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# Varietal Difference in Growth, Yield and Grain Quality of Rice Grown at Different Altitudinal Locations

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ABSTRACT : **Growth and quality of rice are affected by various factors including the location of cultivation. This study was conducted to investigate the effects of altitudinal locations on the growth and yield-related components of rice. Nineteen Japonica type varieties were grown at Iksan (altitude, 10 m), Imsil (altitude, 150 m), Jinan (altitude, 275 m) and Jangsu (altitude, 430 m) at a similar latitude in Jeonbuk province in the south western Korea. Minimum air temperature showed a strong negative correlation with altitude. The morphological traits and yield- and quality-related components were analyzed. Longer days to heading was required at higher altitudes. However, culm length, panicle length, panicle number, grain number and rice yield were reduced at higher altitudes. Protein content of brown rice increased but fatty acid content decreased at higher altitudes. Amylose content was affected by neither the altitude nor the ecotype. Palatability of polished rice tends to be improved at higher altitudes and in early-maturing ecotypes but its relationships with altitude and ecotype were not significant. Head rice ratio was lower at higher altitudes but broken rice ratio vise versa. These results indicate that growth and quality of rice are affected significantly by changes in temperatures at the locations of different altitude. Also, the characters related to yield and quality of rice often respond incompatibly to the changes in altitudes. These results could provide valuable information for the strategic planning of rice production in geographically diverse areas.**

***Keywords***: altitude, growth characteristic, quality, rice, yield

Air temperature is an important environmental factor which alters growth and development of plants as it directly affect the metabolism of plant cells. Plants as an individual or a community respond to diurnal and seasonal changes of air temperature. Diurnal and seasonal air temperatures are significantly altered by the altitude of locations. Consequently, growth and quality of rice are influenced by altitudes of cultivation areas, frequently leading to ecotypes adapted to those unique environments.

Ecotypes with differentiated characters which are adapted to a particular set of environmental conditions occur by genetic fixation. In general, mid- to late-maturing varieties better suit to lower altitude areas, whereas early-maturing varieties to higher altitude areas. Therefore, mid- and late-maturing varieties are high yielding at low altitude areas, whereas early-maturing varieties at high altitude areas. However, various ecotypes of rice have been cultivated at various altitudes under practical considerations of the cropping system and quality of rice produced.

Rice yield is primarily determined by the number of spikelets per unit area and additionally by the percent ripened grain which is affected by the amount of assimilate translocated to panicle before and after the heading stage. Number of spikelets and percent ripened grain differ by ecotypes and altitudes (Yoshida & Hara, 1977). The number of spikelets and percent ripened grain and grain weight contribute 60% and 21% of rice yield, respectively (Yoshida, 1981). Also, the number of spikelets per unit area can explain over 80% of the variation in rice yield (Yoshida & Parao, 1976). Thus, rice yield is primarily determined by the total amount of assimilates accumulated on panicles as carbohydrate is the major component of rice seed. Starch composition of starch cereals is closely related to the amount of harvest (Crafts-Brandner & Egli, 1987).

Quality and palatability of rice are determined by multiple factors such as variety, weather and soil conditions, cultivation method, harvesting time, drying, milling, storage, and cooking conditions. Among the factors, production area, water management, amount of nitrogen application, harvesting time and lodging are significantly influenced by variety. Webb(1985) pointed out the five elements of rice quality as nutritive value, cooking and palatability, processing characteristics, visual and milling characteristics and marketability. Choi *et al.* (1974) reported that amylose, protein, and several inorganic compounds could be used as indices of palatability. Especially, the contents of these components show

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highly positive correlations with palatability evaluation values. As the chemical composition of rice is affected by movement and accumulation rate of photosynthate at the physiological ripening stage, temperature significantly affects quality of rice (Matsuo *et al.*, 1995). Importance of palatability as a factor for quality is increasing as quality of rice is valued even higher by consumers (Chae *et al.*, 2003).

Rice is a major income source of farm household thus, high yield and milling recovery could contribute to stable income. On the other hand, satisfying consumers' desire for rice with good appearance quality and palatability is important to keep their continuous purchase of rice. Thus, the aim of this study was to investigate the effects of altitudes and ecotypes on the yield and quality-related factors of rice.

## MATERIALS AND METHODS

### Varieties and cultivation managements

Nineteen varieties, 4 early-maturing, 10 medium-maturing, and 5 mid-late- maturing varieties, used in this experiment are shown in Table 1. Experiments were conducted in four locations at different altitudes at a similar latitude like Iksan (altitude, 10 m), Imsil (altitude, 150 m), Jinan (altitude, 275 m) and Jangsu (altitude, 430 m) in Jeonbuk province in the south western Korea (35N). Rice seedlings were transplanted on May 30, May 25, May 20 and May 15, 2003, at the altitude of 10 m, 150 m, 275 m and 430 m, respectively. Spacing between seedlings were 30×15 cm at the altitude of 10 m and 150 m, and 30×12 cm at the altitude of 275 m and 430 m. Fertilizers were applied at the rato of 110-45-57(N-$P_2O_5$-$K_2O$) kg/10ha at the altitude of 10 m and 150 m, and 120-64-78 (N-$P_2O_5$-$K_2O$) kg/10ha at the altitude of 275 m and 430 m. Nitrogen was applied in three splits (at basal, tillering stage, and panicle initiation stage by 50%, 20%, and 30%), and potassium in two splits (at basal and panicle initiation stage by 70% and 30%). Phosphorus was applied once as a basal fertilization (Table 2). All the measurements of growth and yield characteristics were conducted according to the investigation standards of Rural Development Adminstration (RDA), Korea (1995).

### Quality measurements

The quality of brown rice was investigated for random sampled 1,000 grains with a single grain rice inspector (RN-500, Kett, Japan). Contents of protein, amylose and fatty acids were measured using a near-infrared grain tester (AN-700, Kett, Japan). Palatability was measured with a Midometer (TOYO MA-90B, Japan).

### Soil analysis

Soil chemical properties were analyzed by the method established by the National Institute of Agricultural Science and Technology (1988). Soil pH was measured in the solution of the mixture of soil and distilled water (v/v, 1:5) using a pH meter (Istek 460CP). Organic content was analyzed by Tyurin method, and phosphate content by Lancaster method using a colorimeter (HP 8452A). The exchangeable cation contents ($K^+$, $Ca^{++}$, $Mg^{++}$) were measured for the filtrates of 1 N $NH_4OAC$ leachates and $SiO_2$ content for the filtrate of 1 N NaOAC leachates using an atomic absorption spectrometer (SpectrAA 220FS, Varian). The chemical properties of experimental field before the initiation of these experiments were as in Table 3.

Experiments were conducted in a completely randomized design in each location. Analysis of variance and correlations were conducted using SAS (Cary, USA).

## RESULTS AND DISCUSSION

Generally, each plant species has its own optimal ranges

**Table 1.** Varieties tested were classified into the three groups by the ecotype.

| Ecotype | Early maturing variety | Medium maturing variety | Mid-late maturing variety |
|---|---|---|---|
| Variety | Jungsanbyeo, Saesangjubyeo, Manchubyeo, Taesungbyeo | Samphyeongbyeo, Haephyeongbyeo, Hwaanbyeo, Manphyungbyeo, Sukjeongbyeo, Manweolbyeo, Saegyehwabyeo, Kemanbyeo, Daephyeongbyeo, Samdukbyeo | Hojinbyeo, Junambyeo, Dongjin 1 hobyeo, Jongnambyeo, Seoganbyeo |

**Table 2.** Cultivation method at locations at different altitudes.

| Altitude (m) | Latitude | Longitude | Seeding (month.day) | Transplanting (month.day) | Spacing (cm) | Fertilization(kg/10ha) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | N | $P_2O_5$ | $K_2O$ |
| 10 | 35°35'N | 126°57'E | Apr. 30 | May 30 | 30×15 | 110 | 45 | 57 |
| 150 | 35°34'N | 127°18'E | Apr. 25 | May 25 | 30×15 | 110 | 45 | 57 |
| 275 | 35°39'N | 127°21'E | Apr. 20 | May 20 | 30×12 | 120 | 64 | 78 |
| 430 | 35°37'N | 127°30'E | Apr. 15 | May 15 | 30×12 | 120 | 64 | 78 |

of air and soil temperatures for normal growth. When plants are exposed to off the optimal temperatures ranges, growth and development of plants are generally poor as the cellular metabolisms required for the normal growth and development are inhibited. For example, at lower water temperatures, root growth and function are inhibited resulting in decreased nutrient uptake that may cause malnutrition of plants, which in turn causes retardation in plant growth and development, and finally poor yield and quality.

## Altitude and environmental factors

The average minimum air temperatures at the four locations at different altitudes clearly indicate that the temperatures are lower at higher altitudes (Table 4). However, daylight hours are higher in the locations at the altitude of

**Table 3.** Chemical properties of soils before the initiation of experiments.

| Altitude (m) | pH (1:5) | OM (g/kg) | $P_2O_5$ (mg/kg) | Ex cation($comol^+/100$) | | | $SiO_2$ (mg/kg) |
|---|---|---|---|---|---|---|---|
| | | | | K | Ca | Mg | |
| 10 | 5.8 | 34 | 164 | 0.20 | 6.90 | 1.70 | 82 |
| 150 | 5.0 | 29 | 203 | 0.22 | 4.40 | 1.40 | 114 |
| 275 | 5.9 | 43 | 242 | 0.25 | 3.15 | 0.57 | 183 |
| 430 | 6.1 | 18 | 116 | 0.19 | 4.40 | 1.10 | 82 |

OM: organic matter

**Table 4.** Monthly average minimum air temperature and hours of daylight by altitude.

| Meteorological facter | Altitude | Apr. | May | Jun. | Jul. | Aug. | Sep. | Oct. |
|---|---|---|---|---|---|---|---|---|
| Minimum air temperature (°C) | 10 | 7.4 | 12.6 | 16.3 | 20.0 | 20.5 | 17.0 | 8.7 |
| | 150 | 6.9 | 12.7 | 16.9 | 20.0 | 20.5 | 17.2 | 5.4 |
| | 270 | 5.4 | 11.0 | 15.2 | 19.2 | 19.8 | 16.1 | 5.0 |
| | 430 | 4.9 | 10.5 | 14.5 | 17.7 | 18.5 | 14.5 | 3.9 |
| Hours of daylight (hr) | 10 | 193.4 | 215.9 | 155.6 | 84.0 | 124.3 | 168.6 | 221.2 |
| | 150 | 208.8 | 236.1 | 203.1 | 138.9 | 175.7 | 188.8 | 237.3 |
| | 270 | 219.8 | 233.3 | 203.3 | 141.3 | 174.0 | 194.2 | 239.5 |
| | 430 | 199.0 | 198.7 | 177.9 | 111.9 | 143.0 | 149.1 | 212.2 |

**Table 5.** Comparison of growth characters on altitude and ecotype.

| Altitude (m) | Ecotype | Heading stage (date) | Days to heading from transplanting (days) | Culm length (cm) | Panicle length (cm) |
|---|---|---|---|---|---|
| 10 | Early | Aug. 4 | 66 | 78.0 | 19.5 |
| | Medium | Aug.12 | 74 | 79.0 | 20.2 |
| | Mid-late | Aug.16 | 78 | 75.6 | 20.2 |
| | Average | Aug.11 | 73 | 77.5 | 20.0 |
| 150 | Early | Aug. 3 | 70 | 67.0 | 19.0 |
| | Medium | Aug.13 | 80 | 70.1 | 19.8 |
| | Mid-late | Aug.15 | 82 | 66.0 | 19.4 |
| | Average | Aug.10 | 77 | 67.7 | 19.4 |
| 275 | Early | July 31 | 72 | 60.3 | 17.0 |
| | Medium | Aug.12 | 84 | 65.5 | 18.6 |
| | Mid-late | Aug.16 | 88 | 60.6 | 18.6 |
| | Average | Aug. 9 | 81 | 62.1 | 18.1 |
| 430 | Early | July 31 | 77 | 58.0 | 17.5 |
| | Medium | Aug.12 | 89 | 59.2 | 18.0 |
| | Mid-late | Aug.15 | 92 | 62.2 | 18.8 |
| | Average | Aug. 9 | 86 | 59.8 | 18.1 |
| Correlation with altitude | | - | 0.3984* | -0.8741** | -0.5696** |

*, **Significant at 5% and 1% level, respectively.

150 m and 270 m than those in the locations at the altitude of 10 m and 430 m (Table 4). Thus, it is easily envisioned that rice growth and development are altered by the altitudes of locations due to changes in the temperature and daylight conditions. Days to heading of rice is hastened at higher temperature, whereas delayed at lower temperature (Roberts and Carpenter, 1965; Hanyu *et al*, 1983; Vergara & Chang, 1985).

### Altitude and growth characters

As generally expected, the higher the altitude, the later the heading stage. In other words, the days from the germination to the panicle primordia initiation which is the vegetative growth stage was longer at higher altitudes in all ecotypes, showing a highly significant positive correlation between the altitude and the vegetative period. Differences in heading date at different altitudes were more significant in the early-maturing than in the medium- or mid-late-maturing varieties. Thus, the period was shorter in order of early-, midium-, and mid-late-maturing varieties at all the altitudes (Table 5). The reduction of the vegetative growth period at higher altitudes were also reported in onion (Hong *et al.*, 2000). As the primary environmental factor changing accompanied by the altitude is temperature, this result is consistent with the earlier report that heading of rice is promoted at higher temperatures but delayed at lower temperatures (Hanyu *et al.*, 1983; Vergara and Chang, 1985).

The culm length was also significantly altered by the altitude of locations. In general, it was significantly reduced as the altitude gets higher in all ecotypes, indicating a highly significant negative correlation between the altitude and the culm length. On average, the culm length at the altitude of 150 m, 275 m, 430 m was reduced by 10, 15.6 and 17.9 cm, respectively compared to that at the altitude of 10 m (Table 5). Similarly, average panicle length was also significantly changed by the altitudes. Average panicle length at the altitude of 150 m, 275 m, 430 m was reduced by 0.6, 0.9 and 0.9 cm, respectively compared to that at the altitude of 10 m. However, the panicle length of the early- and mid-late-maturing varieties did not reduce at the altitude of 275 m and 430 m. A highly significant negative correlation was indicated between the altitude and the panicle length (Table 5). Reduction of plant length at high altitude was also observed in lily (Woo *et al.*, 1997).

### Altitude and yield characters

Panicle numbers per $m^2$ were decreased at higher altitudes. Average panicle numbers per $m^2$ at the altitude of 150 m, 275 m, 430 m were reduced by 1, 37 and 40, respectively compared to those at the altitude of 10 m (Table 6). This result may imply more significant reduction in the numbers at higher altitudes than that indicated in the data as the planting density was considerably higher at 275 m and 430 m altitudes. A highly significant negative correlation was indi-

**Table 6.** Comparison of yield component and yield on altitude and ecotype

| Altitude (m) | Ecotype | Panicle number (no./$m^2$) | Grain number (grain/$m^2$) | Percent ripened grain | 1,000 grains weight of brown rice (g) | Milled rice (kg/10ha) |
|---|---|---|---|---|---|---|
| 10 | Early | 389 | 33,454 | 78.0 | 20.9 | 5,090 |
| | Medium | 371 | 34,318 | 75.7 | 21.7 | 5,165 |
| | Mid-late | 360 | 34,632 | 74.3 | 23.0 | 5,366 |
| | Average | 373 | 34,135 | 76.0 | 21.9 | 5,207 |
| 150 | Early | 373 | 33,122 | 81.4 | 20.3 | 4,955 |
| | Medium | 378 | 35,683 | 74.7 | 21.2 | 5,146 |
| | Mid-late | 364 | 33,706 | 74.9 | 22.4 | 5,212 |
| | Average | 372 | 34,170 | 77.0 | 21.3 | 5,104 |
| 275 | Early | 333 | 23,576 | 76.2 | 20.7 | 4,418 |
| | Medium | 336 | 26,779 | 75.9 | 21.5 | 4,953 |
| | Mid-late | 338 | 25,620 | 74.7 | 22.2 | 4,812 |
| | Average | 336 | 25,325 | 75.6 | 21.5 | 4,728 |
| 430 | Early | 340 | 24,650 | 77.8 | 20.3 | 4,420 |
| | Medium | 331 | 25,653 | 78.0 | 21.5 | 4,795 |
| | Mid-late | 329 | 25,859 | 76.3 | 21.7 | 4,884 |
| | Average | 333 | 25,387 | 77.4 | 21.2 | 4,700 |
| Correlation with altitude | | -0.6128** | -0.6183** | 0.0392 | -0.0909 | -0.5009* |

*, ** Significant at 5% and 1% level, respectively.

cated between the altitude and the panicle numbers. Though the numbers were generally reduced at higher altitudes in all ecotypes, there were typical variations in the responses of the numbers to the altitude. For example, the numbers were increased in mid-maturing and mid-late-maturing varieties at the altitude of 150 m compared to at 10 m.

Grain numbers per $m^2$ showed characteristic responses to the altitude. On average, the numbers increased at 150 m but decreased at 275 m and 430 m compared to those at 10 m. The numbers showed mixed responses to the altitude among the ecotypes. In general, a highly significant negative correlation was indicated between the altitude and the panicle length (Table 6).

Percent ripened grain showed little difference by the altitude in all ecotypes. This result is contrary to the report that percent ripened grain were changed by the altitudes in the chilling-stressed year (Park *et al.*, 1983). Similary, 1,000 grains weight of brown rice were little affected by the altitude in all ecotypes. Only the mid-late-maturing varieties showed a consistent decrease in 1,000 grains weight at higher altitude. Thousand grains weight was consistently highest in mid-late-maturing varieties in all altitudes (Table 6).

Rice yield was significantly affected by the altitudes in all ecotypes. On average, yield at 150 m, 275 m, and 430 m altitudes were reduced by 103, 479 and 507 kg/10ha, respectively compared to that at 10 m altitude (Table 6).

Yield was higher in order of mid-late-maturing, mid-maturing and early-maturing varieties in all altitudes, except in 275 m altitude where yield was highest in mid-maturing varieties. Reduction in yield by altitude was smallest in mid-maturing varieties at all altitudes. The reduction in yield was highest in the early-maturing varieties at the altitudes higher than 275 m. There was a significant negative correlation between the altitude and yield. These results clearly indicate that rice yield is reduced significantly at higher altitudes in all ecotypes and the reduction is mostly caused by the decreased temperature at higher altitudes. Monsi & Murata (1970) and Kumura (1975) reported that decreases in nutrient absorption and dry matter distribution at higher altitudes were related to the low temperature at higher altitudes. The results for the analysis of variance on yield suggest that yields are significantly affected by the main effects of the altitude and the ecotype but not by the altitude eoctype interactions (Table 7).

**Table 7.** Analysis of variance of altitude and ecotype on yield.

| Factor | SS | MS | F-Value |
|---|---|---|---|
| Altitude | 14,484 | 3,621 | 12.91** |
| Ecotype | 30,071 | 10,023 | 35.73** |
| Altitude×Ecotype | 4,042 | 449 | $1.60^{ns}$ |

### Altitude and quality characters

Average protein contents of varieties used in this study ranged from 6.8% to 7.8% and the contents were consis-

**Table 8.** Chemical component of brown rice according to ecotype and altitude.

| Altitude(m) | Ecotype | Protein (%) | Amylose (%) | Fatty acid (mg) | Evaluation value |
|---|---|---|---|---|---|
| 10 | Early | 8.0 | 19.1 | 17.8 | 65.5 |
| | Medium | 7.7 | 19.0 | 17.5 | 67.6 |
| | Mid-late | 7.6 | 19.0 | 17.0 | 68.4 |
| | Average | 7.8 | 19.0 | 17.4 | 67.2 |
| 150 | Early | 7.6 | 18.9 | 17.2 | 67.3 |
| | Medium | 7.5 | 18.8 | 16.7 | 67.2 |
| | Mid-late | 7.3 | 18.7 | 16.4 | 69.8 |
| | Average | 7.5 | 18.8 | 16.8 | 68.1 |
| 275 | Early | 7.4 | 18.9 | 16.9 | 63.8 |
| | Medium | 7.1 | 18.9 | 16.5 | 68.1 |
| | Mid-late | 6.9 | 18.1 | 16.0 | 67.4 |
| | Average | 7.1 | 18.6 | 16.5 | 66.4 |
| 430 | Early | 7.0 | 19.0 | 17.5 | 68.7 |
| | Medium | 6.8 | 18.9 | 17.2 | 71.9 |
| | Mid-late | 6.6 | 18.8 | 16.7 | 72.2 |
| | Average | 6.8 | 18.9 | 17.1 | 70.9 |
| Correlation with altitude | | -0.7663** | 0.3258 | 0.5214* | 0.4017 |

^Tatal rice score; *, **Significant at 5% and 1% level, respectively.

tently lower at higher altitudes and in late-maturing varieties. A highly significant negative correlation was indicated between the altitudes and proteins contents (Table 8). Average amylose contents of varieties used in this study ranged from 18.6% to 19.0% and the contents were consistently lower in late-maturing varieties. The contents decreased at higher altitudes of up to 275 m but the contents increased at the altitude of 430 m to the levels similar to those at the altitude of 150 m. No significant negative correlation was indicated between the altitudes and amylose contents (Table 8). Average fatty acid contents ranged from 16.5 mg/g to 17.4 mg/g and the contents were consistently lower in late-maturing varieties. The contents decreased at higher altitudes of up to 275 m but the contents increased at the altitude of 430 m to the levels similar to those at the altitude of 10 m. A significant positive correlation was indicated between the altitudes and fatty acid contents (Table 8). Average evaluation values by chemical components of brown rice ranged from 66.4 to 70.9 and the values were consistently higher in late-maturing varieties. The values increased at higher altitudes, being highest at the altitude of 450 m, except at the altitude of 275 m where the values were lowest (Table 8).

Compounds such as proteins, amylose, fatty acids are important determinants of nutritional and palatability values of rice. As quality is becoming a major index for purchasing power, roles of these compounds are increasingly important as quality factors. Proteins composed of over about 50 L-amino acids (acid amide combination) are nitrogen compound polymers. Their contents affect quality of rice and taste. In general, as protein content gets higher, palatability deteriorates (Ishima *et al.*, 1974). Protein contents of brown rice increase with increased nitrogen fertilization (Honjo *et al.*, 1980, Heu *et al.*, 1969), and the contents are positively correlated with changes in glutelin contents in different environments (Cagampang *et al.*, 1966). The contents increase at higher water temperature (Gomez, 1979) and at higher temperature at maturity (Juliano *et al.*, 1964). Thus, the significant decrease in protein contents at higher altitudes is consistent with the previous reports and the decreased temperatures at higher altitudes might have acted as a major factor (Table 3). Consequently, the average evaluation value by chemical components of brown rice is affected by the production areas of rice.

External characteristics of rice quality include size of grain, appearance, uniformity, transparency, chalkiness, color and gloss, degree of freshness and head rice ratio. Average head rice ratio of polished rice ranged from 54.7% to 82.5% and decreased significantly at higher altitudes, showing a highly significant negative correlation with altitudes. The ratio was highest in mid-maturing varieties at all altitudes (Table 9). Average broken rice ratio of polished rice ranged from 16.0% to 43.9% and increased significantly at higher altitudes, being highest at the altitude of 430 m. It showed a highly significant positive correlation with altitudes. The ratio was highest in early-maturing varieties at all the altitudes, except at the altitude of 430 m (Table 9). Average palatability of pol-

**Table 9.** Quality and palatability value of milled rice according to ecotype and altitude.

| Altitude (m) | Ecotype | Head rice (%) | Floury rice (%) | Broken rice (%) | Palatability value |
|---|---|---|---|---|---|
| 10 | Early | 74.2 | 1.5 | 24.6 | 73.1 |
| | Medium | 84.8 | 1.2 | 14.1 | 65.2 |
| | Mid-late | 88.5 | 2.0 | 9.4 | 66.3 |
| | Average | 82.5 | 1.6 | 16.0 | 68.2 |
| 150 | Early | 74.4 | 2.3 | 23.3 | 68.9 |
| | Medium | 86.4 | 1.7 | 12.3 | 57.9 |
| | Mid-late | 81.8 | 3.9 | 14.4 | 60.0 |
| | Average | 80.8 | 2.6 | 16.7 | 62.2 |
| 275 | Early | 64.6 | 0.8 | 34.6 | 68.9 |
| | Medium | 78.2 | 3.0 | 19.0 | 62.8 |
| | Mid-late | 78.1 | 3.3 | 18.6 | 62.6 |
| | Average | 73.6 | 2.4 | 24.1 | 64.8 |
| 430 | Early | 55.0 | 1.4 | 44.1 | 71.7 |
| | Medium | 56.1 | 0.7 | 42.5 | 70.1 |
| | Mid-late | 52.9 | 0.9 | 45.3 | 70.0 |
| | Average | 54.7 | 1.0 | 43.9 | 70.6 |
| Correlation with altitude | | -0.8245** | -0.4188 | 0.8095** | 0.4565 |

*, **Significant at 5% and 1% level, respectively.

ished rice ranged from 62.2 to 70.6 and was highest at the altitude of 430 m. It showed a non-significant positive correlation with altitudes. Palatability was higher in the early-maturing varieties in all altitudes (Table 9).

In summary, various characteristics associated with growth, yield, and quality of rice were significantly affected by the altitudes in all ecotypes. At the expense of reduction in yield, appearance quality, palatability and evaluation values by chemical components were improved at higher altitudes. These results can provide valuable information for the strategic deployment of suitable ecotypes and for the quality control of rice products considering regional geographical factors such as altitude.

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