Table 4.13 Correlation matrix (PEARSON) of characteristics of milled rice samples (n=60).

	PI	ZN	P	PR	AMY	HEA	GEL	ALK	CHK	GL	GW
PI	1.00										
ZN	0.42**	1.00									
P	0.42**	0.47**	1.00								
PR	0.21	-0.48**	0.47**	1.00							
AMY	-0.29*	-0.21	-0.21	-0.10	1.00						
HEA	0.27*	0.21	-0.06	0.14	0.06	1.00					
GEL	-0.16	-0.14	-0.28*	-0.06	-0.38**	-0.11	1.00				
ALK	-0.47**	-0.27*	-0.29*	-0.20	0.55**	-0.13	-0.12	1.00			
CHK	-0.12	-0.32*	0.11	-0.25*	-0.38**	0.09	0.05	0.05	1.00		
GL	0.54**	0.42**	0.22	0.24	-0.03	-0.10	-0.27*	-0.27*	-0.40**	1.00	
GW	0.60**	0.45**	-0.35**	0.23	0.06	0.01	-0.33**	-0.31*	-0.41**	0.95**	1.00

Note: *r>0.25 (Rejection level r=0.250 at 5%) , **r>0.33 (Rejection level r=0.325 at 1%).
PI=price of rice, ZN=zinc content, P=phosphorous content, PR=Protein content, AMY=amylose content, HEA=head rice percentage of total milled rice, GEL=gel consistency, ALK=alkali spreading value, CHK=chalkiness score, GL=grain length, GW=grain width.

Results also demonstrated that there was a negative association between amylose and chalkiness level. Amylose content was highly corresponded to gel consistency and alkali spreading value which affected cooking quality.

It was found that protein content was significantly related to Zn and P content. There was a positive relationship between protein content and P content, but a negative association between Zn and protein content. In addition, results also showed that there was negative correlation between protein content and degree of chalkiness of grain.

♦ Principal component analysis

Based on the magnitude of the variable loading associated with each principal component, the variables of milled rice characteristics could be grouped into 7 components, accounting for 97.7% of the total variability (Table 4.14). Generally, loading below 0.50 was disregarded for purpose of interpretation. The interrelationships among variable within components are presented in Figure 4.8. This finding could be used as the basis for selecting variables of implicit price model.

C1, grain length and width, accounting for 32.9% of total variability, named appearance quality. Grain width was positively correlated with grain length.

C2, amylose, accounting for 20.6% of total variability, called eating quality.

C3, head rice, accounting for 13.8% of total variability, defined as milling quality.

C4, gel-consistence and alkali spread value, accounting for 11.4% of total variability, referred to as cooking quality. It showed that gel consistency was negatively correlated with alkali spread value.

C5, head rice, accounting for 8.1% of total variability, termed milling quality.

C6, chalkiness, accounting for 5.8% of total variability, grouped into appearance quality.

C7, zinc content, accounting for 5.1% of total variability, classified as nutritional quality.

Table 4.14 Principal component matrix with variable loading of physicochemical characteristics of milled rice samples (n=60), Yunnan, 1994.

Variable	Component						
	C1	C2	C3	C4	C5	C6	C7
Zn	-0.42	-0.13	-0.30	0.16	0.21	0.42	-0.63
Protein	-0.31	-0.11	-0.38	0.43	0.49	-0.28	0.50
Amylose	0.06	0.67	-0.14	0.13	-0.19	-0.14	0.07
Head rice	0.05	-0.06	-0.74	-0.24	-0.52	0.19	0.21
Gel consistency	0.18	-0.41	0.21	0.54	-0.36	0.41	0.29
Chalkiness	0.26	0.49	-0.04	0.13	0.33	0.65	0.17
Alkali	0.31	-0.30	-0.10	-0.55	0.41	0.18	0.24
Grain length	-0.50	0.09	0.30	-0.19	-0.03	0.20	0.30
Grain width	-0.52	0.08	0.21	-0.25	-0.10	0.17	0.23
Total variance %	32.9	20.6	13.8	11.4	8.1	5.8	5.1
Cumulative variance %	32.9	53.5	67.3	78.7	86.6	92.6	97.7

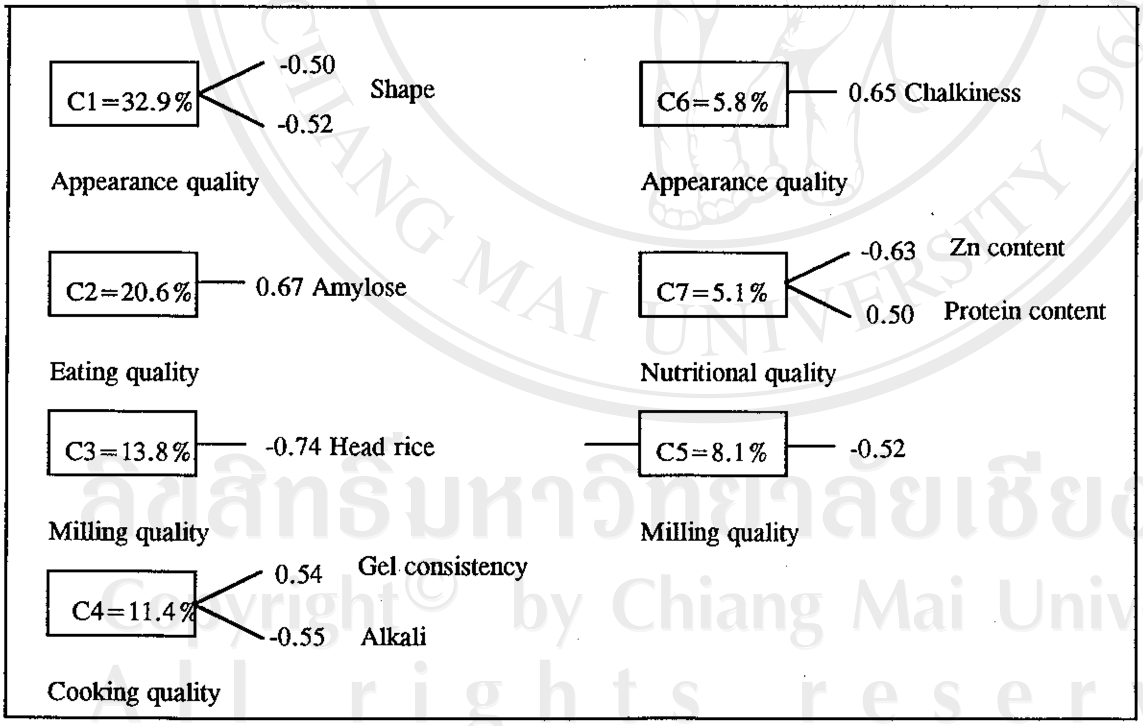


Figure 4.8 Scheme illustrating the effect of principal components on variables

◆ Market price variation

Market price of rice reflects quality characteristics of rice grain as well as the preferences of consumers. The data from collected samples confirmed that there was a large gap of market price at provincial level, with a range from 1.80 to 4.80 yuan/kg. Of which, low to medium price (less than 2.00 and between 2.00 to 2.50 yuan/kg) accounted for 75%; high price (over 4.00 yuan/kg) only accounted for 8.3%, respectively (Figure 4.9). The statistic results (Table 4.15-19) showed that the price variation in capital city (Kunming) was higher than that of smaller cities (Dali, Xishuangbanna), and it was different among genotypes (Figure 4.10 and 4.11).

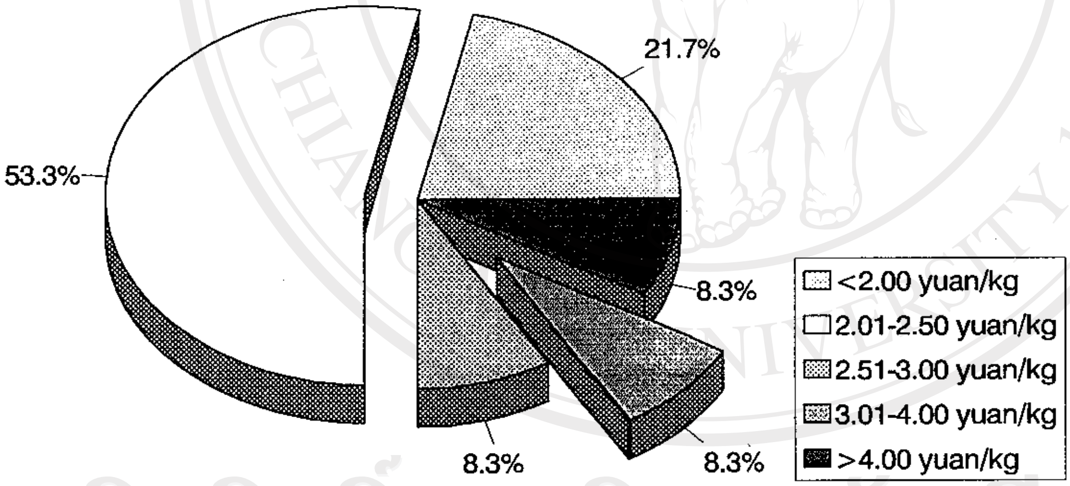


Figure 4.9 Classification of market price of rice in Yunnan, 1994.

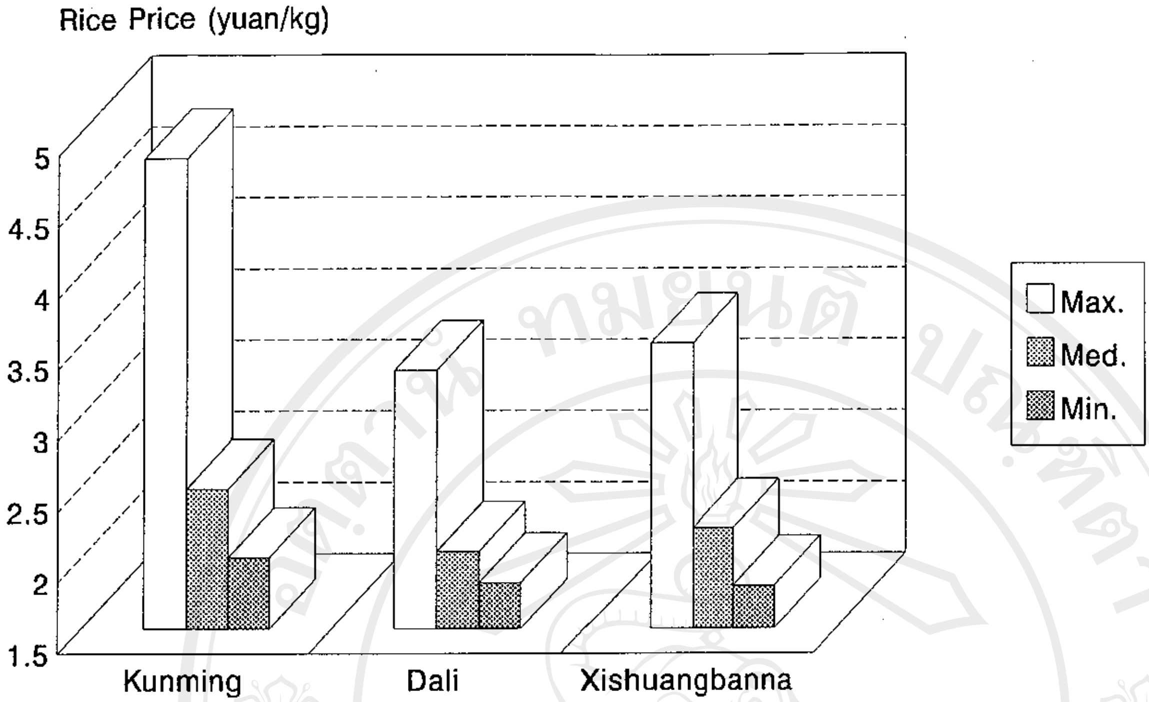


Figure 4.10 Rice price variation in three locations, Yunnan, 1994.

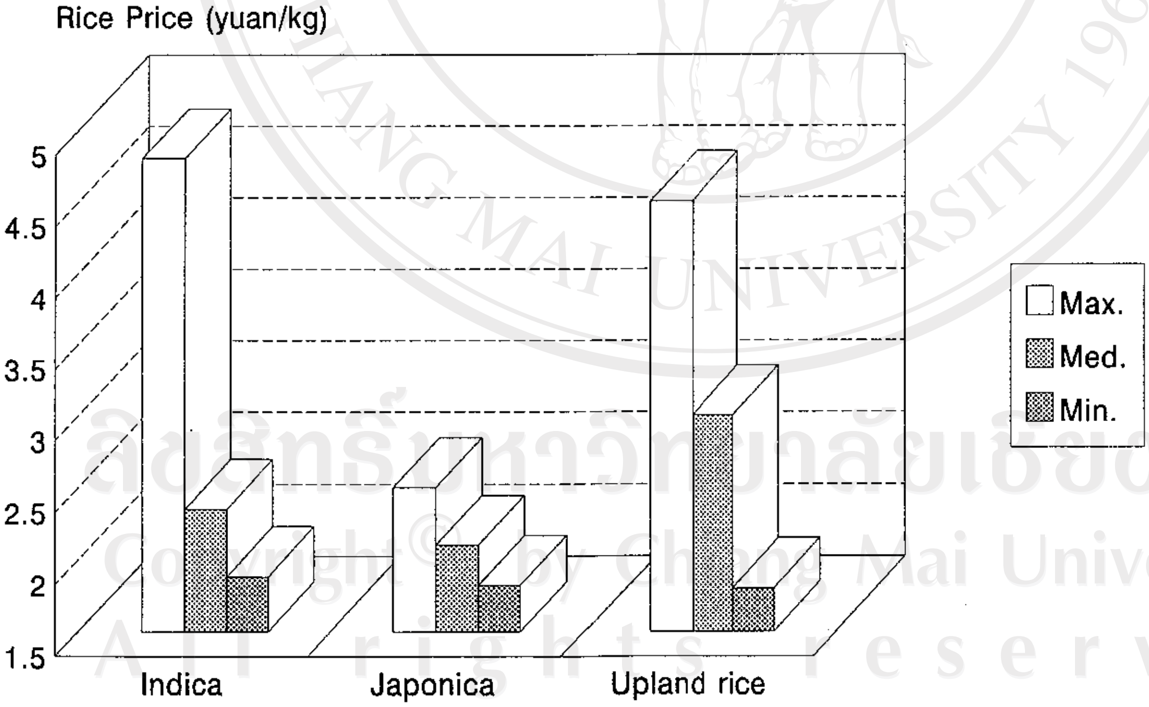


Figure 4.11 Rice price variation among three types of rice genotypes, Yunnan, 1994.

Table 4.15 Rice price classification at three locations, Yunnan, 1994.

Price classification (yuan/kg)	No. of samples			
	Kunming	Dali	Xishuangbanna	Total
<2.00	0	3	10	13
2.01-2.50	11	15	6	32
2.51-3.00	1	2	2	5
3.01-4.00	3	0	2	5
>4.00	5	0	0	5

Table 4.16 Rice prices at three locations, Yunnan, 1994.

Location	No. of samples	Market price (yuan/kg)		
		Min.	Med.	Max.
Kunming	20	2.00	2.48	4.80
Dali	20	1.82	2.04	3.31
Xishuangbanna	20	1.80	2.20	3.50
All	60	1.80	2.20	4.80

Table 4.17 Rice prices of different rice genotypes, Yunnan, 1994.

Genotype	No. of samples	Market price (yuan/kg)		
		Min	Med.	Max.
Indica	22	1.88	2.35	4.80
Japonica	29	1.82	2.10	2.50
Upland rice	9	1.80	3.00	4..50
Total	60	1.80	2.20	4.80

Table 4.18 One way AOV for price and LSD (T) pairwise comparisons of means of price by location.

Location	Sample size	Mean	Group Std. Dev.	Homegeneous groups
Kunming	20	3.040	1.010	a
Xishuangbanna	20	2.237	0.530	. . . . b
Dali	20	2.132	0.223	. . . . b

Note: $LSD_{0.05}$=0.425; a, b belongs to different groups.

Table 4.19 One way AOV for price and LSD (T) pairwise comparisons of means of price by genotype.

Genotype (D)	Sample size	Mean	Group Std. Dev.	Homegeneous groups
Upland rice	9	3.02	1.03	a
Indica (paddy)	22	2.68	0.96	a
Japonica (paddy)	29	2.14	0.17	. . . . b

Note: Standard errors and critical values of differences vary between comparisons because of unequal sample size; a, b belongs to different groups.

4.2.2 The Estimation of Implicit Price Model

The variables for implicit price model were selected based on the results of principal analysis (Figure 4.7). Consequently, the selected variables in the model involved in rice appearance, milling, cooking-eating, and nutritional qualities. However, the variable in terms of grain ratio was not included in the model since that the milled samples comprised of diversified types of grain size, i.e. long (indica) and short (japonica). In addition, the variables such as grain width and P content was eliminated out of the model, this is simply due to the concerns with problem of multicolinearity among the variables.

Estimates of implicit prices of grain quality characteristics for each and all three locations are presented in Table 4.20. The first set of regression equations comprised only 20 samples of each area, namely regional regression. The second set of regression equation involved total 60 samples with two dummy variables, indicating provincial regression.

Variables in two sets of regression equation could explain more than 50% price variation. On the average, most of variables specified showed the expected sign, i.e. the more chalky, the lower price; the longer grain length, the better price; the lower amylose, the higher price; the higher head rice recovery, the higher price; and in general, the higher Zn content, the higher price. Protein content was negatively associated with price in general case, but it was positively related to price in some case, i.e. in Dali and Xishuangbanna.

Analysis results (including regional and provincial regressions) indicated that amylose content and shape of grain were the most significant variables that directly affected the market price of rice. That was return to 1% decrease in amylose content raises price by 3 to 7 fen/kg* with average of 4.4 fen/kg, respectively.

In each individual area, the quality characteristics of chalkiness score, gel consistence, and protein value were not significant affecting on the market price. However, consumers in Dali also significantly preferred better milling quality with respect to high head rice recovery.

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*Fen is Chinese Currency, where 1.00 Yuan=100 Fen.

The best-fit equations of Dali seems to provided a higher R^2. An increase of 1 mm in rice length would result in a price increment of 26 fen/kg, while 1% increase in head rice recovery would increase price by 0.8 fen/kg. The return to 1% decrease in amylose content would raise price by 3 fen/kg. Together, these variables explained about 78% of price variation in the local domestic markets.

Table 4.20 Regression estimates of implicit prices for rice quality characteristics in three locations in Yunnan, 1994 (dependent variable is price in yuan/kg; t- statistics in parenthesis).

Location regression	Kunming	Dali	Xishuangbanna	All
No. of samples	20	20	20	60
Intercept	2.87 (0.76)	0.192 (0.15)	2.02 (0.63)	1.92 (1.30)
Chalkiness score %	0.002 (0.17)	0.001 (0.57)	0.007 (0.97)	-0.001 (-0.20)
Grain length mm	0.25 (1.60)	0.26 (3.38)**	0.35 (1.40)	0.31 (3.33)**
Percentage of head rice	0.04 (1.28)	0.008 (1.74)*	0.013 (1.18)	0.007 (1.01)
Amylose content %	-0.07 (-1.36)	-0.03 (-3.26)**	-0.06 (-1.74)	-0.044 (-2.45)**
Gel consistency mm	-0.012 (-0.89)	-0.002 (-0.03)	-0.062 (-0.58)	-0.012 (-1.96)*
Alkali spreading value	-0.36 (-1.78)*	0.022 (0.35)	0.019 (0.21)	-0.095 (-1.51)
Protein content %	-0.34 (-1.70)	0.068 (0.88)	0.05 (027)	-0.009 (-0.10)
Zinc content mg/kg	0.08 (0.86)	-0.02 (-1.17)	-0.11 (-1.33)	0.0012 (0.04)
D_1				0.27 (1.11)
D_2				0.82 (3.87)**
R^2	0.7371	0.7763	0.5358	0.6362
Durbin watson	2.17	1.69	2.17	2.05

* Significant at 5-10% level; ** Significant at 1% level;
D_1, D_2 represented Kunming and Dali, respectively.

The last set of regression equation was performed on set of data of indica and japonica rice. The regressions of market price on milled indica and japonica rice were shown in Table 4.21.

Regression results demonstrated that, less quality characteristics significantly affected the price of indica rice than that of japonica rice (including upland rice). The significant determinants of irrigated japonica along with upland rice were grain length, amylose content, gel consistency, alkali spreading value, and protein content. However, in irrigated japonica rice, the significant determinant was only alkali spreading value. The significant determinants of irrigated indica rice was percentage of whole rice. Together, these attributes could explain 76%, 53%, and 81% of price variation in irrigated indica, irrigated japonica rice, and irrigated japonica rice along with upland rice, respectively.

Total percentage of head rice of milled rice had a significant positive effect on price of milled indica rice. An increase in 1% head rice led to increase price by 3.4 fen/kg. In japonica rice, quality characteristics of grain length, gel consistency, alkali spreading value were significantly and positively associated with price. An increase of 1 mm grain length would raise price by 64 fen/kg. Similarly, increase of 1 mm or 1 unit of gel consistency and alkali spreading value would result in about 1 fen/kg return in price. In contrast, amylose content had a significantly negative effect on price of japonica rice in the domestic markets. A potential return for reducing 1% amylose content would to be about 3 fen/kg.

Table 4.21 Regression estimates of implicit prices for rice quality characteristics of different types of milled rice in Yunnan, 1994 (dependent variable is price in yuan/kg; t- statistics in parenthesis).

Genotype regression	Irrigated Indica Rice	Irrigated Japonica & Upland Rice	Irrigated Japonica Rice
No. of samples	22	38	29
Intercept	-1.43 (-0.44)	-1.46 (-1.23)	3.61 (3.18)**
Chalkiness score %	-0.01 (-1.23)	-0.004 (-1.51)	-0.001 (-0.09)
Grain length mm	0.18 (1.04)	0.64 (5.47)**	-0.21 (-1.13)
Percentage of head rice	0.034 (3.12)**	0.001 (0.28)	0.003 (1.08)
Amylose content %	0.009 (0.24)	-0.028 (-2.35)*	-0.006 (-0.88)
Gel consistency mm	-0.012 (-1.37)	0.01 (1.72)*	0.005 (1.58)
Alkali spreading value	-0.12 (-0.127)	0.011 (1.92)*	-0.084 (-2.06)*
Protein content %	-0.065 (-0.34)	-0.156 (-2.19)*	-0.05 (-1.16)
Zinc content mg/kg	0.12 (1.01)	0.025 (1.45)	-0.01 (-1.08)
R^2	0.7576	0.8123	0.5259
Durbin watson	2.68	1.84	1.64

* Significant between 5 to 10% level; ** Significant at 1% level.

4.3 Field Experiment

4.3.1 Environmental Conditions

The average mean monthly temperature was between 16.5 to 19.8°C during crop growing period. Distribution of rainfall was from May to September, which monthly mean rainfall ranged from 93.5 to 216.3 mm.

The initial soil conditions in the experimental field was characterized as pH 7.18 to 7.23, and contained 3.02% OM, 120, 76, 12 ppm of effective nitrogen (N), potassium (K), phosphorous (P), 0.9 ppm available zinc (Zn), respectively.

4.3.2 Crop Phenology

Rice was harvested at 208 days after sowing (from March 21 to October 15, 1994). Parts of crop phenological date were presented in appendix c-1.

Analysis results (Table 4.22) showed that crop phenological date were differed significantly ($P<0.01$) among three varieties. In Yungeng, the panicle emergence, flowering, and maturity were oberved at 134, 142, and 198 days after sowing. A similar crop phenological date was observed in Xunza 29 and Hexi 34, which the panicle emergence, flowering, and maturity occurred at 130, 140, and 196 days after sowing.

On the other hand, it was evidenced that plant development stage in terms of flowering and maturity, were affected significantly ($P<0.05$) by Zn application, which were advanced about 2 days with Zn applied.

A significant interaction ($P<0.05$) between Zn and P was also found for flowering date. Results indicated that flowering was advanced 1-2 days as increasing in level of P application without Zn applied. In contrast, P application had no effect on increasing plant development when Zn was incorporated.

Table 4.22 Summary of analysis of variance (ANOVA) of crop phenology.

Source of variance	DF	Panicle emergence	Flowering	Maturity
Replication	2	NS	NS	NS
Zinc (A)	1	NS	*	*
Error	2			
Phosphorus (B)	2	NS	NS	NS
Error	4			
A×B	2	NS	*	NS
Error	4			
Genotype (C)	2	**	**	**
A×C	2	NS	NS	NS
B×C	4	NS	NS	NS
A×B×C	4	NS	NS	NS
Error	24			
C.V.%		2.02	1.58	1.11

*Significant at 5% level; **Significant at 1% level; ^{NS} Non significant.

4.3.3 Grain Yield

A significant interaction ($p<0.05$) (Table 4.23) among varieties, Zn and P was observed for grain yield. In general, P tended to inrease grain yield, but the response depended on the Zn level as well as varieties.

The application of P increased the grain yield of both Hexi 35 and Yungeng 34 with or without Zn applied, but more strongly with Zn applied, especially for Hexi 35 (Figure 4.12 and 4.13). However, the grain yield of Xunza 29 decreased with increasing of P application when Zn was not incorporated. With Zn applied, Xunza 29 responded to P application at rate of 150 kg/ha, but a decline in grain yield was identified when P was further applied to 200 kg/ha.

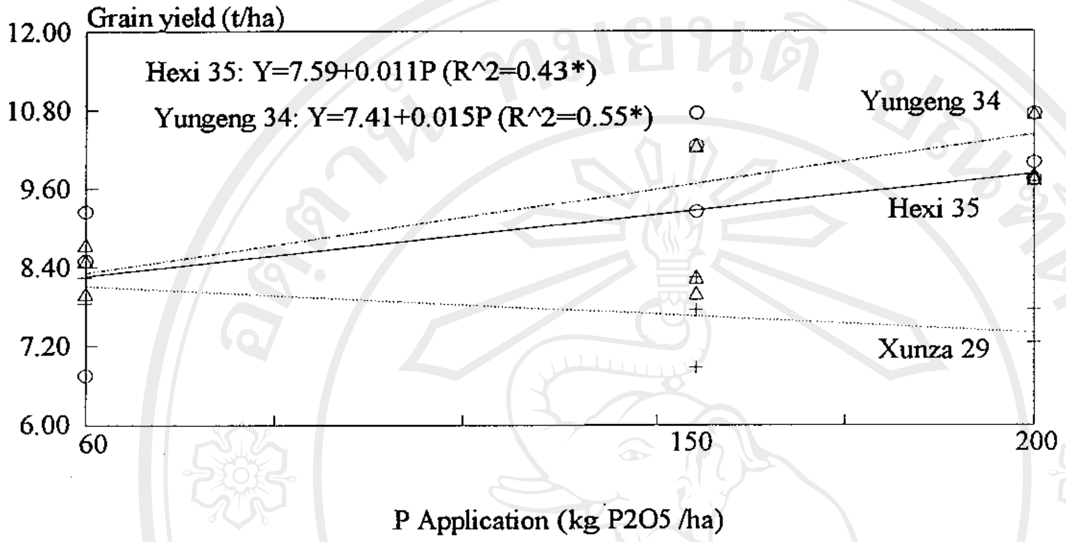

Figure 4.12 Effects of P application (without Zn applied) on grain yield of three rice varieties (*significant at 5% level).

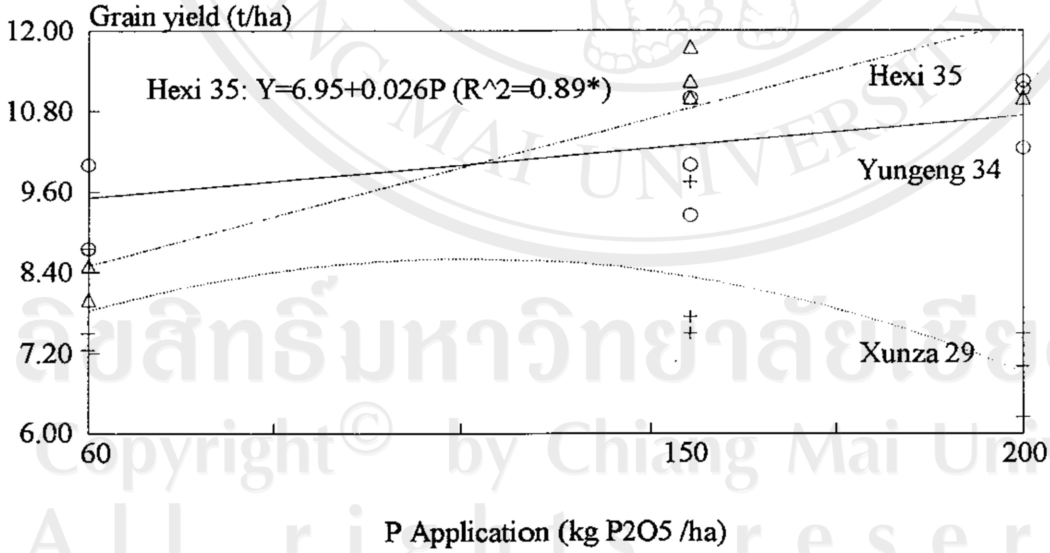

Figure 4.13 Effects of P application (with Zn applied) on grain yield of three rice varieties (*significant at 5% level).

Table 4.23 Summary of analysis of variance (ANOVA) of grain yield and yield components.

Source of variance	DF	Grain Yield (t/ha)	Panicle weight (g/plant)	Percentage of filled grain (%)	Thousand grain weigh (g)	Number of productive tiller (/plant)	Number of total grain (/panicle)
Replication	2	NS	NS	NS	NS	NS	NS
Zinc (A)	1	NS	NS	NS	NS	NS	NS
Error	2						
Phosphorus (B)	2	*	**	NS	NS	NS	NS
Error	4						
A×B	2	NS	NS	NS	NS	NS	NS
Error	4						
Genotype (C)	2	**	**	**	**	**	**
A×C	2	*	NS	NS	NS	NS	NS
B×C	4	**	**	NS	NS	NS	NS
A×B×C	4	*	NS	NS	NS	NS	NS
Error	24						
C.V.%		16.82	11.74	6.78	8.96	16.15	17.01

*Significant at 5% level; **Significant at 1% level; ^{NS} Non significant.

4.3.4 Yield Components

◆ **Panicle weight**

It was observed that panicle weight differed significantly (P<0.01) from variety to variety (Table 4.23). Average panicle weight of Xunza 29, Hexi 35, and Yungen 34 were 21.8, 25.4, and 25.6 g/plant, respectively.

An interaction between P and genotype affected panicle weight significantly (P <0.05) (Table 4.23). Generally, the panicle weights were increased by P applied, but response differed among varieties. Panicle weight of Hexi 35 and Yungeng 34 increased linearly as increasing of amount of P application. In Xunza 29, panicle weight showed little or no response to P (Figure 4.14).

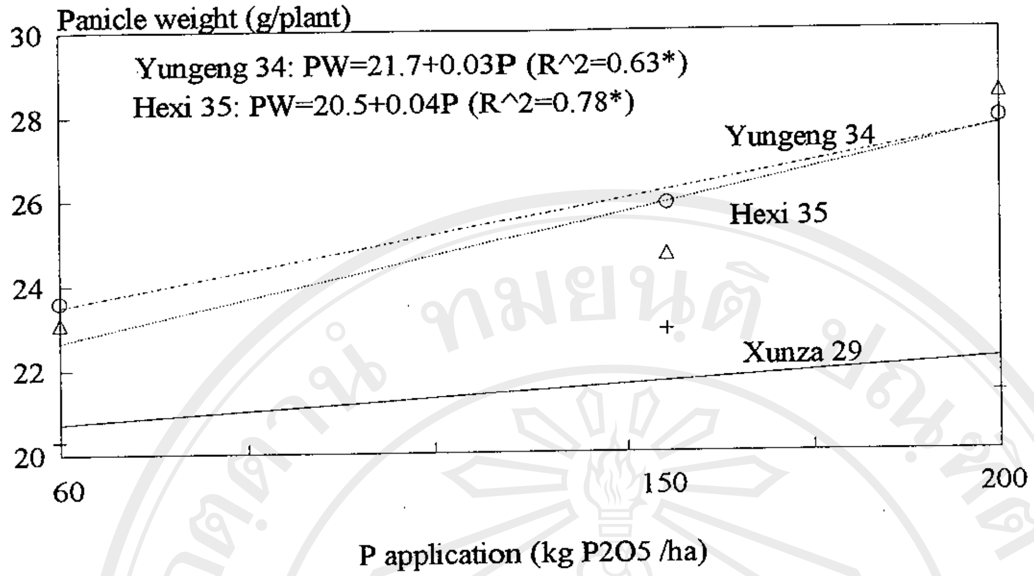

Figure 4.14 Interaction of P×V in panicle weight (g/plant) (*significant at 5% level).

◆ Percentage of filled grains

Zn and P did not show significant ($P>0.05$) effect on percentage of filled grain. The percentage of filled grain of main tillers varied significantly ($p<0.01$) among three varieties (Table 4.23). Hexi 35 gave the highest percentage of filled grain, which was 90.2%. Percentage of filled grain were 84.6 and 80.4% with Yungeng 34 and Xunza 29.

◆ Thousand grain weight

Significant difference ($P<0.01$) was found in thousand grain weight among three varieties (Table 4.23). The thousand grain weights of Yungeng 34, Hexi 35, and Xunza 29 were 30.6, 26.9, and 25.1g, respectively.

◆ **Productive tillers per plant**

The productive tiller per plant was not detected different responses to Zn and P applied, were varied significantly ($P<0.01$) among varieties (Table 4.23). The average number of productive tiller was 5.9, 5.1, 4.4 in Xunza 29, Hexi 35, and Yungeng 34, respectively.

◆ **Total grains per panicle**

The total grain numbers per panicle of main tiller with three varieties showed little or no response to Zn and P applied, and were significant different ($P<0.01$) among varieties (Table 4.23). The average total grain number per panicle was 227, 194, and 182 in Yungeng 34, Hexi 35, and Xunza 29, respectively.

4.3.5 Agronomic Characteristics

◆ **Total biomass**

At harvesting, dry weight of the total biomass (straw and grain) with three varieties were found significant differences ($P<0.01$) (Table 4.24). The average total biomass of Xunza 29, Hexi 35 and Yungeng 34 were 16.2, 18.3, and 20.1 t/ha.

It was found that total biomass was affected significantly ($P<0.05$) by P application (Table 4.24). Total biomass generally increased as increasing level of P, which was 16.9, 18.6, and 19.0 t/ha when 60, 150, and 200 kg P_2O_5 /ha was applied regardless application of Zn and variety.

♦ Harvest index

Analysis of variance results revealed that harvest indices (HI) of three varieties did not significantly responses ($p>0.05$) to Zn and P applied. However, results showed significant difference in HI among varieties (Table 4.24). The average HI was 4.8, 4.9, and 5.4 with respect to Xunza 29, Hexi 35, and Yungeng 34.

Table 4.24 Summary of analysis of variance (ANOVA) of agronomic characteristics.

Source of variance	DF	Total biomass (t/ha)	Harvest index	Plant height (cm)
Replication	2	NS	NS	NS
Zinc (A)	1	NS	NS	*
Error	2			
Phosphorus (B)	2	*	NS	NS
Error	4			
A×B	2	NS	NS	NS
Error	4			
Genotype (C)	2	**	**	**
A×C	2	NS	NS	NS
B×C	4	NS	NS	NS
A×B×C	4	NS	NS	NS
Error	24			
C.V.%		15.04	8.25	11.10

*Significant at 5% level; **Significant at 1% level; ^{NS} Non significant.

♦ Plant height

Table 4.24 indicated that plant height responded significantly ($P<0.05$) to Zn application, which was reduced about 4.5 cm by Zn applied. Nevertheless, plant height was mainly determined by genetic characteristics, it showed significant difference ($P<0.01$) among varieties. The average plant height was 84, 97, and 108 cm in Xunza 29, Hexi 35, and Yungeng 34, respectively.

4.3.6 Zn Distribution

Statistic results (Table 4.25) indicated that Zn content of stem, leaf, and grain at final harvesting were complicated by either the interaction of Zn with P or the interactions among three factors of Zn, P, and variety.

Table 4.25 Summary of analysis of variance (ANOVA) of Zn content in stem, leaf, grain, and total dry matter.

Source of variance	DF	Stem (mg/kg	Leaf (mg/kg)	Grain (mg/kg)	Total content in grain (g/ha)	Total uptake (g/ha)
Replication	2	NS	NS	NS	NS	NS
Zinc (A)	1	NS	NS	NS	NS	NS
Error	2					
Phosphorus (B)	2	NS	NS	NS	NS	NS
Error	4					
A×B	2	**	NS	*	NS	NS
Error	4					
Genotype (C)	2	**	**	**	**	**
A×C	2	*	NS	NS	NS	NS
B×C	4	*	NS	*	NS	NS
A×B×C	4	NS	*	NS	*	NS
Error	24					
C.V.%		31.13	14.43	12.46	15.61	18.62

*Significant at 5% level; **Significant at 1% level; ^{NS} Non significant.

◆ **Stem**

Zn content of stem varied significantly (p<0.01) among varieties. Xunza 29 had the highest Zn content in stem (43.46 mg/kg). The lowest Zn content in stem was found in Hexi 35 which was 22.20 mg/kg. Stem of Yungeng 34 contained 30.22 mg/kg of Zn.

Zn content in stem was affected significantly (P<0.05) by interaction between Zn and P. In general, an increasing in level of P application trended to increase Zn content in stem when there was no Zn applied. In contrast, when Zn was applied, the Zn content decreased as level of P application increased (Figure 4.15).

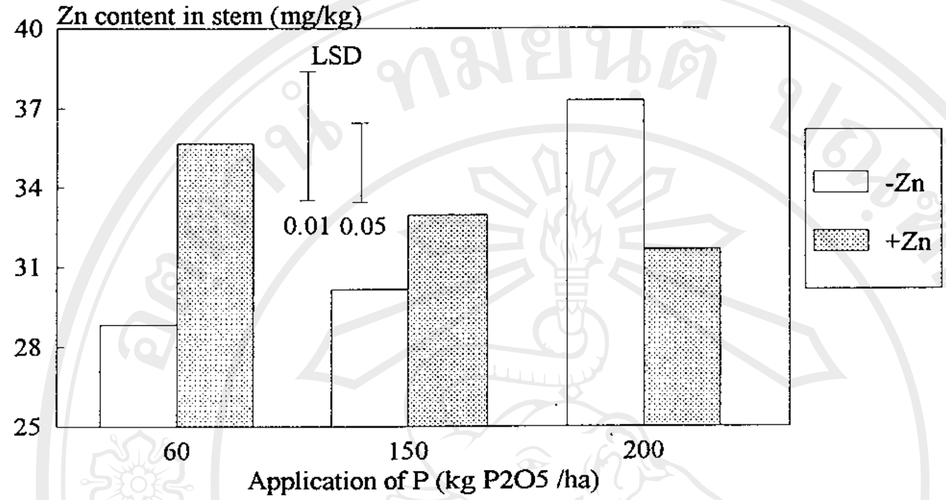

Figure 4.15 Interaction of Zn×P in Zn content of stem (mg/kg).

♦ **Leaf**

Three-way interaction (Zn× P× V) showed significance ($P<0.05$) in Zn content of leaf. Zn content of leaf in Hexi 35 and Yungeng 34 was affected by P, but the response was differed from with Zn and without Zn applied. With Zn applied, Zn content of leaf in Yungeng 34 tented to be reduced by increase of P (Table 4.26). In contrast, Zn content of leaf in Hexi 35 increased as increasing in P when Zn was applied. Without Zn applied, Zn content of leaf in Hexi 35 and Yungeng 34 responded (decreased) to P application at 150 kg P_2O_5 /ha, and it tended to increase slightly when P was further applied to 200 kg P_2O_5 /ha. However, Zn content of Xunza 29 showed little or no response to P and Zn.

Table 4.26 Effects of Zn and P application on Zn content (mg/kg) of leaf (whole leaf) with three rice varieties (at final harvest stage).

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	18.34	17.99	18.63	18.39	19.55	17.69
Hexi 35 Yungeng	20.48	14.32	16.49	15.96	16.47	21.07
34	19.08	16.68	19.90	21.02	21.44	20.85

$LSD_{0.05}$ =3.51 (Zn×P×V)

- **Grain**

Analysis of variance results indicated that Zn content of grain was significantly ($P < 0.05$) affected by an interaction of Zn× P. It was found that Zn content of grain tended to increase as increasing in level of P when no Zn applied. In contrast, when Zn applied, Zn content in grain was decraesed by increasing P application (Figure 4.16).

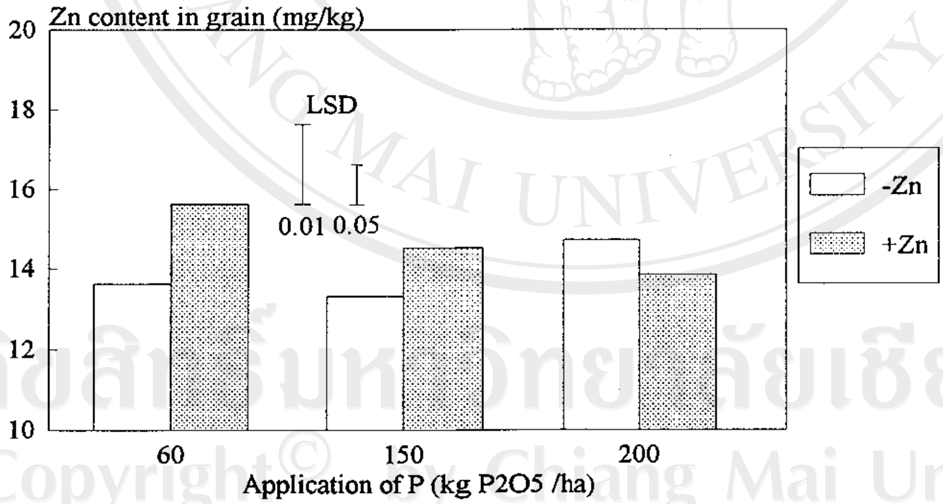

Figure 4.16 Interaction of Zn×P in Zn content of grain (mg/kg).

Zn content in grain also showed significant difference (P<0.01) among varieties. In general, Xunza 29 had the highest Zn content in grain (15.7 mg/kg). The lowest Zn content in grain was found in Yungeng 34, which was 13.9 mg/kg. The average Zn content in grain of Hexi 35 was 13.3 mg/kg.

However, three-way interaction (Zn×P×V) was significant (P<0.05) regarding total amount of Zn content of grain. Despite Zn content (mg/kg) in grain was depressed by high P application when Zn was applied, the total amount of Zn content (g/ha) of grain was generally enhanced either by Zn or increasing of P applied, particularly with respect to Hexi 35 and Yungeng 33 (Figure 4.17 and 4.18).

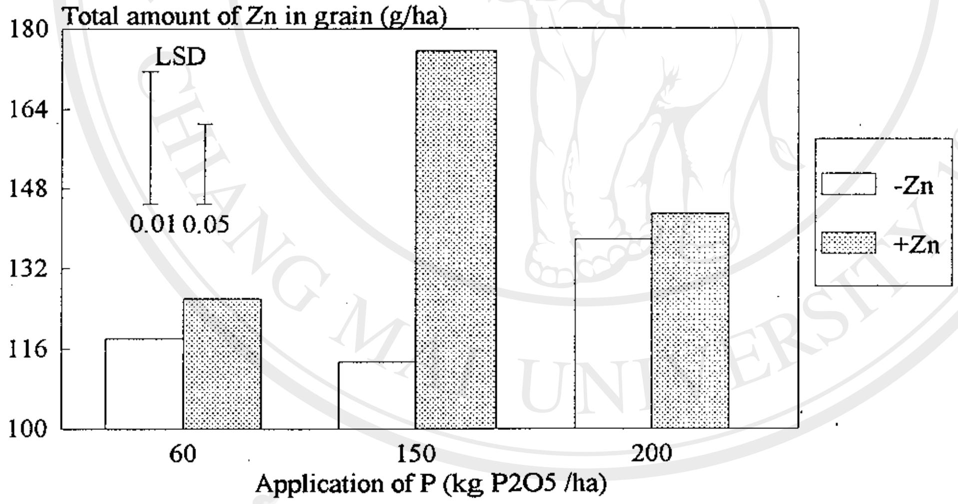

Figure 4.17 Effects of P and Zn application on total Zn content of grain in Hexi 35.

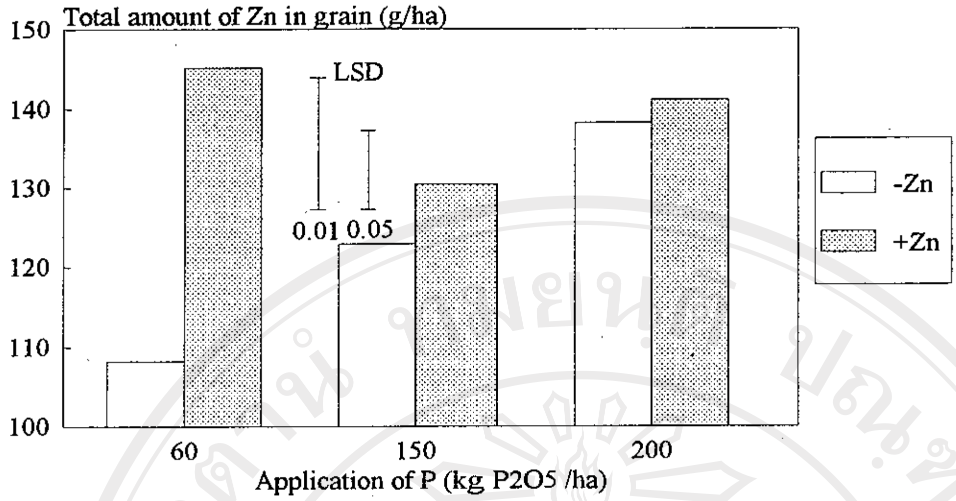

Figure 4.18 Effects of P and Zn application on total Zn content of grain in Yungeng 34.

◆ Total Zn uptake per ha

It was apparent that total amount of Zn uptake (including total Zn in dry weight of stem, leaf, and grain) was significant difference ($P<0.01$) from variety to variety. The highest total amount of Zn uptake was observed in Yungeng 34, which was 38.8 g/ha. The lowest total amount of Zn uptake was 30.4 g/ha in Hexi 35. The average total amount of Zn uptake in Xunza 29 was 38.3 g/ha, respectively.

Although the Zn contents mg/kg in stem, leaf blade, and grain at final harvest were highly interacted by a number of factors, the total amount of Zn uptake showed no significant responses to P and Zn application (Table 4.25).

The interaction of Zn×V seemed no significant ($P=0.06$) in total Zn uptake. However, there was a tendency plant accumulated high total Zn in dry matters with Zn applied, its influence was also depended upon varieties. It was found that the total amount of Zn uptake in Hexi 35 and Yungeng 34 increased with Zn applied. The total amount of Zn uptake in Xunza 29 showed no response to Zn application (Figure 4.19).

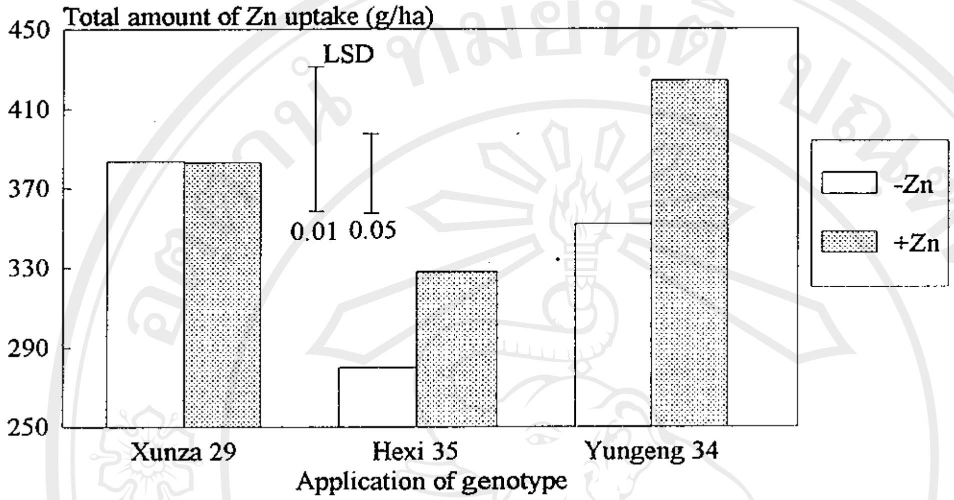

Figure 4.19 Interaction of Zn×V on total amount of Zn uptake.

◆ **Total Zn distribution in different plant parts**

The proportion of Zn distribution in stem, leaf, and grain showed on no significant (P>0.05) response to Zn and P application (Table 4.27). Analysis of variance results showed significant differences (P<0.01) in Zn distribution among varieties. This indicated that different cultivars had various capabilities to absorb and translocate Zn into stem, leaf and seed. Computing total amount of Zn content g/ha of plant dry matters at harvest stage, similar trends of Zn distribution ratio were found in Xunza 29 and Yungeng 33, which showed high proportion in stem, followed by grain and less in leaf. In Hexi 35, plant could translocate more Zn in grain than that of stem and leaf (Figure 4.20).

Table 4.27 Summary of analysis of variance (ANOVA) of Zn proportion (%) in stem, leaf, and grain.

Source of variance	DF	Stem	Leaf	Grain
Replication	2	NS	NS	NS
Zinc (A)	1	NS	NS	NS
Error	2			
Phosphorus (B)	2	NS	NS	NS
Error	4			
A×B	2	NS	NS	NS
Error	4			
Genotype (C)	2	**	**	**
A×C	2	NS	NS	NS
B×C	4	NS	NS	NS
A×B×C	4	NS	NS	NS
Error	24			
C.V.%		19.84	17.54	19.71

*Significant at 5% level; **Significant at 1% level; ^{NS} Non significant.

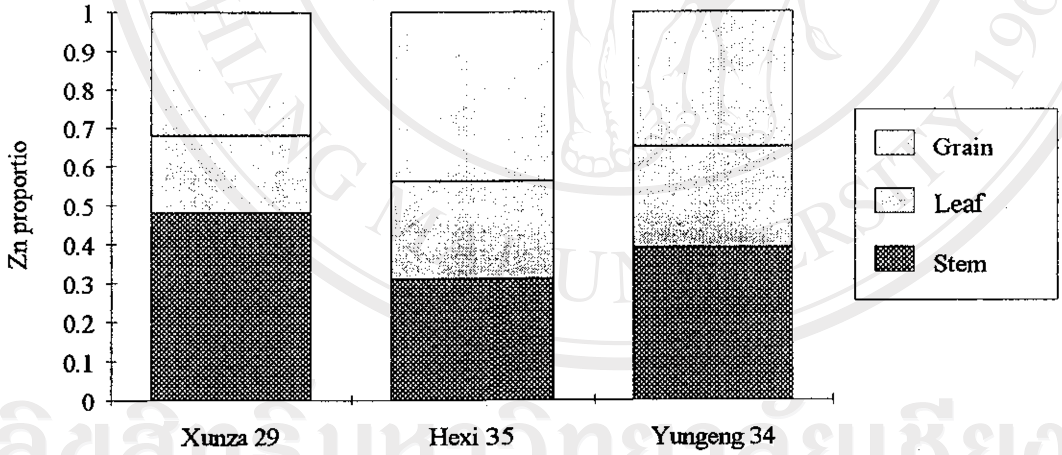

Figure 4.20 Average Zn proportion in stem, leaf, and grain of three rice varieties (at final harvest stage).

4.3.7 P Distribution

♦ Stem

Analysis of variance results revealed that Zn and P application had no significant (P>0.05) effect on P content in stem. It was found that P content in stem was significant difference (P<0.01) among varieties (Table 4.28). In general, P content in stem was 0.094, 0.069, and 0.078% in Xunza 29, Hexi 35, and Yungeng 34.

Table 4.28 Summary of analysis of variance (ANOVA) of P content in stem, leaf grain, and total dry matter.

Source of variance	DF	Stem (%)	Leaf (%)	Grain (%)	Total content in grain (kg/ha)	Total uptake (kg/ha)
Replication	2	NS	NS	NS	NS	NS
Zinc (A)	1	NS	NS	NS	NS	NS
Error	2					
Phosphorus (B)	2	NS	*	NS	*	*
Error	4					
A×B	2	NS	NS	NS	NS	*
Error	4					
Genotype (C)	2	**	**	NS	**	NS
A×C	2	NS	NS	NS	NS	NS
B×C	4	NS	NS	NS	NS	NS
A×B×C	4	NS	**	NS	NS	NS
Error	24					
C.V.%		31.51	19.08	11.81	19.03	17.06

*Significant at 5% level; **Significant at 1% level; ^{NS} Non significant.

♦ Leaf

Analysis of variance results (Table 4.28) showed that P content in leaf was strongly affected (P<0.01) by three-way interaction (Zn×P×V). Generally, P content in leaf tented to increase with increasing level of P application, but response was also depended upon level of Zn and variety (Table 4.29). Without Zn applied, P content in leaf of Xunza 29 and Hexi 35 increased with P to 150 kg P_2O_5 /ha, but were depressed when P was further applied to 200 kg P_2O_5 /ha. On the other hand, with Zn applied, P content in leaf of Xunza 29 and Hexi 35 tended to increase with increasing level of P. Similarly, average P content in leaf of Yungeng 34 was increased linearly as increasing of level of P with or without Zn applied.

Table 4.29 Effects of Zn and P application on P content (%) in leaf with three rice varieties (at final harvest stage).

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	0.106	0.143	0.121	0.111	0.127	0.162
Hexi 35	0.097	0.130	0.118	0.098	0.120	0.117
Yungeng 34	0.089	0.092	0.118	0.090	0.117	0.119

$LSD_{0.05}$=0.01 (Zn×P×V)

- **Grain**

In general, there was no significant differences for P content in grain among all treatments (Table 4.28). The mean P content in grain of all treatments was 0.125%.

On the other hand, it was observed that the total P content in grain varied significantly ($P<0.01$) from variety to variety (Table 4.28). The average total P content in grain were 9.85, 12.14, 11.95 kg/ha in Xunza 29, Hexi 35 and Yungeng 34, respectively. It was found that total P content in grain was increased significantly ($P=0.05$) as increasing of P applied, which was 10.5, 11.3, and 12.1 kg/ha in 60, 150, and 200 kg P_2O_5 /ha application regardless of application of Zn and variety.

◆ Total P uptake P per ha

A significant interaction of Zn×P was evidenced for total amount of P uptake (including total P in dry weight of stem, leaf, and grain). Figure 4.21 demonstrated that total amount of plant P uptake increased linearly as increasing P with or without Zn applied, but the response was more profound when Zn was applied.

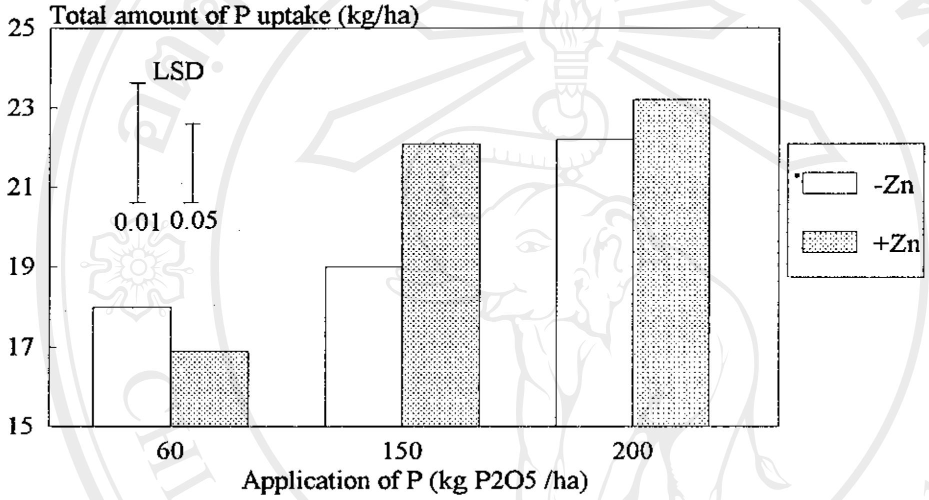

Figure 4.21 Interaction of Zn×P in total amount of P uptake (kg/ha).

◆ Total P distribution in different plant parts

In general, it was found that proportion of P distribution in stem, leaf, and grain were significant difference ($P<0.01$) among varieties (Table 4.30). This also indicated that varieties were differences in capabilities of absorbing and translocating P into stem, leaf and seed. However, accounting total amount of P of plant dry matters at harvest stage, similar trends of P distribution ratio were found inl three varieties, which showed high proportion in seed, followed by leaf and less in stem (Figure 4.22). Additionally, the proportion of P distribution in leaf was found to be affected significantly by P application, which tended to be increased by increase of level of P application. The average proportion of P distribution in leaf was 24.0, 26.9, and 26.3% when 60, 150, and 200 kg P_2O_5 /ha was applied regardless application of Zn and variety.

Table 4.30 Summary of analysis of variance (ANOVA) of P proportion (%) in stem, leaf, and grain.

Source of variance	DF	Stem	Leaf	Grain
Replication	2	NS	NS	NS
Zinc (A)	1	NS	NS	NS
Error	2			
Phosphorus (B)	2	NS	*	NS
Error	4			
A×B	2	NS	NS	NS
Error	4			
Genotype (C)	2	**	**	**
A×C	2	NS	NS	NS
B×C	4	NS	NS	NS
A×B×C	4	NS	NS	NS
Error	24			
C.V.%		26.66	15.04	13.15

*Significant at 5% level; **Significant at 1% level; ^{NS} Non significant.

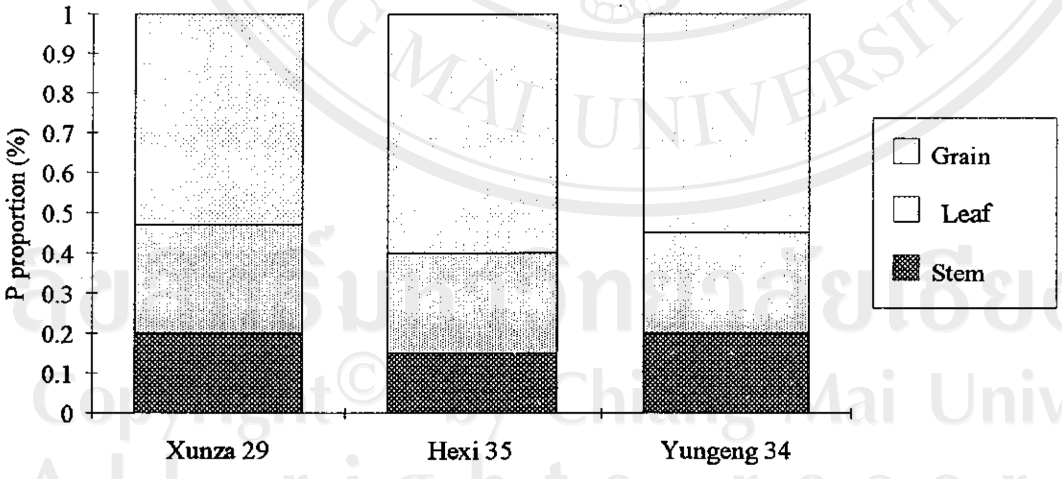

Figure 4.22 Average P proportion in stem, leaf, and grain of three rice varieties (at harvest stage).

4.3.8 Grain Physicochemical Characteristics

◆ Grain physical characteristics

The physical quality characteristics of grain including grain size and shape, and chalkiness were found non significant ($P>0.05$) association with Zn and P application, but they were mainly determined ($P<0.01$) by varieties (Table 4.31). The average grain size, shape, and chalkiness of three varieties were presented in Table 4.29. Noticeably, the degree of chalkiness of three varieties were normally less than 15%, particularly with respected to Xunza 29 and Hexi 35 which were semi-translucency varieties.

Table 4.31 Summary of analysis of variance (ANOVA) of physical quality characteristics of grain.

Source of variance	DF	Output of brown rice (%)	Milled rice recovery (%)	Head rice recovery (%)	Grain length (mm)	Grain width (mm)	Hardness of kernel (Newton)	Chalki -ness (%)
Replication	2	NS	NS	NS	NS	NS	NS	NS
Zinc (A)	1	NS	NS	NS	NS	NS	*	NS
Error	2							
Phosphorus (B)	2	NS	NS	*	NS	NS	NS	NS
Error	4							
A×B	2	NS	NS	NS	NS	NS	NS	NS
Error	4							
Genotype (C)	2	NS	NS	NS	**	**	**	**
A×C	2	NS	NS	NS	NS	NS	NS	NS
B×C	4	NS	NS	NS	NS	NS	NS	NS
A×B×C	4	NS	NS	NS	NS	NS	NS	NS
Error	24							
C.V. %		2.11	2.41	4.40	5.26	2.36	18.42	75.93

*Significant at 5% level; **Significant at 1% level; ^{NS} Non significant.

It was found that the degree of grain hardness significantly reduced significantly ($P<0.05$) with Zn applied regardless application of P and variety. On the other hand, results indicated that the grain hardness was also genotypically determined (Table 4.31), which were varied significantly ($P<0.01$) among varieties (Table 4.32). The grain hardness showed no response to P application.

Milling quality including output of brown rice, milled rice recovery showed no difference ($P>0.05$) among all treatments (Table 4.31). The mean value of output of brown rice, milled rice recovery of all treatment were 84.45 and 76.34%, respectively.

Table 4.32 Average physical quality characteristics of rice grain with three varieties.

Var./Characteristics	Grain length (mm)	Grain width (mm)	Chalkiness score (%)	Hardness of kernel (Newton/grain)
Xunza 29	4.7	2.9	4.4	45.7
Hexi 35	4.8	3.0	2.7	45.9
Yungeng 34	5.3	2.9	13.1	50.9

Head rice recovery

Analysis of variance results show that one of the important milling quality characteristics, head rice recovery, was significantly ($p<0.05$) affected by P application (Table 4.31). Regardless application of Zn and variety, Figure 4.23 illustrated that head rice recovery generally tended to increase linearly as increasing amount of P application.

Head rice recovery showed no significant ($P>0.05$) response to Zn application regardless of P and varieties. However, it was a tendency that head rice recovery decreased slightly (0.55%) when Zn applied. Noticeably, head rice recovery was found no difference ($p>0.10$) among three varieties (Table 4.31).

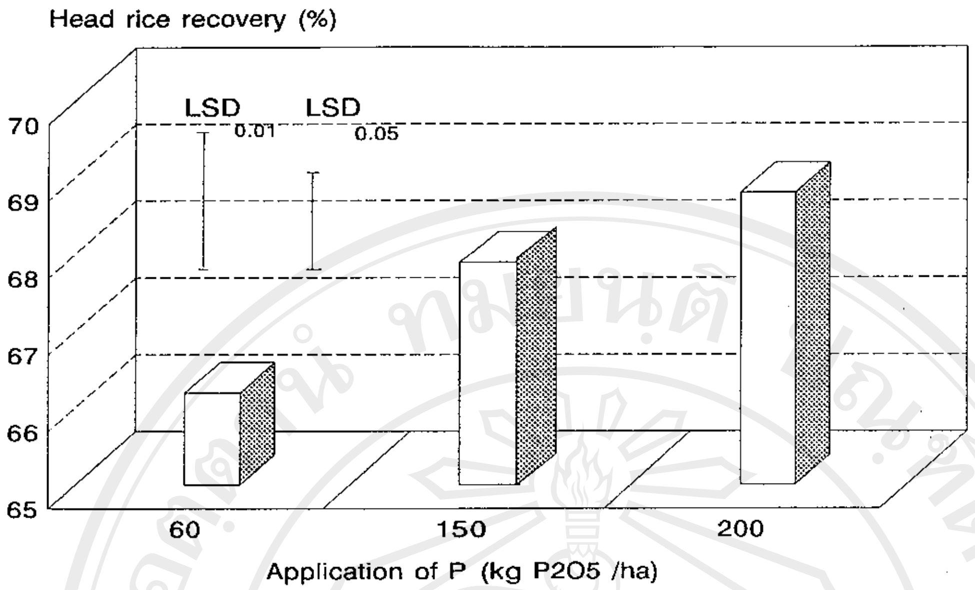

Figure 4.23 Effects of P application on head rice recovery.

◆ **Grain bio-chemical characteristics**

Protein content

Protein content of grain was significant difference ($P<0.01$) among three rice varieties (Table 4.33). Among these, the highest protein content of grain was generally observed in Xunza 29 (9.67%). Hexi 35 gave the lowest protein content in grain, which was 8.86%. The average value of protein content in grain of Yungeng 34 was 9.16%.

P application had remarkable ($p<0.01$) effects on protein content of grain. As the results, protein content of grain tended to increase as increasing of amount of P application (Figure 4.24). Zn application showed non significant influence on protein content of grain, but there was a tendency that protein contents of grain were declined slightly (0.8%) by Zn applied with regardless of application of P and variety (Figure 4.25).

Table 4.33 Summary of analysis of variance (ANOVA) of chemical quality characteristics of grain.

Source of variance	DF	Amylose content (%)	Protein content (%)	Total protein in grain (kg/ha)
Replication	2	NS	NS	NS
Zinc (A)	1	NS	NS	NS
Error	2			
Phosphorus (B)	2	NS	**	**
Error	4			
A×B	2	NS	NS	NS
Error	4			
Genotype (C)	2	**	**	**
A×C	2	NS	NS	NS
B×C	4	NS	NS	**
A×B×C	4	NS	NS	NS
Error	24			
C.V.%		8.80	8.59	15.20

*Significant at 5% level; **Significant at 1% level; ^{NS} Non significant.

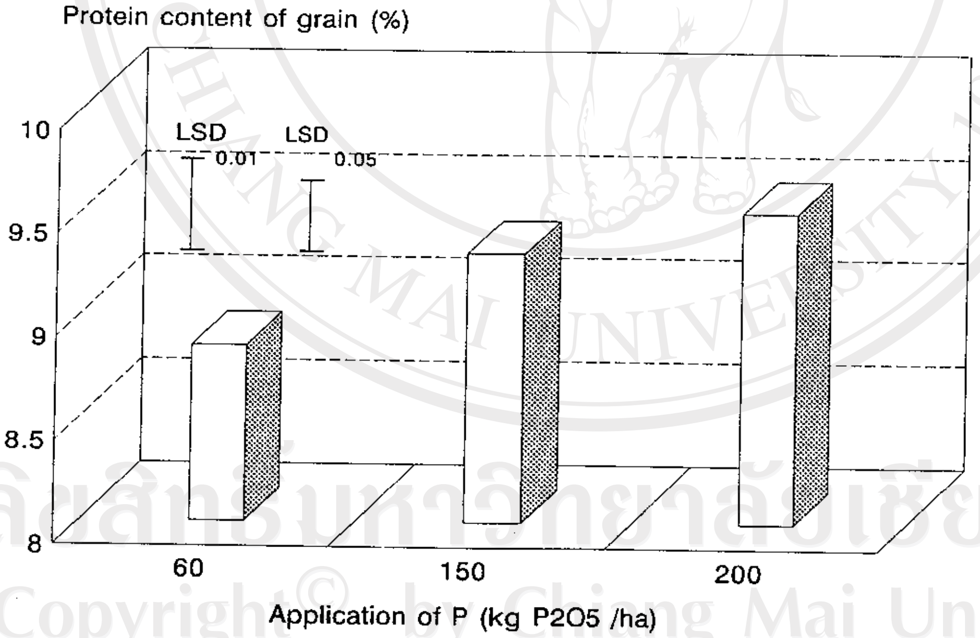

Figure 4.24 Effects of P application on protein content (%) of rice grain.

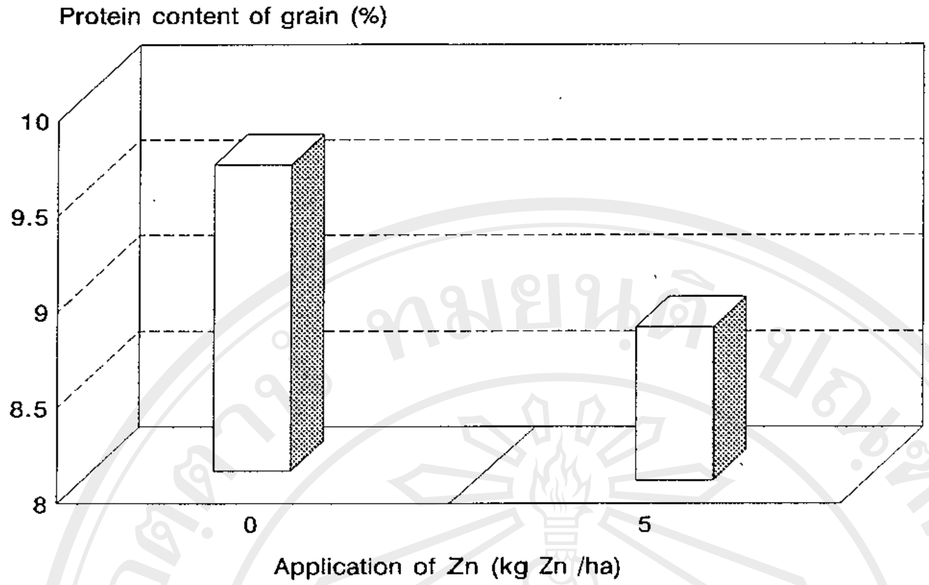

Figure 4.25 Effects of Zn application on protein content (%) of rice grain

The total amount of protein content in grain corresponded strongly (P<0.01) to various P applications, but the response was also affected significantly (P<0.01) by interaction of P× V. Increase of the total grain protein in grain due to P applications was more profound with Hexi 35 and Yungeng 34 (Figure 4.26).

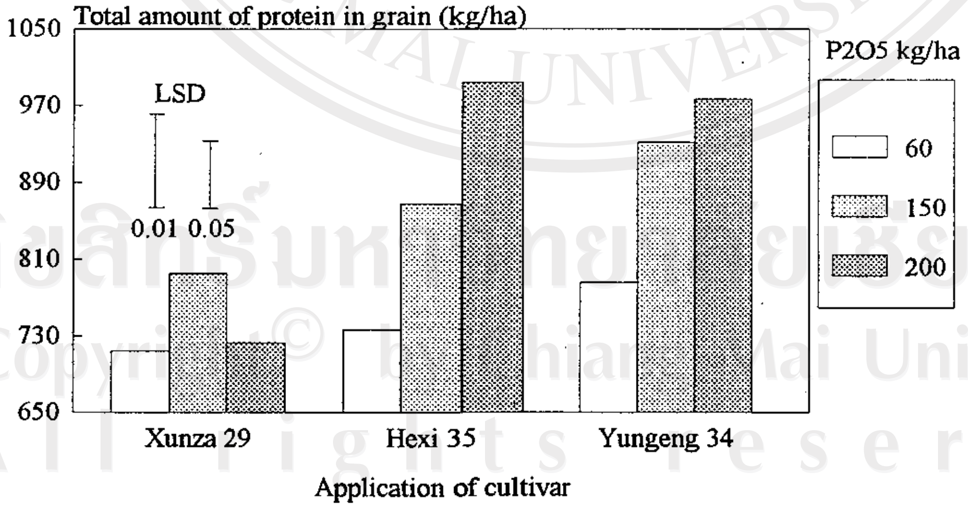

Figure 4.26 Interaction of P×V in total protein content of grain (kg/ha).

Amylose content

Amylose content of grain was mainly determined by variety, it was significant ($p < 0.01$) difference among three varieties (Table 4.33). The highest amylose content of grain was observed in Xunza 29 (20.5%). The lowest amylose content of grain was given by Hexi 35, which was 17.3%. The average value of amylose content in gain of Yungeng 34 was 18.9%.

Table 4.33 showed that response of amylose content of grain to Zn and P application was non significant ($P>0.05$). Nevertheless, it was found that amylose content of grain tended to be increased slightly (0.8%) by Zn applied. The average amylose contents of grain were 18.5 and 19.3% with 0 and 5 kg Zn /ha application.

4.3.9 Correlation Among Various Characters

Table 4.34 gave details about correlation among various characters of varieties under treatments (excluding Xunza 29).

The grain yield had high correlation with biomass ($r=0.68$) and panicle weight ($r=0.56$). Grain yield was negatively associated with protein content, but correlation between yield and protein was not significant ($r=-0.24$).

The Zn and P contents of grain were not associated significantly with protein content of grain ($r=0.13$ and $r=0.18$). There was significant positive correlation between the degree of hardness and protein content of grain ($r=0.52$). Apart from this, there was a significant negative association between protein content and amylose content of grain (r=-0.35).

Amylose content of grain evidently related to chalkiness, Zn content of grain, P content of grain, texture hardness of grain, and total biomass. There was positive relationship between amylose content of grain and chalkiness (r=0.51), P content of grain (r=0.41), total biomass (r=0.45). In contrast, amylose content was negatively related to Zn content of grain (r=-0.38) and hardness of grain (r=-0.37).

As expected, head rice recovery was strongly corresponded to grain yield (r=0.38), output of brown rice (r=0.59), and milled rice recovery (r=0.70).

Table 4.34 Correlation matrix of characteristics of rice with two varieties (n=36).

Charact.	Y	ZNG	PG	PRO	AMY	BRO	MIL	HEA	CHA	HAR	BIO	PW
Y	1.00											
ZNG	-0.29	1.00										
PG	-0.13	0.41*	1 .00									
PRO	-0.24	0.13	0.18	1.00								
AMY	-0.09	-0.38*	-0.35	-0.05	1.00							
BRO	0.37*	-0.29	-0.13	-0.10	0.19	1.00						
MIL	0.30	-0.16	-0.02	-0.13	-0.11	0.91**	1.00					
HEA	0.38*	-0.10	0.18	0.02	-0.20	0.59**	0.70**	1.00				
CHA	0.07	-0.13	-0.05	0.20	0.51**	-0.03	-0.28	-0.14	1.00			
HAR	-0.23	-0.02	0.04	0.52*	-0.37*	-0.17	-0.08	0.02	-0.20	1.00		
BIO	0.68**	-0.36*	-0.27	-0.10	0.45**	0.22	-0.03	0.05	0.63**	-0.34*	1.00	
PW	0.56**	-0.28	-0.09	0.14	0.19	0.40*	0.33	0.38	0.03	-0.05	0.37*	1.00

*r>0.33 (Rejection level at 5%: r=0.325); **r>0.41 (Rejection level at 1%: r=0.412)
Y: grain yield; ZNG: Zn content of grain; PG: phosphorus content of grain; PRO: protein content of grain; AMY: amylose content of grain; BRO: yield of brown rice; MIL: milled rice recovery of total brown; HEA: head rice recovery of the total milled rice; CHA: degree of chalkiness of grain; HAR: degree of texture hardness of grain; BIO: yield of total biomass (straw); PW: panicle weight per plant.