CHAPTER 3

MATERIALS AND METHODS

This research comprised of three related sets of studies, which were (1) an informal survey of rice production systems in Yunnan, (2) determination of the important quality characteristics of rice in selected markets of different rice regions in Yunnan, and (3) field experiment.

3.1 Informal Survey

An informal survey was undertaken during March to May and October to December 1994 in Kunming, Dali, and Xishuangbanna (Figure 3.1). These locations are the predominant rice growing areas of Yunnan, the People's Republic of China. The survey were aimed to understand systematically current rice production systems of Yunnan with respect to (1) the issues and farmer's concerns in current rice production, (2) possible causes of raising of rice price, (3) impacts of rice quality on its market price, and (4) rice experts (including rice breeders, agronomists, and officers of rice research and extension agencies) and farmers opinions on environment and genotypes in relation to rice quality.

The study procedures included on-farm survey and market survey, involving personal communications, interviews with rice experts, farmers and consumers. The survey was mainly to gather background information and secondary data on biophysical and socioeconomic conditions of rice production, such as climate, soil, farmers' practice especially water and fertilizer management, harvest and post harvest technologies, grain yield, varieties and grain quality, market price, market demand, farmer and consumers' preferences for rice.

3.2 Determination of Important Quality Characteristics

Market sampling of rice was undertaken in order to measure the importance of quality characteristics by the implicit price model. Variations in consumer preferences for rice from region to region were determined in three selected locations, namely Kunming, Dali, and Xishuangbanna, representing central, south, and northern west rice region of Yunnan province, respectively (see map of Figure 3.1). The major markets selected in the study areas have a substantial number of retailers and wholesalers, indicating that these are major trading centers.

During April of 1994 (a spring season), consumer respondents were interviewed to obtain their status in terms of socioeconomic characteristics and preferences for rice quality. The gathered information included age, educational attainment, occupation, family size, income, quantity of rice consumed, and other additional information. Respondents were also asked about the rice they bought, its price, and the reasons for buying it. Interviews were conducted while consumers were purchasing rice in the markets.

At the same time of market survey, twenty samples of milled rice were also collected from markets in Kunming, Dali, and Xishuangbanna. The total of sixty milled rice samples (with diversified market prices) were collected from selected markets within one month period in order to avoid price fluctuation.

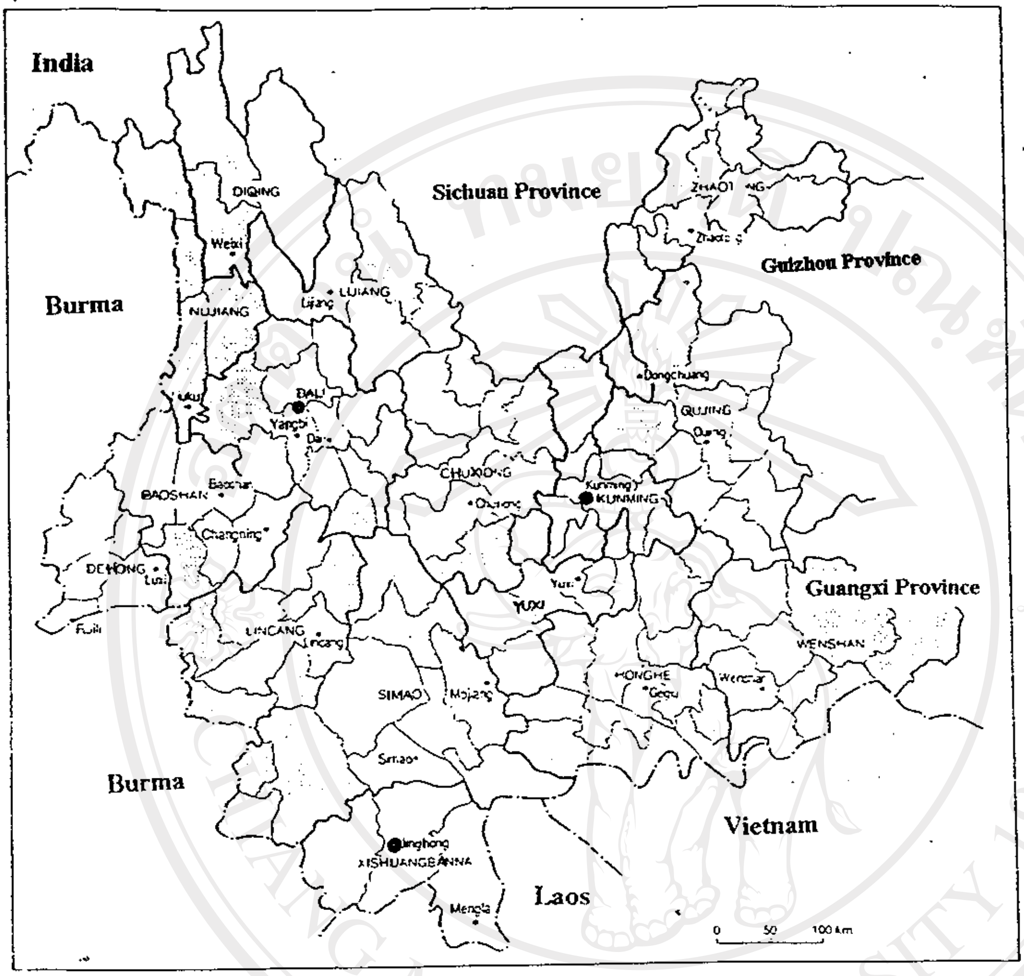

Figure 3.1 Yunnan Map

3.2.1 Implicit price model

The importance of quality characteristics of rice grain were determined by using implicit price model. In this study, the model can be expressed mathematically as the following function (1).

$$P = f(X_j, D_1, D_2, u) \quad (j=1 \text{ to } m)$$

$$= a + P_1X_1 + P_2X_2 + \ldots + P_jX_j + a_1D_1 + a_2D_2 + u \quad \ldots\ldots\ldots\ldots (1)$$

Where P = The market price of rice;

X_j = amount of characteristics j in one unit of rice;

a = intercept of market price in connection with rice grain quality;

P_j = implicit value of characteristics;

u = random error term;

D_1, D_2: dummy variables for the certain location.

This function shows that the average price paid by consumer for different grades of rice with attribute Xj. Using the ordinary least square (OLS) regression of observed market prices on measures of quality, the independent variables (X_j) explain the variance in price of rice while the estimated coefficients (P_j) measure the implicit value of each characteristics (Unnevehr et al. 1985, 1992).

The characteristics (X_j) of rice grain included parameters of appearance quality (grain length, chalkiness); milling quality (head milled recovery); cooking and eating quality (gel consistency, alkali spread value, amylose content); and nutritional quality (protein and zinc contents). The variables (X_j) for running the model were selected on the basis of principal components analysis.

The dummy variables (D_1, D_2) were used to adjust the market price variations among three districts. Xishuangbanna was selected as base area, then D_1, D_2 would represent for Kunming and Dali. The model was run for each location without dummy variables. Running regression of each location, only twenty samples could be put into the model.

3.3 Field Experiment

Field experiment was carried out at Rice Research Institute of Yunnan Agricultural University, Kunming (25° N 109° E, 1950 msl.), Yunnan, the People's Republic of China. The experiment consisted of three factors, i.e. Zn fertilizer, P fertilizer, and rice genotypes.

Factor 1: Two levels of Zn, i.e. 0 and 5 kg Zn /ha as $ZnSO_4.7H_2O$ (which contains 21.8% Zn) were applied at 7 days after transplanting (top dressing). The broadcast method (De datta, 1981) was used for Zn application.

Factor 2: Three levels of P, i.e. 60, 150 and 200 kg P_2O_5 /ha as $Ca(H_2PO_4)_2$ (which contains 19.2% P_2O_5) were incorporated into soil before transplanting (base dressing).

Factor 3: Three japonica rice cultivars, namely Xunza 29 (hybrid), Hexi 36 and Yungeng 34 (conventional) were selected for this study.

The experimental layout was a split-split plot with 3 replications. Zn, P and genotype were applied as the main, sub and sub-sub plots, respectively.

The size of each experimental unit (sub-sub plot) was 10m² (4 m × 2.5 m). A small passage of 20 cm was made to separate sub-sub plots (see experimental layout in appendix). The main and sub plots were separated by bounding with protection of plastic sheet.

Rice seed was sown into wet seed beds on March 21, 1994. The seedlings were transplanted on May 8, 1994, at the plant population of 700 hills per experimental unit (see spacing layout in Appendix B).

The basal fertilizers, 300 kg/ha urea (48% N), 225 kg/ha K_2SO_4 (45% K_2O_5) were applied to the field before transplanting. The crop was treated at the optimum level for general management, i.e. irrigation, diseases, insects, pests and weeds control.

3.3.1 Sampling procedures and data collection

♦ **Soil sample**

The composite soil samples were collected (0-30 cm depth and analyzed for initial soil available nutrients (N, P, K, Zn, OM) and pH.

♦ **Plant sample**

Sampling for analysis of Zn and P contents in plants were undertaken at seedling stage and final harvesting. The sampling procedures were followed after Si (1989), which were:

At plant developmental stage of 3 leaves, 100 seedlings of each genotype were collected randomly from seed beds. The samples were cleaned by distilled water and dried immediately in ventilated oven at 60°C for 60 hours.

At final harvest, 20 plants were collected from each experimental unit. Plant samples were then cleaned by distilled water and dried immediately in ventilated oven at 60°C for 60 hours.

- **Phenological data**

The observation on seed emergence date (at 75%) and other developmental stages including tillering, flowering, and maturity date were recorded.

- **Grain yield and yield components**

At maturity stage (18-20% grain moisture), a sample of 2 m^2 was harvested from each experimental unit, and grain yield and thousand grain weight were measured.

At the same time as harvesting, another subsample of 20 plants were randomly selected from the sub-sub plots for measuring total dry matter, panicle weight, plant height, numbers of productive tillers, and randomly took 10 main tillers to measure the total grain numbers and numbers of filled grains of panicles.

- **Physicochemical grain quality characteristics**

At final harvest, 1 kg of grain in each experimental unit was taken for analysis of grain quality characteristics, which included physical parameters (brown rice, milled rice recovery, head rice yield, grain size and shape, chalkiness, translucency), and biochemical parameters (amylose content, protein content, and Zn and P content).

All the physical and chemical analysis on soil nutrients and pH, grain quality characteristics, Zn and P content of plant samples were analyzed at Soil and Fertilizer Testing Center & Agricultural Products' Quality Supervisory Station of Yunnan. The international and national standard methods were applied to test soil and plants. The method of NY 144-88 (Yukun, 1988) was adopted for analysis of grain quality characteristics.

3.4 Data Analysis

In order to generate properly results of experimental and economic analysis, data were analyzed by various statistical procedures, which included analysis of variance (ANOVA), linear and multiple regression, correlation, and principal components.

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).

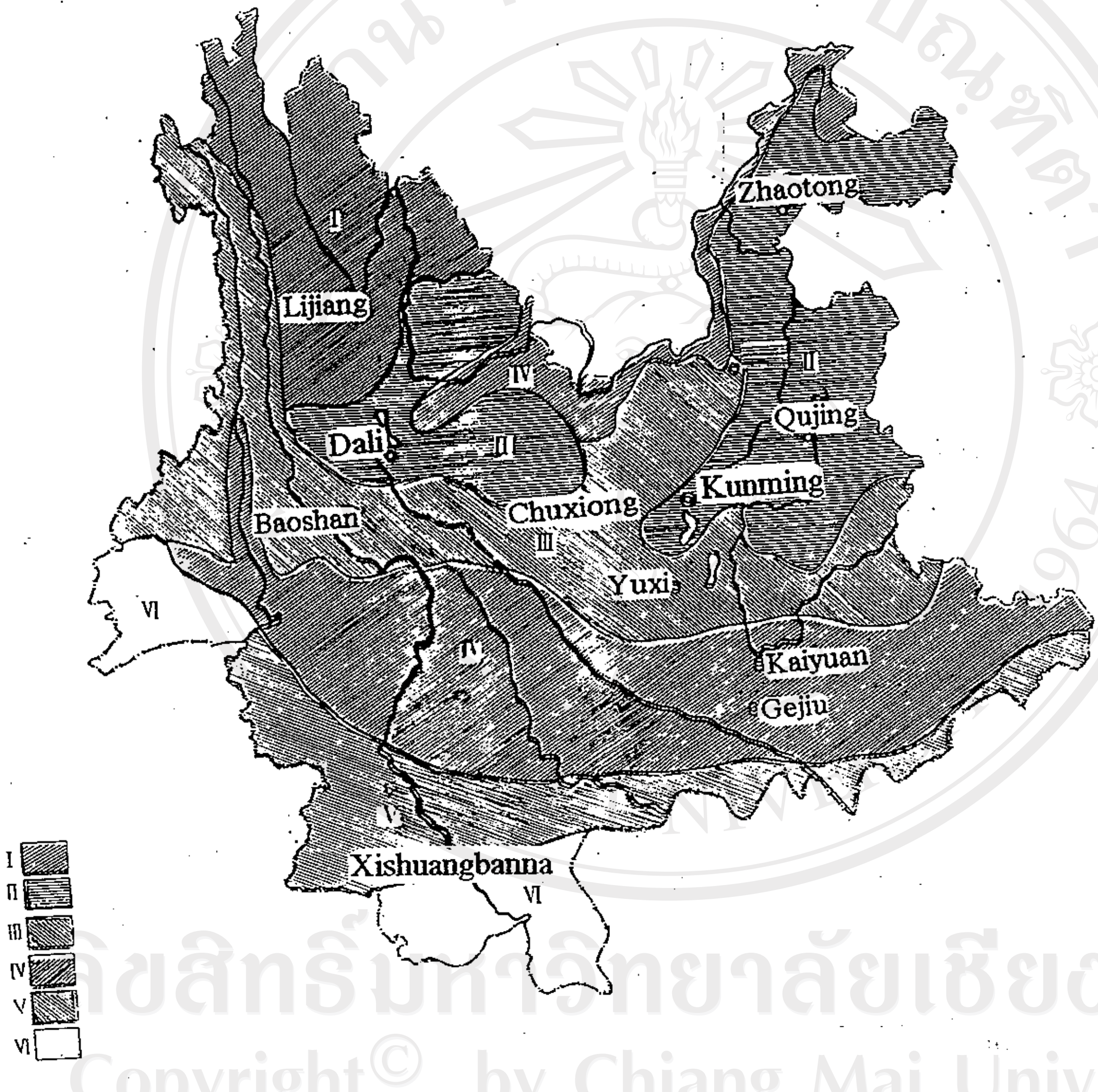

Figure 4.1 Classification of Rice Cropping Regions in Yunnan

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).

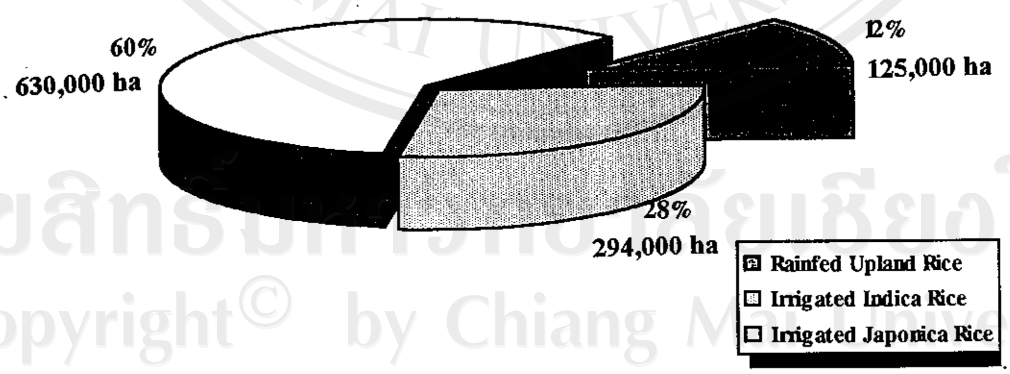

Figure 4.2 Rice Production System in Yunnan (1960's-1990's)
(Data source: Yang, 1992).

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).

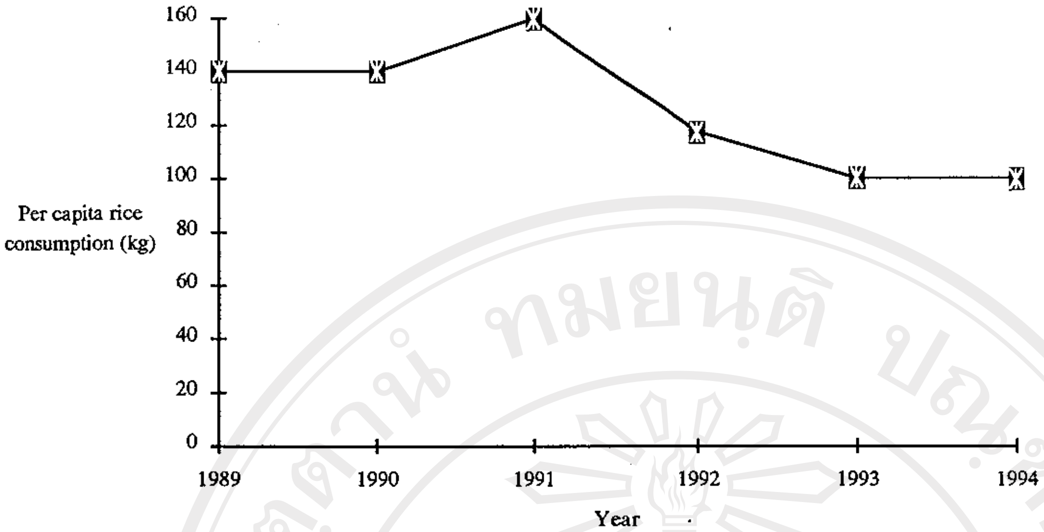

Figure 4.3 Per capita rice consumption of urban people, Yunnan, 1989-1994.
(Data source: Statistic Year Book of Yunnan, 1994).

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.

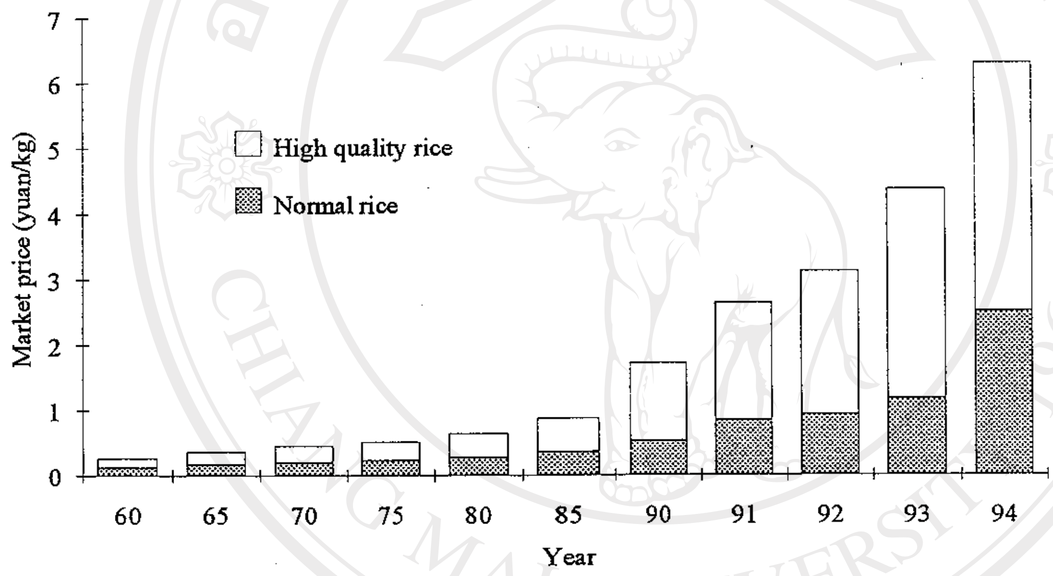

Figure 4.4 Market price of rice in Yunnan, 1960-1994.
(Data source: Statistic Year Book of Yunnan, 1994; IRRI, 1991).

*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.

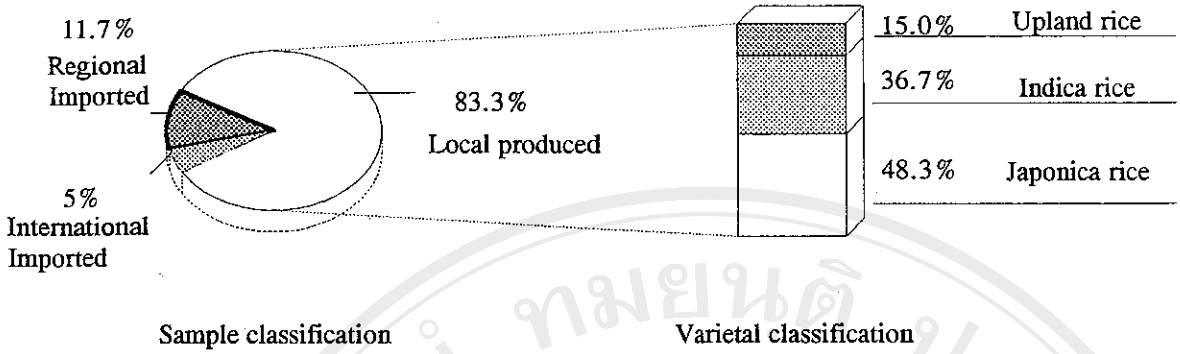

Figure 4.5 Milled rice available in the market and the sample classifications, Yunnan, 1994.

♦ **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.

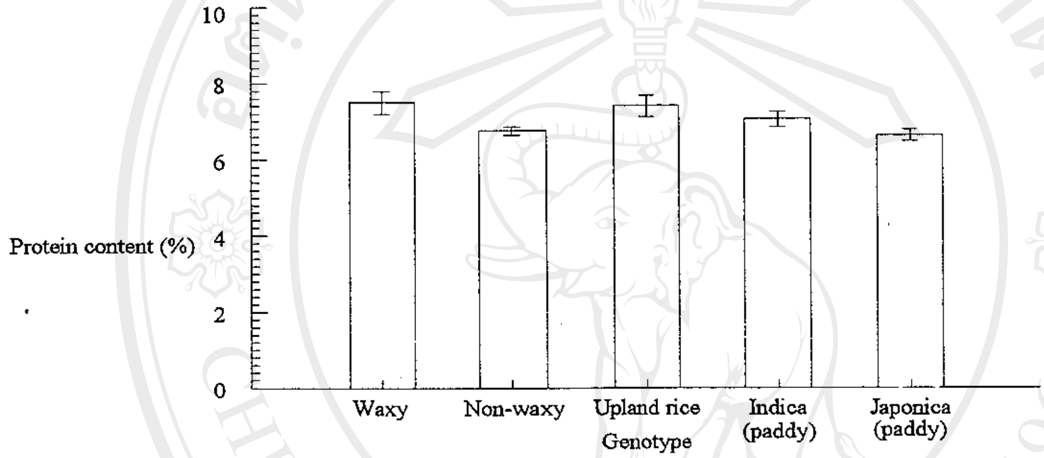

Figure 4.6 Nutritional quality (Zn content of grain) of different rice genotypes (the S.E of groups were showed as small bar in figure).

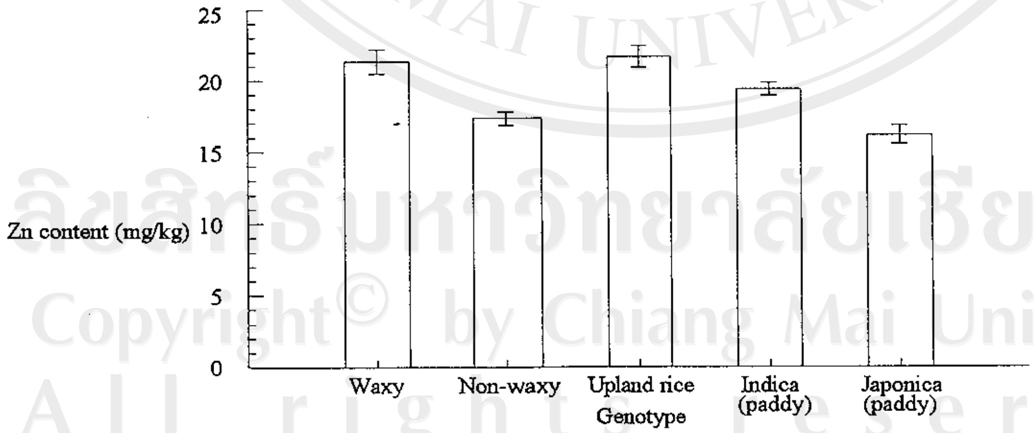

Figure 4.7 Nutritional quality (protein content of grain) of different rice genotypes (the S.E of groups were showed as small bar in figure).

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

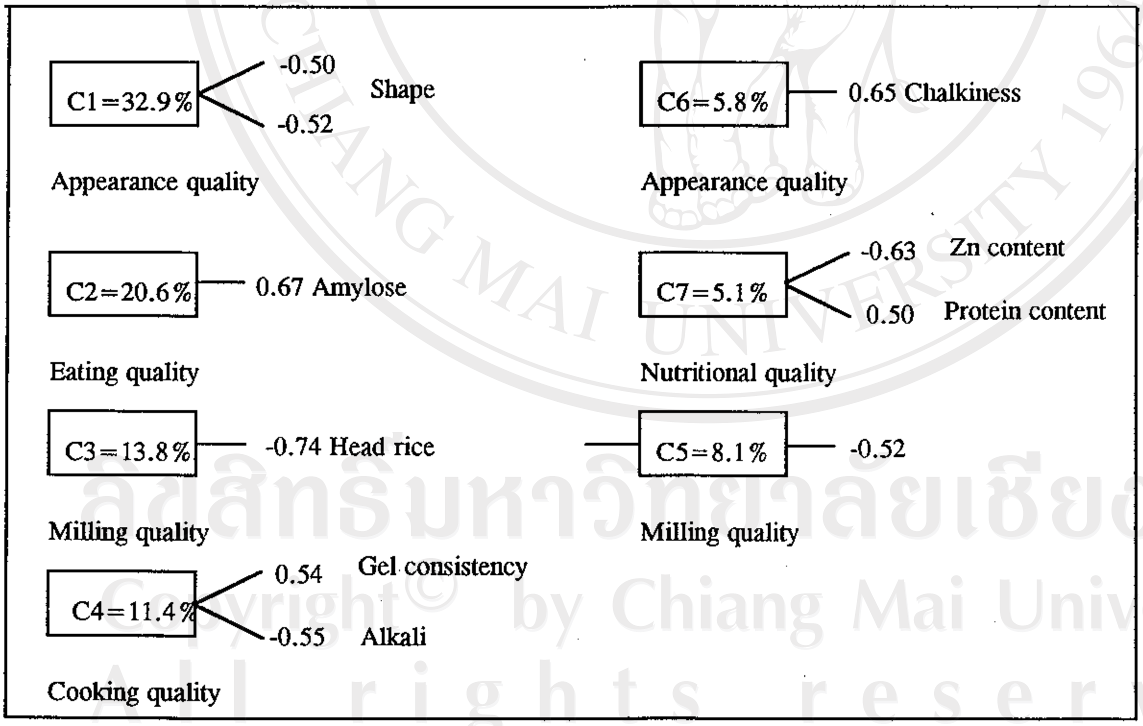

Figure 4.8 Scheme illustrating the effect of principal components on variables

♦ **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).

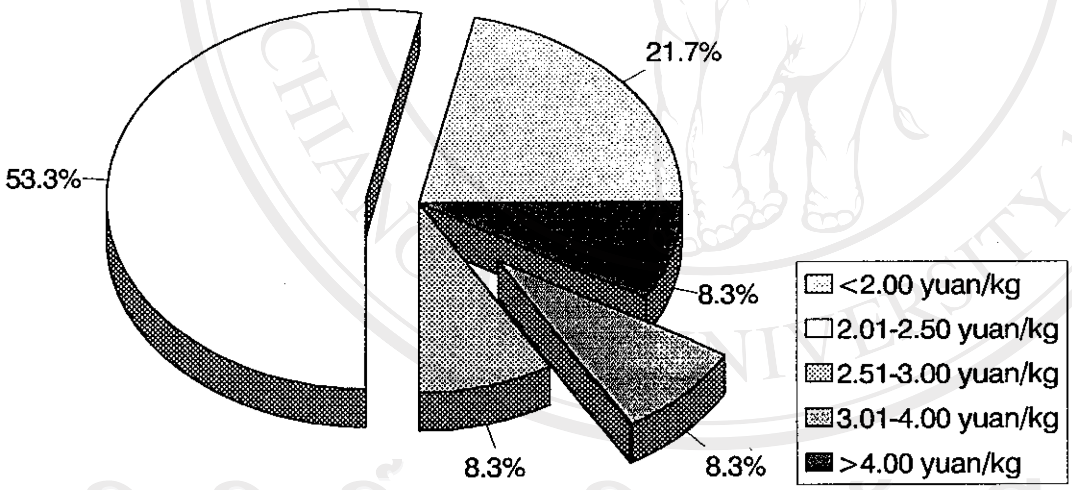

Figure 4.9 Classification of market price of rice in Yunnan, 1994.

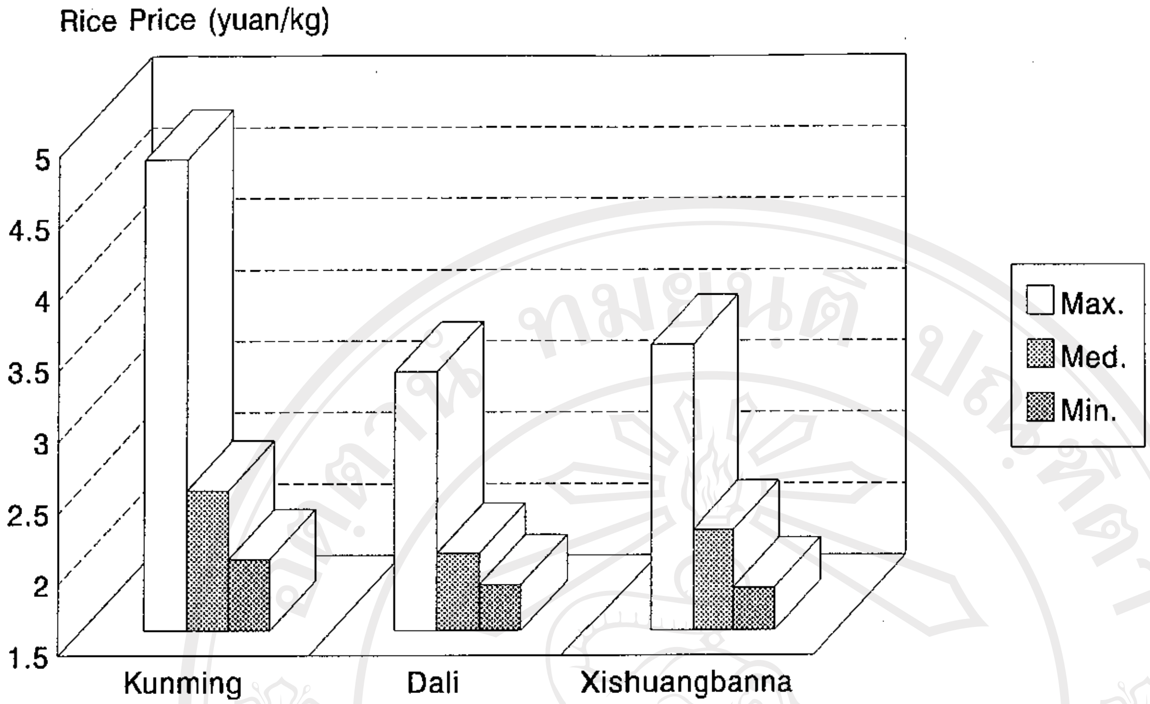

Figure 4.10 Rice price variation in three locations, Yunnan, 1994.

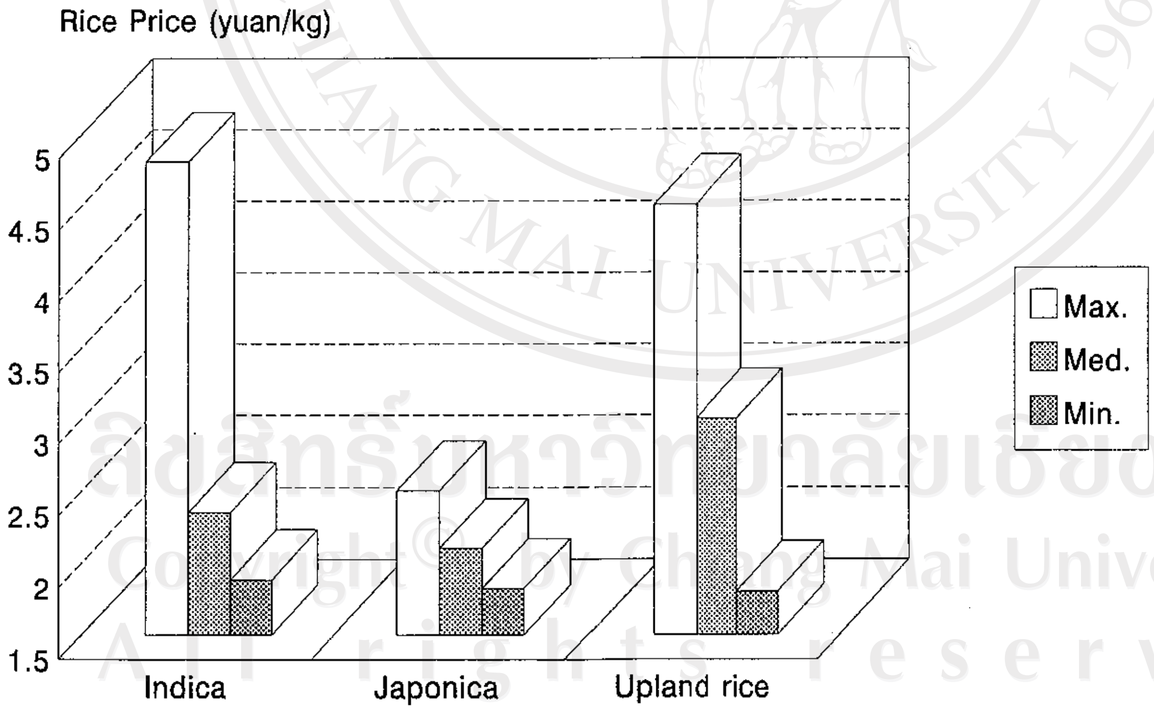

Figure 4.11 Rice price variation among three types of rice genotypes, Yunnan, 1994.

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.

*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.

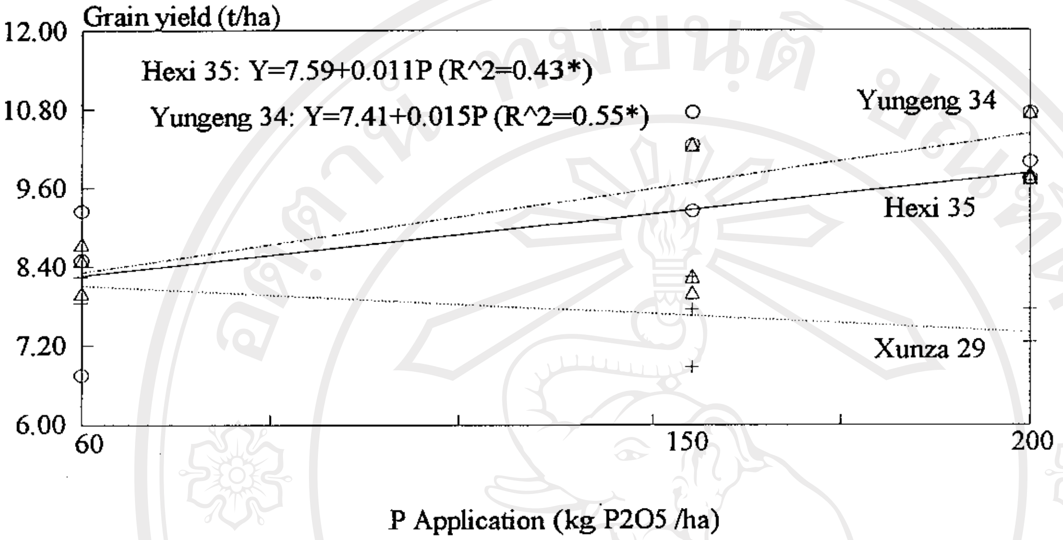

Figure 4.12 Effects of P application (without Zn applied) on grain yield of three rice varieties (*significant at 5% level).

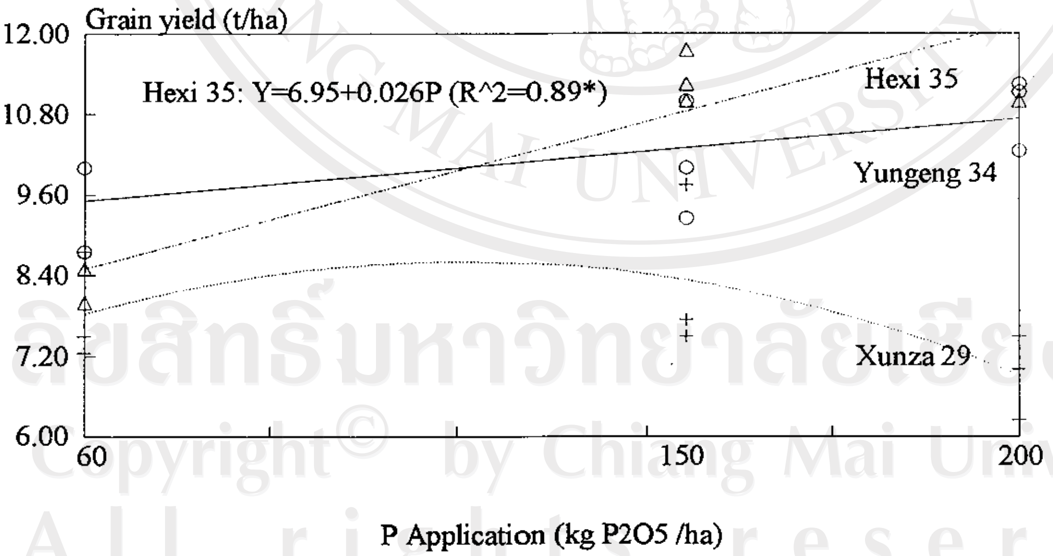

Figure 4.13 Effects of P application (with Zn applied) on grain yield of three rice varieties (*significant at 5% level).

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).

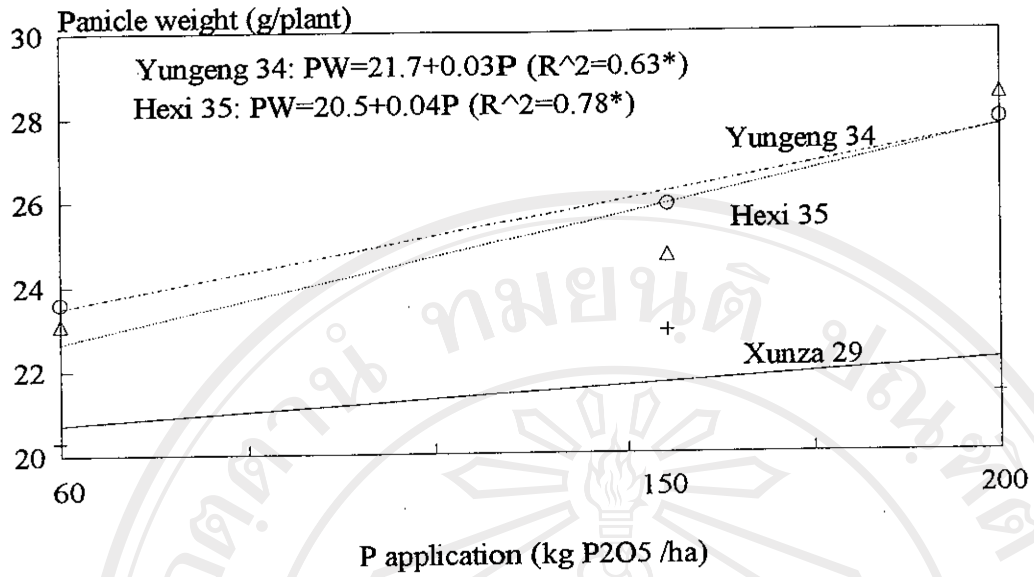

Figure 4.14 Interaction of P×V in panicle weight (g/plant) (*significant at 5% level).

♦ **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).

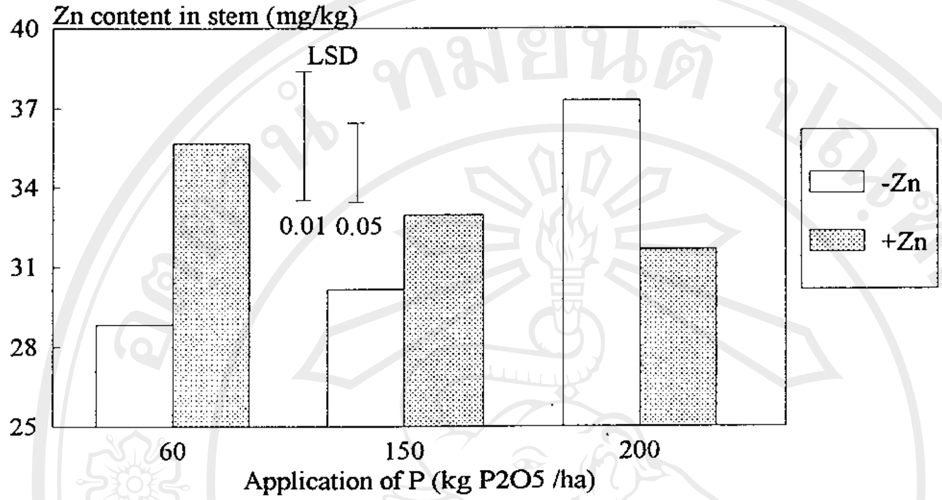

Figure 4.15 Interaction of Zn×P in Zn content of stem (mg/kg).

♦ **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).

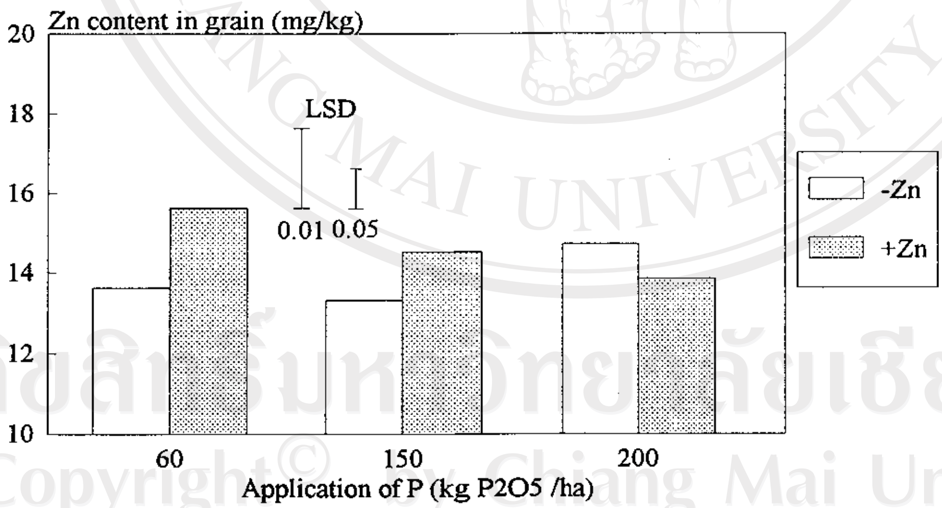

Figure 4.16 Interaction of Zn×P in Zn content of grain (mg/kg).

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).

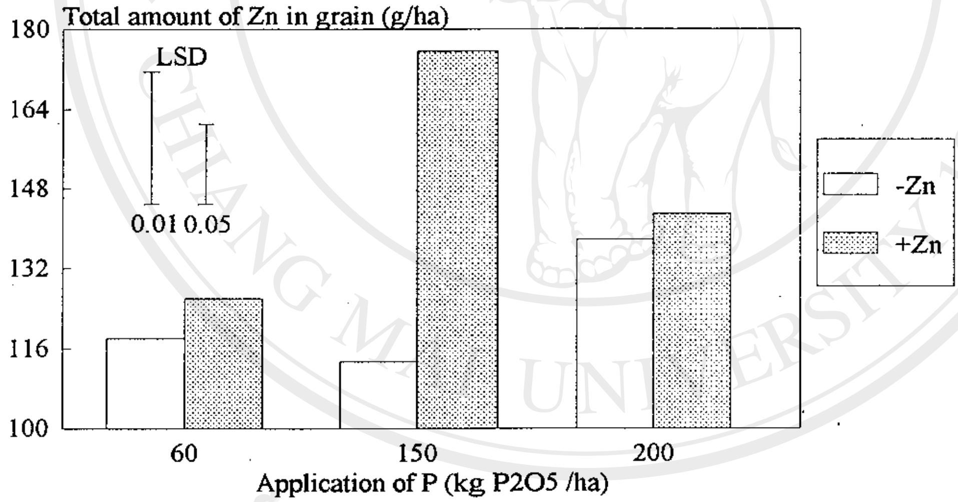

Figure 4.17 Effects of P and Zn application on total Zn content of grain in Hexi 35.

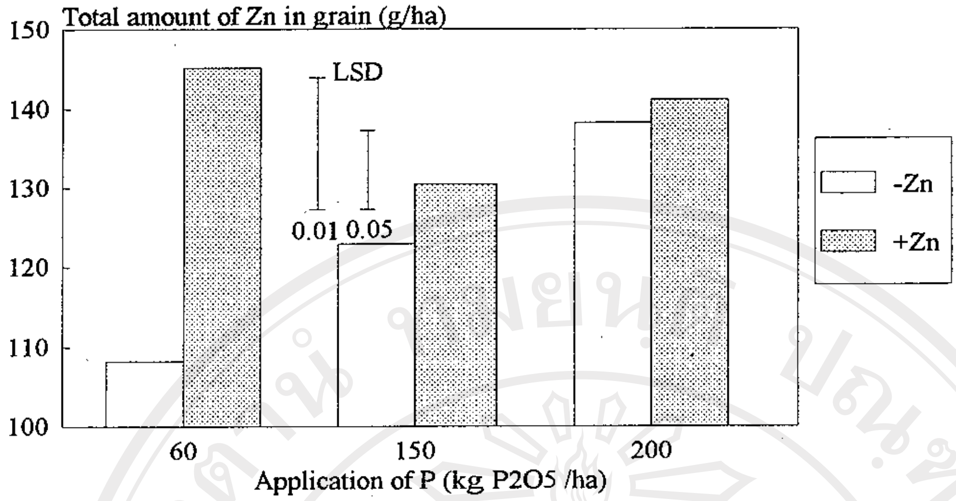

Figure 4.18 Effects of P and Zn application on total Zn content of grain in Yungeng 34.

♦ **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).

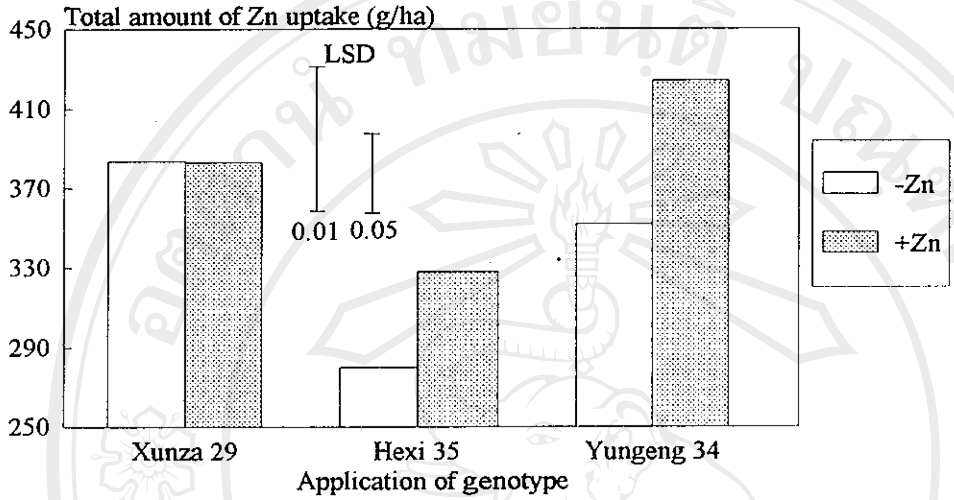

Figure 4.19 Interaction of Zn×V on total amount of Zn uptake.

♦ **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.

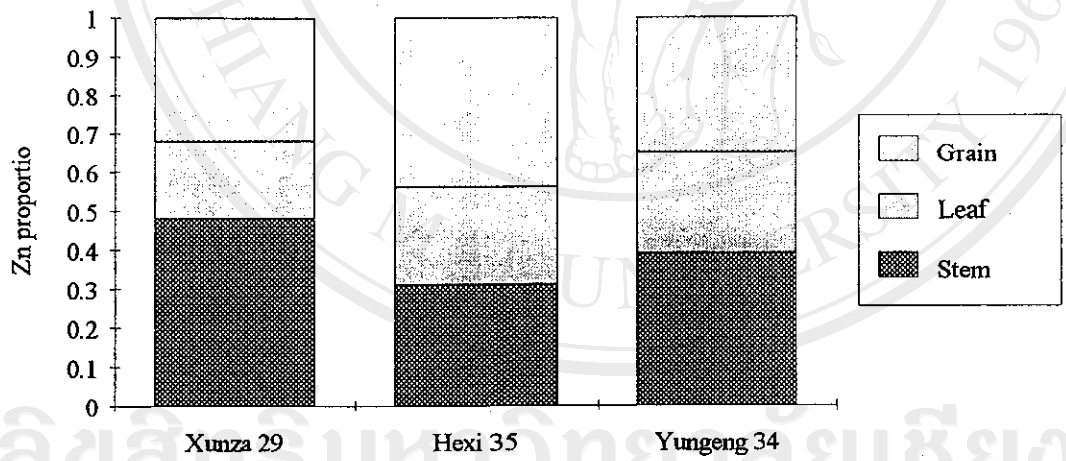

Figure 4.20 Average Zn proportion in stem, leaf, and grain of three rice varieties (at final harvest stage).

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.

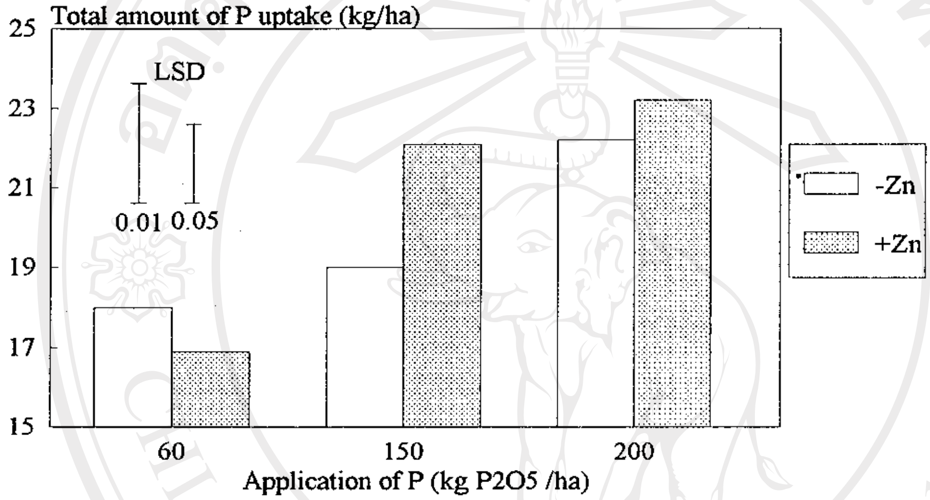

Figure 4.21 Interaction of Zn×P in total amount of P uptake (kg/ha).

♦ **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.

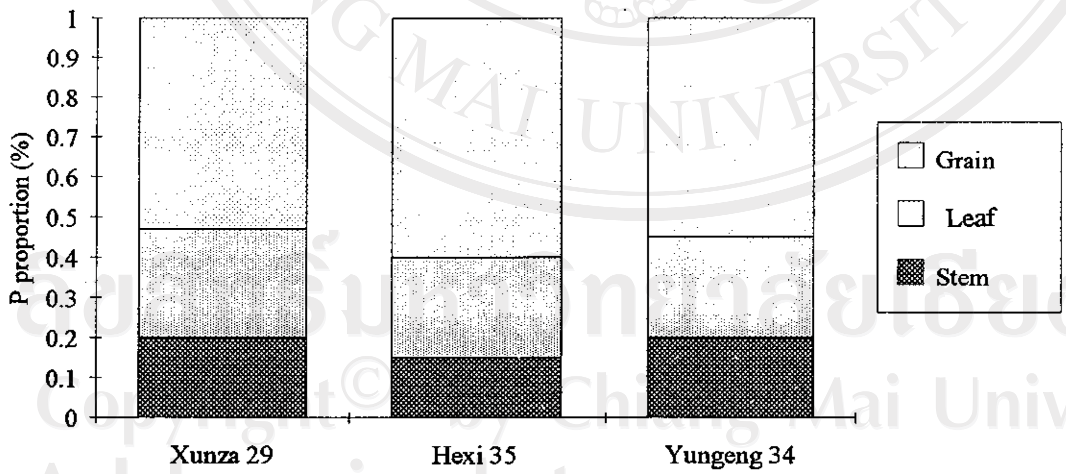

Figure 4.22 Average P proportion in stem, leaf, and grain of three rice varieties (at harvest stage).

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).

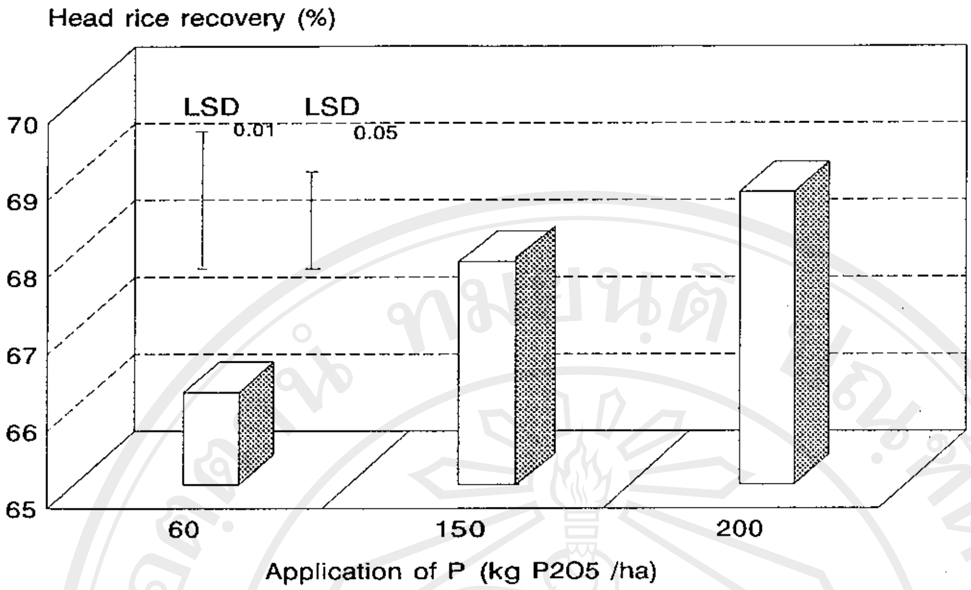

Figure 4.23 Effects of P application on head rice recovery.

♦ **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.

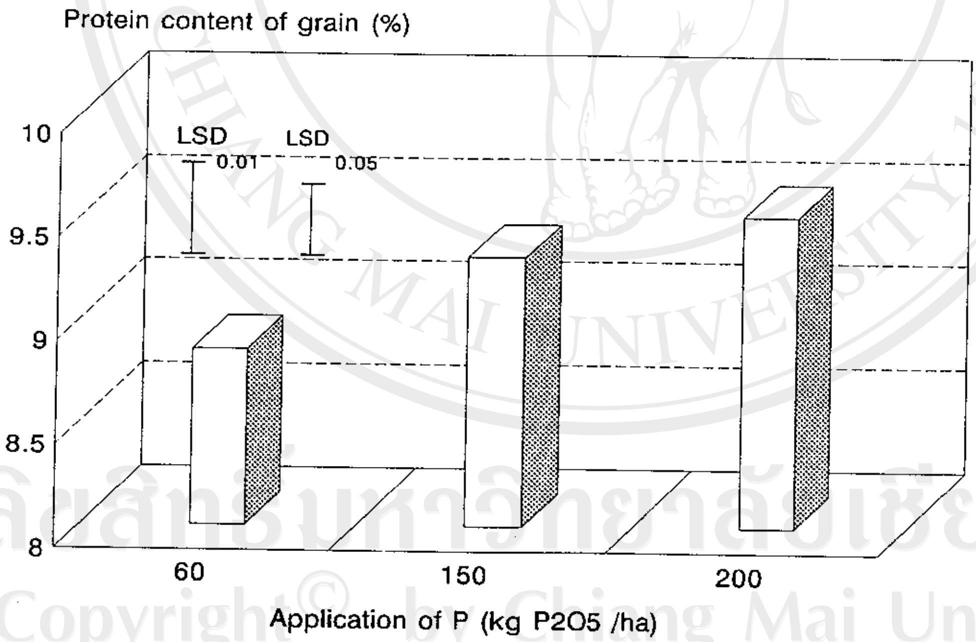

Figure 4.24 Effects of P application on protein content (%) of rice grain.

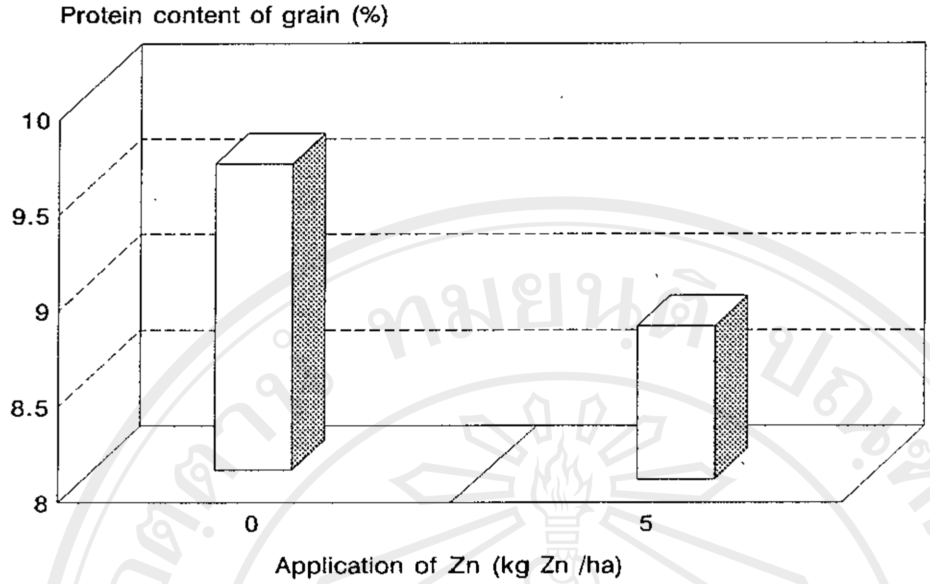

Figure 4.25 Effects of Zn application on protein content (%) of rice grain

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).

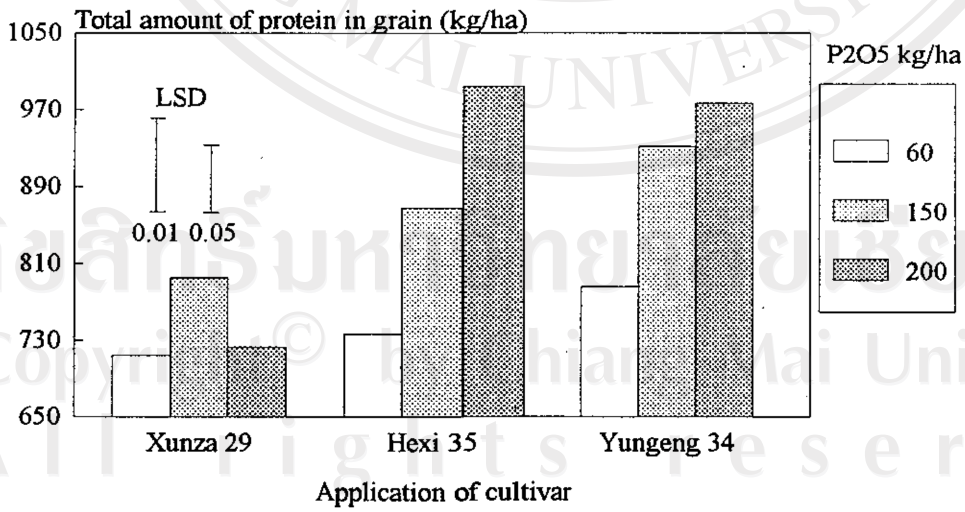

Figure 4.26 Interaction of P×V in total protein content of grain (kg/ha).

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.

CHAPTER 5
DISCUSSION

5.1 Rice Consumption and Production in Yunnan

A well-documented finding is that as income increases, significant changes occur in dietary patterns (Bouis, 1990; Marks and Yelley, 1988). Duff (1991) suggested that, as incomes rise, consumer are able to substitute more preferred foods in their diet, and shifts in food demand occur. The implicit assumption is that consumers desire to improve the quality of their diets. The survey information of this study support Duff's assumption, indicating that there is substitution between quantity and quality of rice consumption in Yunnan since late of 1980's. As Cai et al. (1992) concluded that, for its low elasticity, per capita rice consumption for food will tend to reduce along with the improvement in food structure. Similar trends were reported by Huang et al. (1990), showing that over last thirty years, per capital rice consumption has declined in Japan, Taiwan, Singapore, Malaysia, and Thailand.

Over the past fifteen years, modern agro-technology has had a significant impact on increasing rice production in Yunnan. From being one of the largest rice importer, Yunnan almost achieved rice self-sufficiency in 1984 (Li, 1988). Self-sufficiency in rice as well as increase of living standard of Chinese people have made quality of rice becoming increasingly important. Consequently, it also implies that both breeders and producers need to concern more about increasing demand of quality rice in the future's rice production. Improvement in high quality rice production would provide benefits to all sectors of society.

5.2 Economic and Agronomic Considerations for Rice Quality Characteristics and Market Prices

Varietal classification of sixty milled rice samples showed that percent indica rice available in the markets accounted for 36% in 1994, was nearly 8% higher than the percent area of indica-growing of Yunnan. This is mainly due to the unbalance of per unit grain yield between indica rice and japonica rice. In 1990, hybrid rice varieties have covered nearly 80% indica-growing area in Yunnan (Yang, 1992). Hence, high promotion of hybrid indica rice along with double cropping of indica would have made very high quantity of market supply. Aside of import of good quality indica rice from Thailand, the trade of crossing provinces and regions would also result in relative high opportunity for indica rice available in the domestic market in Yunnan.

At present, the diversified milled rice with various prices were available in the domestic market, it is the reflection of advantages of free trade marketing systems. In the past years especially before 1988, Chinese government imposed restriction regulation in grain marketing by contracting or negotiated price system that controlled by government policy. Under this system, farmers were not free to sell their grains directly to consumers at negotiated prices. As a result, most of the farmers did not care about the quality of their produced rice. Despite the tremendous achievement have been obtained in rice production and rapid increment in national economy since 1980's, the planning economic systems which is single price brought about inefficiencies in rice production systems as well as in rice marketing systems (Zhang et al., 1991).

The information based on market survey and samples confirmed that there was a big variation in market prices within one region as well as among the three regions. The possible cause of these price variation involve a number of factors which are mostly determined by socioeconomic and biophysical conditions of region. As summarized by Abansi et al. (1992), the price determinations for rice involved consumers characteristics (i.e. income, location, education, age, occupation), and physicochemical characteristics of rice.

In the consumer's sense, quality characteristics such as aromatic and whiteness are among the most important indicators for "high quality rice. In the study, these two parameters were not analyzed, simply because of the difficulty of pricise measurement. However, degree of chalkiness score in total milled rice provided insight into how consumer considered whiteness.

The laboratory analysis of sixty milled rice samples showed that on an average, grain physicochemical quality characteristics of the majority predominantly grown rice varieties (which cover more than 6,600 ha) belong to the medium grade in terms of quality classification. The similar situation was found in most of the rice-producing provinces in China (Luo et al., 1992). This indicates that there is a significant room for quality improvement, especially in terms of hybrid rice breeding programs.

Recently, food based strategy for improving human health being raised attention of researchers worldwide. As human malnutrition is still prevail widespread in the rice-consuming countries, nutritional quality of rice has attracted the attention of many nutritionists. In this study, upland and glutinous rice showed high nutritional quality in terms of Zn and protein content. Thus, the finding that Zn contents were high in upland and glutinous rice opens up many possibilities in the efforts to improve Zn nutrition for rice. Upland rice may take advantage of their deep root systems to absorb more Zn from soil. Graham et al. (1993) believe that the better approach to solve problem of Zn-deficiency is to breed cereals with root systems which will penetrate subsoil of low phosphorous and micronutrient availability.

The correlation analysis showed the positive association between P and protein. This finding is similar with Zhang' report (1992). However, it was found that there was a negative relationship between protein content and Zn content of grain. This result was contrasted to Zhang' finding (1992). Noticeably, results of this study demonstrate a negative association between protein and degree of chalkiness. This finding could probably support that highly translucent rice was significantly related its higher protein content (Zhang, 1992).

Regional regression equations of this study indicated that consumers' preference for rice varied among three regions, namely Dali, Kunming and Xishuangbanna. This finding agrees with suggestion of Unnevehr et al. (1985). Nevertheless, the results of implicit price estimation in this study suggested that two types of quality improvement in modern rice varieties benefit to consumers and producers in all three regions. First, development of low to mediate amylose rice would have widespread benefits because consumers in all three regions prefer low to mediated grains. Second, improvement of grain length would also benefit to consumers and producers. This is why consumer normally consider slender long-grain as one distinguish indicator for good quality of indica rice, such as Dianrui 408, Dianrui 446, Dianlong 201, Diantun 502, and Thai rice " Khao Dok Mali 105", all of them are well-known by their slim long-grain.

In most cases of regression estimates of implicit price for rice quality characteristics in Yunnan, the percentage of head rice was not found to be significantly associated with rice price. This means that producers in Yunnan used to sell their rice which head rice was not separated from broken rice. There are two major explanations related to issue of head rice percentage. First, Chinese government paid more attention to high yield for rice production due to rapid increasing of population, while milling quality in terms of head rice recovery was given less attention. Second, the producers were not very much interested in the head rice recovery due to the single price of grain marketing systems in the past years.

Meanwhile, head rice percentage showed expected sign (positive) in case of indica rice regression. For this reason, it implies that consumers' preferences for good milling quality (particularly with respect to indica rice) are quite similar among the most of Asian countries (Unnevehr et al., 1985).

The study demonstrated a simple methodology for testing consumer preferences. Laboratory measures of physical and chemical quality characteristics of rice grain can be regressed on rice prices to explain observed difference in market prices. The regression parameter estimates show the implicit value of characteristics to consumers, and the significant of parameter estimates indicates the importance of those characteristics. Such estimates are useful to identify the grain characteristics that plant breeding programs should focus on to improve quality.

Because consumer preferences for other characteristics vary, provincial programs have substantial room to tailor varieties to local preferences. Provincial rice research should provide regional programs with plant materials having diversity of grain characteristics. Regional programs should further study consumer preferences to focus on quality objectives important to most consumers of that region.

In fact, in the consumer's sense, variety was recognized as the most important indicator for rice quality. This means that breeding can offer one of most promising solution in improve rice quality. Quality improvement without the reduction in yield will generally benefit consumers by lowering the cost of better quality rice. Improving grain quality characteristics of genetic sources or varieties could reduce processing costs and directly increase returns to farmers. If higher quality varieties were widely adopted, producers would not receive extra price premium because of satisfaction of consumer's demand as well as market supply, but would benefit in two other ways. First, they would remain better quality rice for their own consumption. Second, they would have a wider domestic market for their rice.

Moreover, the results indicated that environmental conditions and crop management techniques had some effects on rice quality, this impact could further affect on market price of rice. This information should warrant greater attention among breeders, agronomists, as well as producers.

5.3 Effects of P and Zn Application on Rice Grain Quality

Stunted plant growth and delayed flowering and maturity in rice could be resulted from soil Zn deficiency (Xie, 1986; Yang and Huang, 1986; Quijano, 1988) as well as by P deficiency (Shi, 1988). However, such symptoms were not observed in this experiment, presumably because the available Zn and P excess critical value in the natural soil. The critical limited value for Zn and P supplies of soil have been recommended by a number of literature (Xie, 1986; Yoshida and Tanaka, 1969; Lui, personal communication). The soil conditions of experimental field were classified as low Zn and low P but not critical as deficiency. In this experiment, it was evidenced that plant developmental stage in terms of panicle emergency, flowering and final maturity were advanced 2 days with increasing of P or Zn applied. This finding may also suggested that Zn and P play an important role for maintaining the normal plant development. There is general agreement that most distinct zinc deficiency symptoms are stunted growth and little leaf which are related to disturbance in the metabolism of auxins, indoleacetic acid (IAA) in particular (Marschner, 1986). It has been reported that supplementation of Zn to Zn-stressed plants (maize, barley, and oat) roots not only increased growth but also increase levels of gibberellin-like substances (Suge et al., 1986).

The responses of grain yield to Zn and P applications showed differences among three various varieties. However, grain yield of Xunza 29 was the lowest among three varieties, this was because of problem of seeds contamination. In this experiment, it has been confirmed that, grain yield of Xunza 29 was mainly determined by the numbers of contaminated plants (male sterile line) which gave very low grain set (0-30%).

Productivity of Hexi 35 and Yungeng 34, whether measured in terms of total grain yields and the dry matter of biomass (straw) at the period of final harvesting, all indicated clearly advantage of P and Zn application. Moreover, in Hexi 35, the grain yield with combined 5 kg Zn /ha and 150 kg P_2O_5 /ha application reached 11.3 t/ha (see Appendix c-2), which excesses the grain yield in application by 200 kg P_2O_5 /ha. Therefore, in addition to the advantage in relative term, there is also absolute beneficial effect of combined Zn and P application, due to its lower cost of Zn fertilizer, and the farmer can expect a higher economic return from combined Zn and P application. Similar advantages of this combined Zn and P application have been observed in previous study on rice (Yang et al., 1986) and barley (Lian, 1989).

Increase of grain yield was due to an enhancement of panicle weight and thousand grain weight in Hexi 35 and Yungeng 34. Although there was only slightly increase in thousand grain weight, notable effect of added Zn and P for panicle weight of Hexi 35 and Yungeng 34 were clearly observed confirming higher P or Zn requirement for reproductive growth. The prime effect of P and Zn application, which resulted in an increase in vegetative growth in terms of biomass and reproductive growth in terms of numbers of productive tiller, numbers of filled grain, and thousand grain weight, has been observed in rice (Yang et al., 1986; Yoshida, 1975) and in barley (Afudaoning, 1992).

Noticeably, in this experiment, plant height was detected a reduction (about 5.0 cm) as applied Zn regardless application of P and variety. This finding contradicted with the general principles (Marschner, 1986; De Datta et al., 1981). Nevertheless, it was hardly to predict whether the plant height was really reduced with applied because there was limited information about nutritional status of plant and soil throughout the whole period of this experiment. Hence, this finding need to be verified by conducting further research.

The most common interaction in which P salts decrease plant Zn concentrations encountered when the supplies of both P and Zn are marginal or limiting and addition of P promotes growth sufficiently to dilute the concentration of Zn in plant to levels which induce or enhance Zn deficiency (Boawn et at., 1954; Loneragan et al., 1979; Singh et al., 1988). It has been recognized that the incident of Zn deficiency throughout the rice-growing world was due to increased use of P fertilizer resulting in P-induced Zn deficiency (De Datta, 1981). Yang et al. (1986) confirmed that P induced Zn deficiency often occur when grown rice in low Zn or Zn deficiency soils. In this study, results only showed trend of P-induced Zn deficiency in Hexi 35. In contrast, P-induced Zn deficiency was not observed in Xunza 29 and Yungeng 34. This probably due to a number of factors concerned. There are many factors affecting Zn deficiency, i.e. soil available Zn content, soil pH, internal requirement of plants etc. Recent study (Robson, 1993) indicated that there is wide variability in Zn-efficiency among rice genotypes, it may explain the differences of the Zn concentration in Xunza 29 and Yungeng 35. Those finding might also suggest that: it does not necessarily indicate that higher rate of P application will cause Zn deficiency (Afudaoning, 1988).

Yang et al. (1986) cited that plant absorption and translocation of P and Zn were affected by levels of P and Zn application. In this study, both P content of dry weight in stem, leaf and grain and total amount of P uptake were increased by increase of P applied, moreover they were also enhanced by Zn applied. These findings were confident with conclusions of Yang et al. (1986) as shown in Table 2.5 (see Chapter 2). On the other hand, the total amount of Zn uptake showed an enhancement with Zn applied regardless applications of P and genotype. Similar result was also observed in previous works of Yang et al. as given in Table 2.6 (see Chapter 2).

Experimental results indicated that there were similar trends in terms of plant distributions of P and Zn of all three varieties regardless of application of Zn and P. However, the proportion of P and Zn differed among varieties regardless application of Zn and P. Therefore, the results revealed that different varieties have various capability to absorb and translocate P and Zn into grains. This basically suggested that genetic selection could be one efficient way for higher Zn in grain.

The concentration of Zn in edible plant parts can vary widely depending on a number of complex, dynamic and interacting factors including plant genotype, plant part, and plant's environment (including soil-Zn availability) during development (Robson, 1993). In this study, Zn content of grain in Xunza 29 was increased under higher Zn supply. Similar result was only demonstrated in barley by Lian (1986). This finding confirmed that it is an alternative way to improve nutritional quality in terms of Zn content in grain through Zn application. This finding also suggested that Zn fertilizer application may alleviate the problem of Zn deficiency in cereal crops included in rice. However, in case of Xunza 29, increase of Zn content in grain due to applying Zn was only about 2.5 ppm. Therefore, to be economically flexible, the further research is needed before recommendation ready for Zn application in farmer practice.

On the other hand, results of this experiment indicated that although Zn content of grain for Yungeng 34 and Hexi 35 were reduced as Zn applied, the total amount of Zn in grain increased with Zn applied. This result suggested that reduction of Zn content of grain in these two varieties may probably due to remarkable contribution of Zn for yield increment. This might also explain why Xunza 29 only gave relatively lower grain yield but gained higher Zn content of grain with Zn applied.

Zn content of grain is one of the important nutritional quality characteristics in rice. Ross and Welch (1993) listed the medium (16 mg/kgdw) and range (10-22 mg/kgdw) of Zn concentrations in rice (whole kernel). However, it has also been found (Hambidge et al., 1986, Welch and House, 1984; Torre et al., 1991) that crop contain substances which interfere with Zn absorption and utilization (i.e. bioavailibility) to human, example of these substances include phytic acid and certain types of fiber, especially fiber from whole cereal grain (such as cereal brans are associated with reduced Zn bioavailablity).

Hence, results of this experiment, especially with respect to the genotypic differences in response to Zn and P application, provided new insight into impact of genotype and crop management on Zn in grain. That is: first, it is not wise to increase Zn content in grain without a more through understanding of their roles in plant growth and human health. Second, practically, it may be more desirable to increase the Zn concentration in grain through genetic selection, breeding cultivars which should be higher Zn content in grain and/or respond to Zn applying but produce grain yield economically as well.

One of the limitation of this experiment is that Zn content in brans and roots have not been measured. For further research, it is worth to determine the edible Zn in grain of cultivars before and after conducted field experimental treatments. Zn distribution from soil to plant and further to human should become to be an important and interesting topic for future research.

P play important role in protein synthesis, Mosulofu and Fuleit (Afudaoning, 1992) stated that there was a positive correlation existed between P supply and protein content of grain in wheat for example, but it might be a negative influence of P supply on protein synthesis in some other cereal crops. In this experiment, the protein content of grain was found to be increased by P applied regardless applications of Zn and varieties. Meanwhile, the experimental results showed that protein content of rice grain was linearly increased by P. This means that the optimal levels of P that produces the highest protein content will also produce maximum grain yield accordingly. To be economically flexible, hence, breeders should warrant theses attention to be paid to protein content in grain in breeding program. That is, comparing efforts to be paid for genetic selection and crop management, P management may be more efficient practice to improve protein content in grain regarding large scale of rice production.

Theoretically, the adequate Zn supply is considered as an important factor affecting protein synthesis in crops including rice (Robson, 1993; Academy of Agricultural Sciences of China, 1984). However, in this experiment, there was no clear advantage in use of Zn, in terms of protein content and total amount of protein of grain of Hexi 35 and Yungeng 34. In contrast, it was found that protein contents of grain of all three varieties were not significantly affected by Zn applied, but there was a tendency that the protein contents of grain of Hexi 35 and Yungeng 34 declined with Zn applied. This finding was not consistent with previous research, and other evidences remained lacking. With Zn applied, lower Zn content of grain due to higher grain yield in Hexi 35 and Yungeng 34 might probably explain depression of protein content of grain, because the Zn content of rice grain was positively associated with protein content of grain (Zhang, 1993). This means that an increase in grain yield induced a reduction of protein content of grain with Hexi 35 and Yungeng 34. At this point, the results of the study might suggest that there was a trade-off between yield and protein quality which should be considered for Zn application in rice production. Yet the negative correlation between grain yield and protein content of grain has been commonly found in many rice cultivars (Chuangdaolianyi, 1985).

Phytates are presumably involved in the regulation of starch synthesis during grain filling (Michael et al., 1980). However at current study, amylose content of grain was not detected significant in association with P application. This is because grain amylose is directly related to temperature and water supply during the process of grain filling. During period of grain filling, higher temperature and drought were believed to be significant factors which could probably increase amylose content of grain in rice

(Resurreccion et al., 1977; Paul, 1977).

This experimental results revealed that amylose content of grain seems to be increased approximately 1.0 % by Zn applied regardless application of P and genotype. Thus, Zn may play an important role in the metabolism of starch (Marschner, 1986). A reduction of starch formation under Zn deficiency has been confirmed in beans (Jyung et al., 1975) and other cereal crops (Reed, 1940). Juliano (1993) reported that an increase in protein content was essentially at expense of reduction in starch content (Juliano, 1993). Consequently, for Hexi 35 and Yungeng 34, an enhancement of grain amylose content might also relate to reduction of grain protein. If so, interaction between Zn and P should be considered as one limiting factors for gaining rice with lower amylose and higher protein in farmer's practice. Furthermore, it is possibility that interaction between Zn and P will make negative impact on consumers' preference based on information of implicit price estimation.

Results of this study exhibited an increase of head rice recovery as increasing in amount of P applied. In fact, higher head rice recovery was also found to be associated with higher grain protein content. This explained that the increase in head rice recovery in the chalky varieties as a result of P application was due to an increase in the protein content of brown rice and increase in hardness of kernels. Similar relationships were found with nitrogen application (Nangju and De Datta, 1970).

Milling quality, in terms of brown rice yield and milled rice recovery did not show clear response to P, Zn, and varieties. This finding supported to general agreement that yield of brown and milled rice recovery were not distinguished among genotypes which belong to the same sub-species, i.e. japonica or indica rice (Chen and Lui, 1994.

personal communications).

The degree of hardness of grain is believed to be positively associated with head rice recovery (Juliano, 1993). In this study, it was found that the degree of hardness of grain significantly was negatively correlated with Zn applied. This might further explain an reduction of head rice recovery due to applying Zn.

Milling quality especially with respect to head rice recovery, one of important quality characteristics which determine rice price in the market, showed no differences among three varieties in this experiment. Nevertheless, the results also provided information with alternative solution how to solve problem in terms milling quality improvement, i.e. P management might be more desirable. This finding need to further verify and explore to indica rice. Accordingly, P management will create benefit for farmer since percentage of head rice was identified as one of price determinants in indica rice.

The physical quality characteristics in terms of grain length and width, did not respond to P and Zn application for any varieties and this traits remained fairly constant. This is because that grain shape and size was genotypically determined (Juliano et al., 1990). It also suggested that effect of P on grain physical properties was not as profound as that of nitrogen. Previous researches indicated that increment nitrogen fertilizer would increase the physical characteristics of grain which including length, width, and thickness (Attaviriyasuk et al., 1990; Jongkeawattana, 1990; Somchit, 1995, personal communication).

In summary, the field experimental study demonstrated how the grain yield and grain quality advantages were related to their Zn and P nutrition in both soil supply and plant uptake two aspects. From view of consumers' preferences as reflected market prices in rice, Zn and P played significant role for improving economically important quality characteristics, for example, percentage of head rice, nutritional value in terms of protein and Zn content. Consequently, farmers and consumers could obtain some benefits from apply rice variety with fertilizer management in terms of Zn and P application.

CHAPTER 6
CONCLUSION

As increasing in living standard of Chinese people, there is substitution between quantity and quality of rice consumption since late of 1980's. For its low elasticity, per capita rice consumption for food will tend to reduce along with the improvement in food consuming pattern High demand of good quality grain is becoming emerging issue which breeders and producers must consider in future's rice production. Improvement in rice quality would provide benefits to all sectors of society.

At present, the diversified milled rice with various price are available in the domestic market in Yunnan. Market price reflect to quality characteristics as well as the preferences of consumers. Hedonic price model is a simple methodology for testing relationships between quality characteristics and market prices of rice. The result of this study has clearly demonstrated that consumers' preference are different among three regions, namely, Dali, Kunming, and Xishuangbanna. The price of rice paid by local consumers in all three regions was affected significantly by grain length, gel consistancy, and amylose content of grain. More quality characteristics significantly affected the price of japonica rice than that of indica rice. That is, the significant price determinants of irrigated japonica along with upland rice included grain length, amylose content, gel consistency, alkali spreading value, and protein content of grain. Accordingly, the nutritional value in terms of Zn and protein content in grain became important price determinants for upland rice. In indica rice, percentage of head rice was identified as one significant price determinant.

The implicit price estimation provide insights into how consumers obtain information about chemical characteristics, which imply that: (1) Development of low to medium amylose rice and improvement of grain length provide benefit for both consumers and producers. (2) Potential head rice recovery is an important quality characteristics that should be considered in indica breeding program. (3) There was potential returns to high nutritional quality rice, in terms of Zn content in grain, and protein content of grain in some cases. (4) Upland rice and glutinous rice due to their high nutritional value could probably consider as a perfect stable or substitution food. (5) Upland rice could also be considered as potential sources for future's Zn rich rice genetic selection, because the genotypic variation in Zn content of rice grain was significant. Upland rice contained relatively high Zn content in grain, particularly in its black rice.

Results from the field experiment demonstrated the potential and limitation of nutritional status of Zn and P in grain yield and quality of various rice varieties. The field experimental results have shown that there is advantage in applying Zn and P, in terms of grain yield, protein content in grain, the total amount of protein content in grain, the total amount of Zn content in grain, and head rice recovery of total brown rice.

Results of field experiment revealed that: (1) Different yield responses to Zn and P applications among rice varieties were observed in field study. Increase of grain yield due to applying of Zn and P was more pronounced with Hexi 35 and Yungeng 34. (2) Amylose content of grain was mainly determined by genotype, showed a slight increase with Zn applied. (3) Protein content in grain was enhanced by increasing amount of P application regardless applications of Zn and genotype. Protein content in grain may be depressed by Zn applied depending on response of grain yield of variety to Zn and P application, an increase in grain yield due to applying Zn induced a reduction of protein content in grain. (4) Head rice recovery increased as increasing in level of P application.

(5) Protein content in grain evidently positively related to degree of hardness of grain, and this explains that increase in head rice recovery as a result of P application was due to an increase in hardness of kernel. (6) Degree of hardness of grain reduced when Zn applied regardless application of P and genotype. As the result, head rice recovery tended to decline with Zn applied. (7) Different cultivars exhibited various capabilities to absorb and translocate P and Zn into the seeds. Zn content in grain was negatively associated with grain yield, this indicated that higher grain yield due to applying Zn and P resulted in a reduction of Zn content of grain in Hexi 35 and Yungeng 34. However, total amount of Zn in grain of Hexi 35 and Yungeng 34 were increased as Zn applied.

Overall advantage of application of Zn and P in grain yield and quality was related to rate of P applied, and genetic effects responsible for Zn and P efficiencies. According to the experimental results, there is a trade-off between grain yield and grain quality need to be considered when applying Zn in Hexi 35 and Yungeng 34. P application as an intensive cultivation method to obtain higher grain yield, higher protein and higher head rice recovery in Hexi 35 and Yungeng 34, it should be further explored for different varieties. The finding of this study may also suggest that it does not necessarily indicate that higher rate of P application will induce Zn deficiency. However, to be economically feasible, the amount of P and Zn together with the effects of P-induced Zn deficiency should also be further verified in large scale experiment before general and long-term recommendation is readily made to farmers.

In summary, overall results of this research provided new insight into consumers' preferences for rice quality characteristics as reflected in market prices and impact of variety and crop management in terms of Zn and P application on improvement of rice quality. This study suggested that rice quality was mainly determined by variety, the biophysical conditions and crop management with respect to Zn and P application also influenced on the economically important quality characteristics. Hence, evaluation and improvement of rice quality should take account of both economic as well as agronomic aspects. Identifying factors in rice that promote grain quality in terms of head rice recovery, amylose content, protein content, and Zn bioavailibility should receive greater attention among breeders, agronomists, economists, as well as nutritionists.

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Appendix A Characteristics of 60 milled rice samples (collected from domestic market), Yunnan 1994.

No	Variety name	PI	ZN	P	PR	AMY	HEA	GEL	CHK	ALK	GL	GW	R	D1	D2	D	D0
1	*	3.00	25.98	0.390	7.40	1.33	90.9	84	1	4	6.41	3.13	2.05	0	0	1	2
2	*	1.90	18.22	0.127	6.40	25.70	71.8	66	75	3	6.32	2.41	2.62	0	0	1	3
3	*	2.00	17.92	0.154	7.14	24.45	86.5	63	35	2	6.02	2.34	2.57	0	0	1	3
4	*	1.90	21.00	0.072	7.06	2.06	65.3	96	1	6	5.84	2.15	2.72	0	0	1	3
5	*	2.60	19.82	0.352	8.57	3.00	71.5	90	1	4	5.88	2.70	2.18	0	0	1	3
6	*	3.50	18.54	0.152	7.38	2.46	41.1	94	1	6	6.52	2.04	3.20	0	0	1	2
7	*	1.80	19.77	0.112	8.92	17.97	75.5	89	55	5	5.64	1.93	2.92	0	0	1	2
8	*	1.90	21.25	0.117	6.90	1.69	75.9	96	1	6	6.00	2.17	2.76	0	0	1	3
9	Guichao 2	2.40	19.11	0.170	6.86	25.63	81.6	84	100	5	5.19	1.83	2.84	0	0	1	3
10	*	1.80	21.38	0.173	7.40	20.94	85.5	80	20	2	5.88	2.14	2.75	0	0	1	2
11	Diantun 502	2.40	20.44	0.109	7.14	15.59	58.2	48	25	6	7.36	3.12	2.36	0	0	1	3
12	Dianlong 201	2.30	19.39	0.103	6.22	14.90	61.0	69	10	6	7.38	3.13	2.36	0	0	1	3
13	*	1.95	18.26	0.122	6.34	25.34	65.6	58	55	2	6.21	2.42	2.57	0	0	1	3
14	*	2.00	21.00	0.152	7.22	20.00	87.5	77	70	4	5.31	1.87	2.84	0	0	1	2
15	Shanyou 63	1.90	18.19	0.152	7.38	22.65	79.3	100	35	2	5.94	2.27	2.62	0	0	1	3
16	Diyou 63	1.92	16.37	0.148	6.84	22.55	58.5	92	25	2	6.09	2.33	2.61	0	0	1	3
17	Shanyou 63	1.90	17.35	0.125	6.48	24.14	64.0	90	40	2	6.08	2.33	2.61	0	0	1	3
18	Ganyou 12	1.88	15.14	0.133	6.19	22.48	50.2	75	50	2	5.96	2.28	2.61	0	0	1	3
19	Dianrui 456	3.50	18.00	0.136	6.78	13.95	95.0	51	15	6	7.15	3.24	2.21	0	0	1	3
20	791	2.20	18.78	0.119	6.88	20.79	92.9	60	35	7	4.71	1.65	2.85	0	0	1	3
21	Daintun 502	3.60	22.51	0.120	6.25	12.99	82.0	51	15	5	6.99	2.97	2.35	1	0	2	3
22	Thai rice	4.20	19.24	0.096	6.19	19.77	99.7	73	0	4	6.78	3.29	2.06	1	0	2	3
23	Korea rice	2.45	15.35	0.126	5.27	19.10	87.5	80	25	7	4.80	1.67	2.87	1	0	2	1
24	*	2.60	20.89	0.266	7.56	19.96	89.0	59	1	6	5.31	1.82	2.92	1	0	2	2
25	Dongbei rice	2.30	16.89	0.118	5.56	18.79	74.1	87	50	7	4.84	1.63	2.97	1	0	2	1
26	*	2.20	15.16	0.112	5.41	16.88	79.2	76	0	4	5.08	1.70	2.99	1	0	2	1
27	*	2.00	14.75	0.122	6.72	17.80	95.0	77	50	7	4.98	1.74	2.86	1	0	2	1
28	Thai rice	4.80	19.30	0.112	7.20	18.69	99.2	77	5	4	7.29	3.33	2.19	1	0	2	3
29	*	2.30	22.94	0.121	8.00	4.03	86.0	95	1	6	4.58	1.43	3.20	1	0	2	1
30	Donting rice	2.50	18.61	0.110	8.41	14.94	88.7	92	15	5	8.68	3.48	2.49	1	0	2	3
31	Diantun 502	3.50	22.00	0.166	7.92	14.52	84.7	46	25	6	7.30	3.01	2.43	1	0	2	3
32	*	4.20	22.09	0.230	5.50	2.00	73.3	100	1	6	5.96	2.28	2.61	1	0	2	2
33	*	4.50	20.83	0.278	7.50	1.38	85.4	100	1	5	6.59	2.70	2.44	1	0	2	2
34	Chugeng 3	2.20	20.41	0.138	6.43	16.23	88.1	94	25	6	4.70	1.59	2.96	1	0	2	1
35	6536	2.10	17.60	0.117	7.12	17.86	92.7	84	70	6	5.15	1.77	2.91	1	0	2	1
36	6536	2.05	20.85	0.166	6.87	16.51	89.0	86	10	6	4.77	1.64	2.91	1	0	2	1
37	Babao rice	4.80	25.05	0.400	9.82	20.28	96.5	39	1	2	6.48	2.87	2.26	1	0	2	2
38	Hunan	3.80	24.52	0.176	7.68	3.22	90.0	100	1	5	7.01	2.90	2.42	1	0	2	3
39	Xinan 175	2.40	15.27	0.154	7.20	16.28	89.0	100	30	6	4.90	1.62	3.02	1	0	2	1
40	Xinan 175	2.30	13.98	0.142	7.20	16.23	90.4	100	20	5	5.20	1.66	3.13	1	0	2	1
41	Hexi 2	1.98	14.11	0.134	7.38	15.94	78.4	80	25	7	4.86	1.68	2.89	0	1	3	1
42	Dianyu 1	2.04	14.54	0.144	7.10	16.27	86.1	74	30	7	4.87	1.73	2.82	0	1	3	1
43	87-66	2.10	18.67	0.132	6.78	15.83	73.1	81	85	7	4.96	1.62	3.06	0	1	3	1
44	Hexi 17	2.04	15.83	0.126	6.13	17.21	81.0	74	60	7	4.97	1.63	3.05	0	1	3	1
45	Dayu 66	2.10	14.50	0.123	5.89	14.08	89.3	84	35	7	5.06	1.64	3.09	0	1	3	1
46	You 37	2.00	9.96	0.116	6.59	15.68	65.8	84	25	7	5.22	1.80	2.90	0	1	3	1
47	You 37	2.04	12.28	0.126	7.02	15.45	59.4	79	30	7	5.16	1.87	2.76	0	1	3	1
48	Chugeng	1.82	23.32	0.166	7.14	15.03	89.4	85	20	6	4.82	1.67	2.89	0	1	3	1
49	Jianshu rice	2.40	18.22	0.155	7.14	3.52	97.8	84	1	5	4.88	1.76	2.77	0	1	3	1
50	*	2.52	15.94	0.096	7.08	1.42	74.1	90	1	7	4.50	1.54	2.92	0	1	3	1
51	Dongbei rice	2.20	15.15	0.179	5.58	16.77	94.5	82	35	5	5.11	1.71	2.99	0	1	3	1
52	*	2.80	19.88	0.130	6.07	10.91	84.9	59	40	7	7.42	3.31	2.24	0	1	3	3
53	Dongbei rice	2.18	16.35	0.171	7.26	15.63	92.4	72	15	7	4.70	1.59	2.96	0	1	3	1
54	Chugeng	2.00	18.24	0.186	6.84	15.15	88.2	84	40	7	4.82	1.58	3.05	0	1	3	1
55	Hexi 2	2.04	13.45	0.117	5.64	9.09	73.5	78	25	7	4.77	1.65	2.89	0	1	3	1
56	*	2.04	14.00	0.142	6.60	8.85	69.7	85	70	7	4.71	1.58	2.98	0	1	3	1
57	Hexi 11	2.20	10.34	0.104	5.69	7.87	83.2	80	10	7	5.07	1.71	2.96	0	1	3	1
58	Hexi 66	2.20	14.09	0.094	6.72	16.82	82.3	74	40	7	4.88	1.69	2.89	0	1	3	1
59	Hexi 17	2.00	12.98	0.118	5.91	15.95	78.0	77	80	7	4.89	1.73	2.83	0	1	3	1
60	Hunnan	1.94	24.14	0.148	7.91	15.46	80.3	55	50	6	5.09	1.74	2.93	0	1	3	1

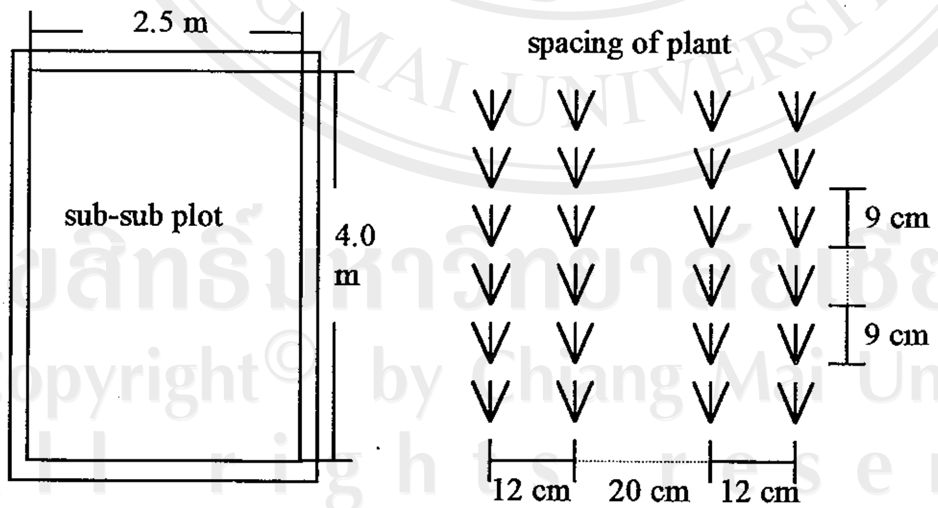
Note: PI=price (yuan/kg) of milled rice; ZN=zinc content (mg/kg); P=phosphorus content (%); PR=protein content (%); AMY=amylose content (%); HEA=percent head rice of total milled rice; GEL=gel consistency; ALK=alkali spreading value; CHK=chalkiness score (%), GL=grain length (mm); GW=grain width (mm); R=grain ratio of GL/G.

Dummy variables: D1=1 standard for Kunming, D2=1 standard for Dali, Xishuangbanna is base area which D1, D2 equal to zero. D=1, 2, 3 standard for Xishuangbanna, Kunming, and Dali. D0=1, 2, 3 standard for irrigated japonica rice, upland rice, and irrigated indica rice, respectively.

*Name of variety is unknown.

+Zn			-Zn			Trt.
V1	V2	V3	V1	V2	V3	P1
V2	V3	V1	V2	V3	V1	
V3	V1	V2	V3	V1	V2	
V2	V3	V1	V2	V3	V1	P2
V1	V2	V3	V1	V2	V3	
V3	V1	V2	V3	V1	V2	
V3	V1	V2	V3	V1	V2	P3
V2	V3	V1	V2	V3	V1	
V1	V2	V3	V1	V2	V3	

Appendix b-1 Layout of Field Experiment.
Treatment, -Zn and +Zn: 0, 5 kg Zn /ha; P1, P2, P3: 60, 150, 200 kg P_2O_5 /ha; V1, V2, V3: Xunza 29, Hexi 35; and Yungeng 34, respectively.



Appendix b-2 Diagram size of per experimental unit and spacing of plant

Appendix C Field Experimental Results

Appendix c-1 Effects of Zn and P application on plant development* with three rice varieties.

Treatment**	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Panicle shooting						
Xunza 29	133	129	129	129	130	128
Hexi 35	131	130	131	131	129	130
Yungeng 34	135	135	135	134	133	130
Flowering						
Xunza 29	142	139	140	139	138	138
Hexi 35	142	139	141	138	138	139
Yungeng 34	144	141	141	141	142	139
Maturity[a]						
Xunza 29	198	196	196	196	194	194
Hexi 35	198	196	195	197	195	195
Yungeng 34	201	200	198	199	198	198

* The days after sowing. Sowing date was March 21, recorded as 0.
** -Zn, +Zn: 0, 5 kg Zn /ha, respectively.
P1, P2, P3: 60, 150, 200 kg P_2O_5 /ha, respectively.
[a]= Maturity, indicating that all the grains turned yellow except one or two green grains at the bottom.

Appendix c-2 Effects of Zn and P application on grain yield t/ha of three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	8.13	7.62	7.42	7.83	8.33	6.92
Hexi 35	8.42	8.83	10.10	8.33	11.33	11.83
Yungeng 34	8.17	10.08	10.17	9.58	10.08	10.88

Appendix c-3 Effects of Zn and P application on panicle weight g/plant of three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	21.5	22.4	22.1	20.4	23.4	20.7
Hexi 35	22.7	24.2	27.0	23.4	25.1	29.9
Yungeng 34	23.6	26.5	27.0	23.1	25.2	28.1

Appendix c-4 Effects of Zn and P application on g/1000-grain-weight of three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	24.84	25.58	25.40	25.54	24.38	25.25
Hexi 35	26.75	26.93	26.21	27.30	26.92	27.38
Yungeng 34	30.20	29.46	31.09	30.76	30.96	31.29

Appendix c-5 Effects of Zn and P application on filled grain % of total grain with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	84.7	82.3	83.7	89.0	84.3	83.7
Hexi 35	85.7	87.3	89.7	93.0	91.0	94.3
Yungeng 34	79.3	80.3	80.3	84.3	78.3	79.7

Appendix c-6 Effects of Zn and P application on numbers of productive tiller/plant with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	5.6	5.8	6.2	6.0	6.0	5.8
Hexi 35	5.0	4.7	5.8	4.7	4.8	5.4
Yungeng 34	4.3	4.0	4.6	4.5	4.6	4.6

Appendix c-7 Effects of Zn and P application on total grain numbers/panicle with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	172.9	195.1	184.5	179.5	176.7	181.9
Hexi 35	199.1	197.6	184.1	190.0	195.7	195.2
Yungeng 34	206.9	218.7	221.2	217.7	241.2	258.0

Appendix c-8 Effects of Zn and P application on total biomass t/ha of three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	17.3	15.6	16.2	15.3	17.3	15.4
Hexi 35	16.0	16.8	19.0	15.7	20.9	21.3
Yungeng 34	17.4	20.7	20.4	20.0	20.4	21.8

Appendix c-9 Effects of Zn and P application on harvest index (HI) of three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	0.47	0.49	0.46	0.51	0.48	0.45
Hexi 35	0.53	0.54	0.53	0.53	0.54	0.56
Yungeng 34	0.47	0.49	0.50	0.48	0.50	0.50

Appendix b-10 Effects of Zn and P application plant height cm with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	85.0	83.9	89.3	80.0	83.5	81.5
Hexi 35	98.0	99.3	101.9	91.6	94.1	94.9
Yungeng 34	109.4	109.4	109.1	104.5	106.8	107.8

Appendix c-11 Effects of Zn and P application on Zn content mg/kg of stem with three rice varieties (at final harvest stage).

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	39.05	45.34	45.28	44.92	46.02	40.18
Hexi 35	21.84	20.36	20.98	25.76	20.24	24.03
Yungeng 34	25.64	24.81	31.16	36.30	32.62	30.78

Appendix c-12 Effects of Zn and P application on Zn content mg/kg of leaf blade 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	20.48	14.32	16.49	15.96	16.47	21.07
Yungeng 34	19.08	16.68	19.90	21.02	21.44	20.85

Appendix c-13 Effects of Zn and P application on Zn content mg/kg of grain* with three rice varieties (at final harvest stage).

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	13.85	15.00	16.83	16.65	15.16	16.46
Hexi 35	14.01	12.82	13.72	15.15	15.52	12.10
Yungeng 34	13.02	12.16	13.63	15.10	12.94	13.00

*brown rice (at 14% of grain moisture), Zn contents were measured by applying atom absorption.

Appendix c-14 Effects of Zn and P application on total amount of Zn content g/ha of grain with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	112.5	114.0	124.9	130.4	126.1	113.6
Hexi 35	118.0	113.4	137.9	125.9	175.7	143.0
Yungeng 34	108.2	122.9	138.2	145.2	130.5	141.3

Appendix c-15 Effects of Zn and P application on total amount of Zn uptake g/ha of plant three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	377.2	365.6	407.9	369.2	422.8	357.1
Hexi 35	276.9	254.7	307.5	278.2	351.3	355.0
Yungeng 34	316.2	343.0	397.2	442.7	408.1	421.7

Appendix c-16 Effects of Zn and P application on Zn proportion* in stem, blade leaf, grain with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Stem						
Xunza 29	0.48	0.49	0.49	0.46	0.49	0.47
Hexi 35	0.29	0.31	0.30	0.34	0.27	0.32
Yungeng 34	0.38	0.38	0.39	0.42	0.40	0.40
Leaf						
Xunza 29	0.22	0.19	0.20	0.19	0.20	0.21
Hexi 35	0.28	0.22	0.24	0.21	0.22	0.28
Yungeng 34	0.28	0.26	0.26	0.25	0.27	0.27
Grain						
Xunza 29	0.30	0.31	0.31	0.35	0.30	0.32
Hexi 35	0.43	0.46	0.46	0.45	0.50	0.40
Yungeng 34	0.34	0.36	0.35	0.33	0.32	0.34

Appendix c-17 Effects of Zn and P application on P content % of stem with three rice varieties (at final harvest stage).

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	0.079	0.090	0.099	0.065	0.100	0.128
Hexi 35	0.061	0.075	0.070	0.052	0.056	0.098
Yungeng 34	0.057	0.080	0.101	0.059	0.083	0.089

Appendix c-18 Effects of Zn and P application on P content % of leaf blade 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

Appendix c-19 Effects of Zn and P application on % P content of grain with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	0.124	0.119	0.146	0.122	0.126	0.130
Hexi 35	0.123	0.123	0.124	0.120	0.130	0.121
Yungeng 34	0.144	0.106	0.132	0.116	0.121	0.115

Appendix c-20 Effects of Zn and P application on the total amount P kg/ha of grain with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	10.1	9.1	10.8	9.6	10.5	9.0
Hexi 35	10.4	10.8	12.5	10.0	14.7	14.3
Yungeng 34	11.8	10.7	13.4	11.1	12.1	12.5

Appendix c-21 Effects of Zn and P application on the total amount of P uptake kg/ha of plant with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	18.6	18.3	20.6	16.1	20.7	21.3
Hexi 35	16.3	18.7	21.1	15.5	23.1	24.5
Yungeng 34	18.4	19.8	24.8	18.9	22.3	23.8

Appendix c-22 Effects of Zn and P application on P proportion* in stem, blade leaf, grain of three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Stem						
Xunza 29	0.20	0.20	0.21	0.15	0.21	0.25
Hexi 35	0.14	0.15	0.15	0.12	0.12	0.19
Yungeng 34	0.14	0.21	0.21	0.16	0.18	0.20
Leaf						
Xunza 29	0.26	0.31	0.26	0.26	0.28	0.32
Hexi 35	0.23	0.27	0.25	0.23	0.25	0.23
Yungeng 34	0.22	0.25	0.24	0.25	0.26	0.27
Grain						
Xunza 29	0.54	0.49	0.52	0.59	0.51	0.42
Hexi 35	0.64	0.58	0.60	0.65	0.63	0.58
Yungeng 34	0.64	0.54	0.54	0.59	0.55	0.52

Appendix c-23 Effects of Zn and P application on length (mm) of grain with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	4.66	4.71	4.69	4.75	4.74	4.72
Hexi 35	4.77	4.72	4.74	4.76	4.81	4.75
Yungeng 34	5.33	5.23	5.21	5.27	5.21	5.27

Appendix c-24 Effects of Zn and P application on ratio of grain length to grain width (L/W) with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	1.63	1.59	1.60	1.64	1.63	1.64
Hexi 35	1.58	1.56	1.60	1.57	1.60	1.61
Yungeng 34	1.82	1.79	1.77	1.77	1.81	1.82

Appendix c-25 Effects of Zn and P application on degree of grain chalkiness with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	3.5	3.8	3.8	5.2	6.3	3.6
Hexi 35	4.8	1.7	2.8	2.0	2.7	2.3
Yungeng 34	12.2	14.6	15.0	13.9	10.0	13.0

Appendix c-26 Effects of Zn and P application on degree of grain hardness* with tree rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	53.8	50.3	48.5	39.8	40.8	40.9
Hexi 35	60.3	50.1	58.8	47.2	40.8	48.0
Yungeng 34	47.0	50.0	53.5	39.7	39.5	46.0

*Indicating stress which just made grain cracked. Measured by device, namely KQ-1, and the stress expressed as Newton/grain.

Appendix c-27 Effects of Zn and P application on of brown rice (%) with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	84.3	84.4	83.8	83.8	83.8	83.9
Hexi 35	83.8	85.3	85.4	83.8	83.4	87.1
Yungeng 34	83.2	83.9	84.2	83.6	86.3	86.7

Appendix c-28 Effects of Zn and P application on milled rice (%) with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	76.9	76.5	76.5	76.1	76.2	76.4
Hexi 35	76.6	77.1	77.8	75.5	75.5	79.4
Yungeng 34	74.9	74.6	75.0	74.4	77.3	77.4

Appendix c-29 Effects of Zn and P application on head rice recovery[a] (%) with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	66.5	66.4	64.6	66.3	68.9	68.1
Hexi 35	67.9	68.9	71.1	65.2	67.7	70.4
Yungeng 34	66.3	69.3	69.1	64.3	66.2	68.0

Appendix c-30 Effects of Zn and P application on protein content (%) of brown rice with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	9.12	10.02	10.65	8.79	9.96	9.50
Hexi 35	9.08	8.98	9.76	8.52	8.31	8.50
Yungeng 34	9.30	9.56	10.11	8.51	8.90	8.57

Appendix c-31 Effects of Zn and P application on total amount of protein (kg/ha) of brown rice with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	74.1	76.1	78.9	68.7	82.8	65.8
Hexi 35	76.4	79.4	98.3	70.9	94.2	100.5
Yungeng 34	75.7	96.3	102.5	81.4	90.0	92.8

Appendix c-32 Effects of Zn and P application on amylose content (%) of milled rice with three rice varieties.

Treatment	-Zn			+Zn		
	P1	P2	P3	P1	P2	P3
Xunza 29	19.63	20.45	19.04	21.66	20.16	21.54
Hexi 35	16.78	17.37	17.22	17.72	17.28	17.66
Yungeng 34	18.01	18.52	18.90	19.27	19.21	19.30

Appendix D Analysis of Variance (ANOVA) of the Field Experiment

Appendix d-1 ANOVA for date of Panicle emergency, Flowering, and Maturity (the days after sowing).

Source of variance	DF	Panicle emergency		Flowering stage		Maturity stage	
		MS	P	MS	P	MS	P
Replication	2	4.574	0.269	8.685	0.108	6.241	0.053
Zinc (A)	1	29.630	0.052	42.667	0.024	44.463	0.008
Error	2	1.685		1.056		0.352	
Phosphorus (B)	2	13.019	0.073	8.963	0.272	11.241	0.097
Error	4	2.407		4.880		2.546	
A×B	2	3.574	0.405	12.667	0.018	10.019	0.053
Error	4	3.130		0.972		1.491	
Genotype (C)	2	83.019	0.000	23.463	0.000	25.796	0.000
A×C	2	3.574	0.315	2.167	0.420	4.463	0.149
B×C	4	2.685	0.473	4.741	0.132	4.519	0.114
A×B×C	4	5.185	0.170	0.833	0.844	1.185	0.703
Error	24	2.944		2.407		2.167	

Appendix d-2 ANOVA for Grain yield, 1000-grain-weight, and Panicle weight.

Source of variance	DF	1000-grain-weight (g)		Panicle weight (g/pl.)		Grain yield t/ha)	
		MS	P	MS	P	MS	P
Replication	2	0.599	0.540	0.743	0.589	8.28	0.907
Zinc (A)	1	2.241	0.216	0.918	0.451	638.60	0.107
Error	2	0.702		1.066		81.32	
Phosphorus (B)	2	0.522	0.421	52.073	0.001	683.50	0.030
Error	4	0.482		0844		71.11	
A×B	2	0.339	0.817	1.537	0.613	59.36	0.547
Error	4	1.600		2.771		84.17	
Genotype (C)	2	142.66	0.000	84.245	0.000	2670.30	0.000
A×C	2	0.897	0.232	5.536	0.119	223.63	0.022
B×C	4	0.582	0.423	13.818	0.002	463.56	0.000
A×B×C	4	1.164	0.125	2.845	0.338	171.27	0.024
Error	24	0.577		2.376		49.99	

Appendix d-3 ANOVA for Filled grain, Grain numbers, Productive tiller numbers.

Source of variance	DF	Filled grain (%)		No. of grain /panicle		No. of prod. tller /pl.	
		MS	P	MS	P	MS	P
Replication	2	0.00035	0.825	1426.70	0.198	0.1973	0.867
Zinc (A)	1	0.00987	0.134	15.23	0.350	0.0504	0.862
Error	2	0.00164		351.67		1.2901	
Phosphorus (B)	2	0.00194	0.425	576.25	0.667	0.9156	0.0894
Error	4	0.00181		1284.25		0.1952	
A×B	2	0.00275	0.214	274.25	0.735	0.3951	0.530
Error	4	0.00118		824.54		0.5291	
Genotype (C)	2	0.04239	0.000	10047.0	0.001	9.6210	0.000
A×C	2	0.00234	0.288	1023.90	0.361	0.2673	0.400
B×C	4	0.00141	0.543	401.65	0.795	0.2827	0.423
A×B×C	4	0.00029	0.957	189.44	0.938	0.0645	0.919
Error	24	0.00178		964.08		0.2806	

Appendix d-4 ANOVA for Plant height, Total biomass, and Harvest index (HI).

Source of variance	DF	Plant height (cm)		Total biomass (t/ha)		Harvest index (HI)	
		MS		MS	P	MS	P
Replication	2	27.445	0.124	175.75	0.732	0.00147	0.347
Zinc (A)	1	276.260	0.014	1195.90	0.256	0.00157	0.347
Error	2	3.891		480.96		0.00078	
Phosphorus (B)	2	32.118	0.402	2185.50	0.044	0.00032	0.700
Error	4	27.797		290.69		0.00080	
A×B	2	10.555	0.176	332.42	0..450	0.00031	0.779
Error	4	3.819		338.09		0.00120	
Genotype (C)	2	2591.200	0.000	6828.30	0.000	0.01919	0.000
A×C	2	12.035	0.305	642.11	0.185	0.00004	0.971
B×C	4	2.036	0.930	898.30	0.067	0.00174	0.243
A×B×C	4	8.319	0.500	637.54	0.162	0.00048	0.803
Error	24	9.633		354.67		0.00118	

Appendix d-5 ANOVA for zinc (Zn) content of stem, leaf blade, and grain (mg/kg).

Source of variance	DF	Zn content of stem		Zn content of leaf		Zn content of grain	
		MS	P	MS	P	MS	P
Replication	2	87.38	0.125	0.757	0.946	5.424	0.173
Zinc (A)	1	115.93	0.093	18.447	0.360	8.252	0.114
Error	2	12.49		13.30		1.133	
Phosphorus (B)	2	2.27	0.953	9.605	0.469	2.184	0.276
Error	4	46.51		10.436		1.207	
A×B	2	65.48	0.03	15.522	0.138	10.009	0.040
Error	4	8.06		4.600		1.243	
Genotype (C)	2	2027.4	0.000	25.402	0.003	26.956	0.000
A×C	2	36.02	0.019	6.716	0.158	0.022	0.982
B×C	4	24.79	0.029	6.771	0.125	5.096	0.010
A×B×C	4	17.85	0.084	12.984	0.015	2.157	0.168
Error	24	7.62		3.362		1.219	

Appendix d-6 ANOVA for total amount of Zn in grain (g/ha), and total amount of Zn uptake of plant (g/ha).

Source of variance	DF	Total amount of Zn in grain (g/ha)		Total amount of Zn uptake by plant (g/ha)	
		MS	P	MS	P
Replication	2	4.687	0.311	18.916	0.535
Zinc (A)	1	3.337	0.058	21.588	0.088
Error	2	2.116		21.764	
Phosphorus (B)	2	4.565	0.159	43.363	0.483
Error	4	1.514		49.456	
A×B	2	9.942	0.119	48.860	0.204
Error	4	2.619		20.155	
Genotype (C)	2	1.127	0.010	40.259	0.000
A×C	2	3.989	0.158	61.175	0.064
B×C	4	3.798	0.144	13.611	0.613
A×B×C	4	7.135	0.020	34.542	0.178
Error	24	2.001		20.021	

Appendix d-7 ANOVA for Zn proportion (%) in stem, leaf, and grain.

Source of variance	DF	Stem		Leaf		Grain	
		MS	P	MS	P	MS	P
Replication	2	0.00261	0.197	0.00246	0.643	0.00353	0.350
Zinc (A)	1	0.00051	0.467	0.00058	0.752	0.00000	0.975
Error	2	0.00064		0.00444		0.00190	
Phosphorus (B)	2	0.00000	0.978	0.00079	0.437	0.00106	0.647
Error	4	0.00161		0.00077		0.00218	
A×B	2	0.00115	0.299	0.00548	0.058	0.00187	0.268
Error	4	0.00069		0.00087		0.00101	
Genotype (C)	2	0.13650	0.000	0.01664	0.000	0.0938	0.000
A×C	2	0.00155	0.200	0.00007	0.913	0.00175	0.387
B×C	4	0.00082	0.471	0.00065	0.543	0.00225	0.308
A×B×C	4	0.00123	0.273	0.00054	0.626	0.00187	0.400
Error	24	0.00090		0.00083		0.00177	

Appendix d-8 ANOVA for phosphorus (P) content(%) of stem, leaf blade, and grain.

Source of variance	DF	P content of stem		P content of leaf		P content of grain	
		MS	P	MS	P	MS	P
Replication	2	0.00027	0.521	0.0004	0.557	0.00027	0.748
Zinc (A)	1	0.00007	0.686	0.0004	0.475	0.00028	0.613
Error	2	0.00059		0.0005		0.00081	
Phosphorus (B)	2	0.01120	0.068	0.0039	0.019	0.00026	0.056
Error	4	0.00396		0.0003		0.00004	
A×B	2	0.00120	0.424	0.0003	0.232	0.00069	0.206
Error	4	0.00220		0.0001		0.00029	
Genotype (C)	2	0.00570	0.000	0.0027	0.000	0.00015	0.342
A×C	2	0.00027	0.550	0.0002	0.233	0.00013	0.397
B×C	4	0.00049	0.697	0.0002	0.270	0.00035	0.066
A×B×C	4	0.00230	0.067	0.0007	0.010	0.00016	0.349
Error	24	0.00530		0.0002		0.00014	

Appendix d-9 ANOVA for total amount of P in grain (kg/ha), and total amount of P uptake of plant (kg/ha).

Source of variance	DF	Total amount of P in grain (kg/ha)		Total amount of P uptake by plant (kg/ha)	
		MS	P	MS	P
Replication	2	24.0.6	0.847	15.536	0.849
Zinc (A)	1	27.678	0.693	149.30	0.321
Error	2	133.14		87.332	
Phosphorus (B)	2	118.37	0.0503	1313.2	0.134
Error	4	17.117		85.895	
A×B	2	112.34	0.0700	180.41	0.034
Error	4	20.208		20.483	
Genotype (C)	2	291.98	0.000	198.73	0.070
A×C	2	61.891	0.079	58.815	0.428
B×C	4	53.059	0.076	63.932	0.449
A×B×C	4	13.79	0.647	33.141	0.739
Error	24	21.945		66.833	

Appendix d-10 ANOVA for P proportion (%) in stem, leaf, and grain.

Source of variance	DF	Stem		Leaf		Grain	
		MS	P	MS	P	MS	P
Replication	2	0.00004	0.982	0.00184	0.603	0.00243	0.805
Zinc (A)	1	0.00003	0.912	0.00063	0.682	0.00036	0.866
Error	2	0.00233		0.00280		0.01000	
Phosphorus (B)	2	0.01171	0.113	0.00408	0.0455	0.02638	0.059
Error	4	0.00297		0.00055		0.00425	
A×B	2	0.00247	0.404	0.00121	0.485	0.00658	0.334
Error	4	0.00216		0.00139		0.00451	
Genotype (C)	2	0.01644	0.000	0.00832	0.003	0.04423	0.000
A×C	2	0.00014	0.862	0.00134	0.302	0.00133	0.589
B×C	4	0.00079	0.502	0.00035	0.858	0.00098	0.808
A×B×C	4	0.00195	0.109	0.00120	0.366	0.00293	0.339
Error	24	0.00092		0.00107		0.00245	

Appendix d-11 ANOVA for Length (L), width (W) of grain and Ratio of L/W.

Source of variance	DF	Grain length (mm)		Grain width (mm)		Ratio of L/W	
		MS	P	MS	P	MS	P
Replication	2	0.0063	0.355	0.0030	0.654	0.0004	0.947
Zinc (A)	1	0.0083	0.261	0.0002	0.873	0.0074	0.399
Error	2	0.0035		0.0057		0.0065	
Phosphorus (B)	2	0.0039	0.375	0.0019	0.536	0.0008	0.824
Error	4	0.0031		0.0026		0.0038	
A×B	2	0.0014	0.705	0.0027	0.518	0.0019	0.081
Error	4	0.0037		0.0035		0.0004	
Genotype (C)	2	1.6370	0.000	0.0570	0.000	0.2420	0.000
A×C	2	0.0033	0.598	0.0011	0.706	0.0009	0.574
B×C	4	0.0037	0.674	0.0011	0.844	0.0009	0.684
A×B×C	4	0.0048	0.561	0.0017	0.730	0.0007	0.763
Error	24	0.0063		0.0032		0.0015	

Appendix d-12 ANOVA for Output of brown rice, Milled rice recovery, and Head rice recovery (%).

Source of variance	DF	Output of brown rice		Milled rice recovery		Head rice recovery	
		MS	P	MS	P	MS	P
Replication	2	1.562	0.660	1.207	0.413	0.650	0.306
Zinc (A)	1	2.622	0.451	0.759	0.445	4.167	0.062
Error	2	3.035		0.852		0.287	
Phosphorus (B)	2	9.465	0.238	8.397	0.334	29.708	0.045
Error	4	4.511		5.755		4.021	
A×B	2	3.251	0.091	5.072	0.091	5.351	0.763
Error	4	0.703		1.093		18.441	
Genotype (C)	2	2.896	0.374	8.836	0.062	15.104	0.163
A×C	2	6.001	0.142	5.481	0.166	21.657	0.080
B×C	4	4.079	0.250	3.821	0.280	8.853	0.358
A×B×C	4	2.025	0.589	2.026	0.589	1.630	0.930
Error	24	2.826		2.829		7.712	

Appendix E Summary of Agronomic and Quality Characteristics of Rice Varieties

Appendix e-1 Plant development, yield and yield components, and agronomic characteristics of three varieties.

Characteristics	Xunza 29	Hexi 35	Yungeng 34
Panicle emergency (day)	129.7	130.2	133.6
Flowering (day)	139.4	139.6	141.5
Maturity (day)	195.4	195.9	197.7
Grain yield (t/ha)	7.70	9.80	9.83
Panicle weight (g/plant)	21.8	25.4	25.6
1000-grain-weight (g)	25.1	26.9	30.6
No. of productive tiller/plant	5.9	5.0	4.4
No. of grain/panicle	181.7	193.6	227.3
Plant height (cm)	83.9	96.6	107.8
Total biomass (t/ha)	16.2	18.3	20.1
Harvest index (HI)	0.48	0.49	0.54

Appendix e-2 Zn and P uptake and distribution in plant of three varieties (at maturity).

Characteristics	Xunza 29	Hexi 35	Yungeng 34
Zn content in stem (mg/kg)	43.5	22.2	30.2
in whole leaf	18.4	17.5	19.8
in whole kernel	15.7	13.9	13.3
Total Zn in grain (g/ha)	120.2	131.1	135.7
Total uptake Zn (g/ha)	383.3	303.9	388.2
P content in stem (%)	0.094	0.067	0.078
in whole leaf	0.128	0.113	0.104
in whole kernel	0.127	0.124	0.122
Total P in grain (kg/ha)	9.8	12.1	11.9
Total uptake P (kg/ha)	19.3	19.9	21.3

Appendix e-3 Grain physical and chemical quality characteristics of three varieties.

Characteristics	Xunza 29	Hexi 35	Yungeng 34
Grain length (mm)	4.71	4.76	5.26
Grain width (mm)	2.91	3.01	2.91
Chalkiness score (%)	4.4	2.7	13.1
Hardness (Newton/grain)	45.7	50.9	45.9
Yield of brown rice (%)	84.0	84.8	84.6
Milled rice recovery (%)	76.4	77.0	75.6
Head rice recovery (%)	66.8	68.5	67.2
Protein content (%)	9.7	8.9	9.2
Total protein (kg/ha)	74.4	86.6	89.8
Amylose content (%)	20.5	17.3	18.9