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Association Between Grain Yield and Several Other Plant Characteristics in Rice.

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ABSTRACT

Experiment 1, which was designed for studying association between grain yield and date of maturity, consisted of 23 pairs of subline strains derived from 23 F_3 lines segregating for date of maturity in a cross between 2 rice varieties, Colusa and Nira. The parents were also included as controls. In each pair of strains one member was made up by bulking seed from at least 5 early maturing plants of an F_3 line, the other was made up from bulked seed of 5 late maturing plants of the same line.

Variance analysis in experiment 1 showed significant differences among lines, between subline strains within lines and a significant lines x sublines interaction in respect to date of maturity as well as in grain yield.

In 20 of the 23 lines of experiment 1, the subline strain formed from early maturing F_3 plants was found to be significantly earlier in maturity than its counterpart formed from late maturing F_3 plants of the same line. In 13 of these 20 lines, the early maturing subline strain significantly outyielded its late counterpart. Furthermore, in 6 of the other 7 lines the early subline strain produced a numerically higher yield than its late counterpart, although the difference was not statistically significant. The correlation coefficient between time of maturity and yield among the 46 early and late subline strains as a whole was -0.650, a significant value. The results provided strong evidence that in the cross concerned high yielding ability

was associated with early maturity.

Experiment 2, which was designed for studying association between grain yield and plant height, consisted of 23 pairs of subline strains derived from 23 F_3 lines segregating for height of plant in the same cross. The parents were also included as controls. The strains of experiment 2 were formed in the same manner as those in experiment 1 except that selection of F_3 plants for use in forming the strains was based on plant height.

In experiment 2, variance analysis showed significant differences among lines and between subline strains within lines in height of plant. In grain yield there was evidence of significant differences among lines but the differences between sublines within lines was not significant.

The presumably short subline strain in 19 of the 23 lines in experiment 2 was significantly shorter in height of plant than its presumably tall counterpart. In 8 of these 19 lines, the short subline strain yielded numerically more than its tall counterpart, while in the other 11 lines the short subline strain yielded numerically less than its tall counterpart. The correlation coefficient between height of plant and yield of grain among the 46 short and tall subline strains was +0.127, a low and non-significant value. It is obvious that there was no evidence that high yield was associated with either short or tall plant stature.

The correlation coefficients between spikelet length and grain yield in the 2 experiments among all subline strains were non-significant values, -0.038 and -0.008, although the sublines were significantly different in spikelet length in both experiments. The correlation coefficients between spikelet breadth and grain yield in the 2 experiments among all sublines were +0.013 and -0.300. The latter one was significant.

INTRODUCTION

In addition to the nature of inheritance of economically important characteristics, a knowledge of the association of grain yield with other characters of the rice plant would be of great help in selecting a useful and high yielding variety through hybridization breeding. With this knowledge available, the rice breeder would know how difficult it would be to combine high yielding ability with other desirable traits as well as the possible direct effect that other plant characters may have on high yielding ability.

Association or independence of plant characteristics with grain yield in rice has been studied by use of (1) existing varieties, (2) strains selected from the hybrid population of a cross and (3) iosogenic lines established after a series of back-cross breeding. A considerable amount of data has been accumulated by use of the first and second methods, especially by the first one. However, only one instance in which the third method was employed has been reported. It is apparent that relatively uniform genetic backgrounds of the plant material is necessary for more critical study on the association of grain yield with other plant characteristics. It is also apparent that more basic information on this subject is needed.

There were 2 objectives of the present studies. One purpose was to gain additional information on the association of date of maturity and height of plant with yield of grain in rice. The second objective was to study the effectiveness of a specific method or procedure for investigating the association between grain yield and other economic quantitative characters. The method evaluated involved the use of paired subline strains in which the members of a pair of strains were derived from a single F_3 line of a cross between 2 rice varieties. A subline strain was formed by bulking seed from 5 or more plants within a heterozygous F_3 line which presented an extreme of expression for date of maturity or plant height. For example, a group of 23 F_3 lines which were segregating for date of maturity were chosen. Within each line, 5 or more plants of the earliest maturity found in that line were selected and the seed from all was bulked to form an early subline strain. A subline strain derived from the 5 or more latest maturing plants within this line was also formed. The early and late maturing subline strains from within a given line were considered as a pair. It was assumed that the 2 strains constituting a pair would be reasonably alike in respect to all other genes except those governing time of maturity. The subline strains formed in this manner were entered in a replicated yield trial where yield of grain and date of maturity were measured for each.

Date of maturity is one of the most important agronomic characters in rice breeding programs in the United States. Selection is practiced for early or midseason maturity dates, with greatest emphasis on early maturity.

Great variation of plant height is known in cultivated rice, varying from an extraordinarily tall floating rice to a dwarf type. It is considered another important agronomic character. As a matter of fact, the number of internodes, internode length and panicle length are the three factors which contribute to this trait. However, they are commonly measured as a whole in terms of plant height. An important feature of plant height is its primary effect on lodging. It is believed by various rice breeders that relatively short plant stature is required in a lodging resistant variety.

Grain yield is one of the most economically important characters in rice as in other grain crops; however, it is affected greatly by various factors. For this reason, it is necessary to employ a relatively large plot size with replications and to arrange the treatments according to a proper field plot design in any evaluation of yielding ability.

REVIEW OF LITERATURE

(1) Association of grain yield with date of maturity

Jacobson (18) studied the association of these characters in rice as early as 1916 by the use of a number of lowland varieties in the Philippines, of which growth period varied from 120 to 210 days, and grain yield varied from 6 to 38 quintals per hectare. He found the following widely varying correlation coefficients between date of maturity and yield among varieties for the five years investigated: -0.403, -0.104, -0.218, -0.015, and -0.143 with an average correlation coefficient of -0.201, which was not significant. He argued against the most common belief that the late-maturing varieties of rice were the highest yielders. However, he noted that extra-early maturity was to be had at the expense of yield and very late maturity afforded too many opportunities for unfavorable weather conditions, diseases and pests to injure the plants, thus lower yield of grain.

Bhide (4) worked on varietal improvement of Kolamba rice of North Konhan, India, and concluded that in the very early strains the yield per plant was generally low, presumably owing to the short period of growth. In the late strains the yield per plant was generally more than in the early strains.

Iso (17) reported his classic research work on breeding and culture of Formosan rice plants in which the association of fourteen characters were presented. The average correlation coefficients between grain yield and heading period for several varieties were estimated to be -0.024 ± 0.099 in the first crop season, which was not sifnificant, and to be -0.314 $\pm$ 0.088 in the second crop season, which was significant.

It has been observed by Sethi (47) that late ripening varieties in the United Provinces, India, were usually tall and generally good yielding although this was not invariably so. In the transplanted series the yield per plant in the late strains was generally more than in the early strains.

In a preliminary note on intervarietal correlation for 147 varieties in Bengal, India, Mahalanobis (29) indicated that the mean yield was independent of growth duration.

The yielding capacity of a number of Japanese varieties was investigated by Harada, Watabe and Kokubu (15) when sown abnormally early or abnormally late. The high yield after early sowing was found to correlate with length of vegetative period and panicle number.

After a series of genic analyses on heading date and other characters in three Japanese rice crosses, Syakudo (50) intended to clarify the mechanism of grain yield, taking into account an association between heading time and yield, particularly the effect of the genes controlling heading period, E_3, E_4, and E_5. Pleiotropy of the genes E_3, E_4, and E_5 for heading date and ear weight was observed, in the same way as in the case of heading date and culm height, with the order of effective magnitude $E_4 > E_3 > E_5$.

Bollich (5) studied a cross between Rexoro and Strain 252-1-2, a selection made at Crowley, Louisiana, and reported that yield and date of heading were closely associated, with a highly significant correlation coefficient, r = -0.61, among lines. All late lines were low in yield in contrast to the early lines which were in most cases high in yield. The evidence suggested that genes for high yielding ability were not expressed when combined with genes for late heading.

Toriyama and Futsuhara (53) investigated the association between grain yield and other characters in F_6 lines of a cross of Japanese rice, and estimated the phenotypic and genotypic correlation coefficients between heading date and grain yield to be -0.245 and -0.363, respectively. They were not significant.

Using thirty-two Japanese leading varieties under four different environments, combinations of years and sowing dates, as well as the segregating generations of hybrid population of a Japanese rice cross, Nei (36) studied the genotypic and phenotypic correlation between heading date and ear weight per plant. His results, without indication of significance, are summarized as follows:

	Genotypic Correlation	Phenotypic Correlation
32 leading varieties	0.396	0.163
F_3	0.413	0.217
F_4	0.252	0.167

Each phenotypic correlation has 30 degrees of freedom. He further estimated the coheritability of heading date and ear weight per plant to be 0.207 in 32 leading varieties from the analysis of covariance, while 0.226 and 0.163 were obtained, respectively, in F_3 and F_4 generations of the cross. When heading date was investigated in the preceding generation and ear weight per plant was investigated in the succeeding generation, the inter-generational correlation coefficients between heading date and ear weight per plant were estimated to be 0.187 for F_3 - $\bar{F}_4$

and 0.206 for $\bar{F}_3$ - $\bar{F}_4$. The inter-generational correlation coefficients between heading date in succeeding generation and ear weight per plant in preceding generation were 0.144, 0.174 and 0.374 for F_2 - $\bar{F}_3$, F_3 - $\bar{F}_4$, and F_4 - $\bar{F}_5$, respectively, while 0.274, 0.267 and 0.261 were estimated for $\bar{F}_3$ - $\bar{F}_4$, $\bar{F}_3$ - $\bar{F}_5$, and $\bar{F}_4$ - $\bar{F}_5$, respectively.

In spite of several reports (4, 9, 18, 47) that the extremely early varieties were generally low in grain yield, Beachell, Scott, Evatt, Atkins, and Halick (3) obtained a very early-maturing, long-grained variety, named Belle Patna, with 100 day growth period, which had high yield potential through the production of a second or stubble crop. This variety was released as a commercial variety in Texas.

Tsai (54) successfully established early maturing isogenic lines of Taichung No. 65 from a series of back-crossing experiments, in which Taichung No. 65 served as the recurrent parent and a northern Chinese variety and a northern Japanese variety were the non-recurrent parents. Variance analysis of grain yield of these isogenic lines showed that highly significant differences existed among the lines. The earliness of these isogenic lines ranged from two to sixteen days earlier than Taichung No. 65, which had 123 day growth period in the first crop season. The grain yield of these isogenic lines was in most cases lower than, but in a few as high as, that of Taichung No. 65. The comparison between heading date and yield capacity of these lines showed the possibility of a loose positive correlation between the two characters in this experiment. The work called attention to the uniform genetic background among isogenic lines.

Forty varieties having requirements of 90 to more than 190 days of growth period were tested during the dry season at the International Rice Research Institute (9), the Philippines. When length of growing period was plotted against grain yield, the resulting parabolic curve indicated that the optimum growing period under the conditions of this test was 130-140 days. Both extremely early or late varieties were lowest in yield. They also observed that the longer the growth period of a variety the more the total plant weight. However, the rate of plant weight increase with the extension of the growth period, became smaller if the duration was extremely long. On the other hand, the curve of panicle-straw ratio against growth duration went down as the length of the growth period increased. The two curves met between 130-140 days of growth duration, at which varieties yielded highest.

Krasnook (27) investigated several agronomic characters of two varieties which were sown at two different dates, and reported that the early ripening one outyielded the later-maturing one, its better tillering on either sowing date being responsible for the higher yield.

Based on the F_2 population of a Japonica rice cross, Chang (8) estimated the phenotypic and genotypic correlations between heading date and grain yield per plant to be -0.017 and -0.276, respectively. They were not significant.

Yeh (59) studied the relation between grain yield and main characters of the plant in six Ponlai rice varieties and reported that the grain yield and the days from transplanting to heading were negatively correlated with $r = -0.150$ within varieties, but the simple correlation coefficient and partial regression and partial correlation coefficient all did not reach the significant level. On the other hand, when the effects of blocks and error were eliminated, the correlation coefficient among varieties was estimated to be 0.768, but non-significant.

Futsuhara, Toriyama and Hashiguchi (13) evaluated visual selection in rice through path coefficient analyses of factors influencing visual selection on 50 F_6 and F_7 lines derived from 25 crosses of rice. They calculated the phenotypic, genotypic and environmental correlation coefficients between heading date and yield to be 0.395, 0.491 and 0.026, respectively. Among these coefficients, only the first one was significant.

(2) Association of grain yield with plant height

Jacobson (18) investigated a number of lowland varieties in the Philippines, grown on six differently located plots, and obtained correlation coefficients between culm length and grain yield among varieties of 0.37, 0.163, 0.372, 0.347, and 0.142 for each of five years, with an average correlation coefficient of 0.361. He did not indicate whether any of the correlation coefficients were significant. He concluded that culm length seemed to be consistently associated with yield even under widely differing conditions. This was more pronounced in the drier and hotter seasons.

Working with the Kolamba rice in India, Bhide (4) estimated the correlation coefficient between mean height of plant and mean yield per plant within strains under the intensive culture to be 0.47 $\pm$ 0.8, with 39 observations. In other two strains, the correlation coefficients were 0.54, and 0.43, which showed fairly close correlation.

According to Iso (17), the average correlation coefficient between grain yield and plant height was 0.069 $\pm$ 0.099 within seven Formosan native varieties in the first crop season and 0.167 $\pm$ 0.093 in the second crop varieties. These correlation coefficients were not significant.

Sethi (47) showed correlation coefficients within strains between plant height and yield per plant in five strains in the United Provinces, India, that varied from -0.16 to + 0.68, with 50 observations each. The strain that showed + 0.68 was late in ripening. On the other hand, Mahalanobis (29), indicated that the mean yield appeared to be independent of plant height among 147 varieties investigated in Bengal, India.

An investigation of several agronomic characters on 950 plants of an ealy variety and 500 plants of a late variety, made by Ting (52) in China, showed that the coefficients of simple correlation of grain yield with plant height were 0.32 ± 0.19 and 0.44 ± 0.024, respectively.

Using 3000 early, medium and late varieties and lines, Pao (38) investigated various agronomic characters and concluded that length of culm exhibited some relation with production. Angeles (2) reported positive correlations between plant height and yield of grains in the Philippines in his unpublished thesis.

Morimoto (32) conducted an analysis of the yield components of Japanese rice varieties and estimated the correlation coefficients between several agronomic characters which were overall figures for all the varieties grown at a single locality. The overall yield of rice at any one locality was positively correlated with culm length and number of panicle per plant.

Almost no contribution by plant height towards grain yield per plant was reported by Lin (28) in his multiple regression analysis, employing seven crosses of Ponlai rice in the F_4 under the ordinary pedigree method of handling of hybrid materials in Formosa.

Employing a cross of Japanese rice, Toriyama and Futsuhara (53) obtained phenotypic and genotypic correlation coefficients between grain yield and plant height, respectively, in F_6 lines of -0.245 and -0.363, which were not significant. The phenotypic correlation coefficient in F_7 lines was -0.143, which also was not significant.

Evatt, Johnson and Beachell (11) determined the response of relatively short sturdy strawed rice varieties to moderate and high levels of nitrogen fertilization. It was concluded that the selection of the short, sturdy-strawed varieties from a hybrid population would be valuable in developing high yielding varieties that would withstand high nitrogen rates without severe lodging.

Nei (36) employed thirty-two Japanese varieties and the segregating generations of a hybrid population of a Japanese rice cross and estimated the genotypic and phenotypic correlation coefficients between plant height and ear weight per plant to be shown as follows, (with 30 degrees of freedom for each of phenotypic correlations).

	Genotypic Correlations	Phenotypic Correlations
32 varieties under 4 environments	0.46 - 0.71	0.36 - 0.43
F_3	0.461	0.786
F_4	0.605	0.754

He further indicated that the coheritability of culm length and ear weight per plant in 32 varieties under four environments varied from 0.228 to 0.406, while that in the segregating generations of the cross ranged from 0.414 to 0.493, on the basis of F_3 and F_4, respectively. When culm length was measured in the preceding generation and ear weight per plant was investigated in the succeeding generation, the inter-generational correlation coefficients between culm length and ear weight per plant were 0.073 in F_2 - $\bar{F}_3$, 0.257 in F_3 - $\bar{F}_4$, and 0.249 in $\bar{F}_3$ - $\bar{F}_4$. The inter-generational correlation coefficients between ear weight per plant in preceding generation and culm length in the suceeding generations, were 0.018, 0.007, and 0.090 for F_2 - $\bar{F}_3$, F_3 - $\bar{F}_4$ and F_4 - $\bar{F}_5$, respectively, while correlation coefficients of 0.202, 0.217 and 0.277 for $\bar{F}_3$ - $\bar{F}_4$, $\bar{F}_3$ - $\bar{F}_5$, and $\bar{F}_4$ - $\bar{F}_5$, respectively were obtained.

Yeh (59) investigated six ponlai rice varieties in Formosa, from which the simple correlation coefficient within varieties between culm length and grain yield was estimated to be 0.241 and non-significant. The correlation coefficient among varieties, excluding block and error effects, was 0.121, also non-significant. However, the partial regression and correlation coefficients, when the total panicle weight was included in regression analysis, were positively significant, although these coefficients were positive but non-significant when the total panicle weight was dropped in regression analysis. As in the case when only block effect was excluded, in other words the variety plus error were concerned, the main culm length was usually positively associated with grain yield. Among six partial regression coefficients, five were positive and exceeded the one percent of significant level. As the result of multiple regression analyses, he indicated that the highest precision in predicting grain yield was obtained by the use of days of heading and length of main culm as the independent variables, when the total panicle weight was not involved. In view of relationships among rice plant characters, he concluded that a plant having long culm, a large number of effective tillers and late heading will be the good yielder.

Ghose, Ghatge and Subrahmanyan (14) described the review made by Ramiah of the results obtained at various research stations in India, in which a correlation between mean yield and plant height was concluded to occur. At the Central Rice Research Institute, India, inter-varietal correlation between grain yield and plant height was found to be 0.47 in a varietal trial with 36 varieties. At the same Institute, the intra-varietal correlation coefficients between grain yield and plant height were found to vary from +0.079 to +0.340, with average +0.216, of which significant levels were not indicated. These correlation coefficients became negligible when the influence of number of heads and mean length of head was eliminated in partial correlation analysis. The percentage contribution of plant height towards yield in the same varieties as mentioned above varied from 0.0005 to 6.05 percent. It was apparent that the contribution of height towards yield was negligible.

Hsieh (16) investigated the stability of several agronomic characters in reciprocal translocation homozygotes. Eleven strains having significantly different plant heights gave significantly different grain yields. The tall strains tended to give higher yields of grains than the original variety.

Using the F_2 population of a ponlai rice cross in Formosa, Chang (8) estimated the phenotypic and genotypic correlation coefficients between plant height and grain yield per plant to be 0.360 and 0.19, respectively. Only the former was significant. Futsuhara, Toriyama and Hashiguchi (13) obtained almost identical values for phenotypic and genotypic correlation coefficients to those obtained by Chang (8); however, these were based on F_6 and F_7 lines of several Japanese rice crosses. The values estimated by them as phenotypic, genotypic and environmental correlation coefficients were 0.460, 0.266, and 0.717, respectively. Only the second one was non-significant.

Narahari (35) studied interracial hybrids of Indica and Japonica rice and their performance in advanced generations. No positive correlation was obtained between grain yield and plant height.

Wang (58) investigated several quantitative characters in the F_2 populations of three groups of crosses, i.e., indica x indica, indica x *japonica*, and *japonica* x *japonica*. He found a moderate positive correlation between plant height and grain yield in the *indica* x *indica* cross and the *japonica* x *japonica* cross; however, a relatively low correlation coefficient was found in the *indica* x *japonica* cross.

Employing two crosses of rice in the United States, Jodon (24) obtained all possible combinations of the four pairs of gene markers recovered in F_5 generation and yield-tested them in single row plots in the F_6 generation at Crowley, Louisiana. His results showed that yield and plant height differences among strains were highly significant in each cross, but the correlation between tests was low. Correlation between height and the yield within crosses was negligible.

According to Jennings and Sornchai (21), attempts to increase the yields of rice in Southeast Asia through culture modification which are successufl in temperate areas, like close spacing and abundant nitrogen fertilization, will tend to increase plant height and to promote lodging. A yield trial, in which the rice was cultivated under two conditions, one being allowed to lodge naturally and the other being fixed by strings to prevent lodging completely, proved that lodging was a primary cause of yield loss and the loss was directly proportional to time and amount of lodging. Chang (7) indicated that cLr-values, being considered as the most representative lodging index, was found to be negatively correlated with plant height in 20 varieties, including *indica* and *japonica*. Plant height contributed the major portion of cLr-values, which he showed by path coefficient analysis.

(3) Association of grain yield with spikelet length and spikelet breadth.

Jacobson (18) obtained an *r* value of -0.005 between ratio of width to length of grains and grain yield among various lowland varieties in the Philippines. Thus, the shape of grains bore no relation to the yield. Consequently, as far as yield of grain itself is concerned, any shape of grain may be selected, he concluded. It has been said that the long grained varieties do not tiller freely; but taking the length dimension only, according to his data, there appears to be no noteworthy correlation between length and tillering.

Iso (17) studied the association between various characters of Formosan native varieties. In his report, it was tabulated that the correlation coefficient of grain yield with grain length within varieties was + 0.047 $\pm$ 0.028, as the average of seven first crop varieties, and was + 0.145 $\pm$ 0.096, as the average of second crop varieties. The average $\underline{r}$ values of grain yield with grain breadth within varieties, was -0.036 $\pm$ 0.098 in first crop varieties and + 0.064 $\pm$ 0.098 in the second crop varieties. All above correlation coefficients were not significant.

Mahalanobis (29), in his preliminary note on intervarietal correlation in the rice in Bengal, indicated that the mean yield appeared to be independent of weight and size of or shape of grains among 147 varieties investigated.

Working with 79 F_4 lines of the cross Rexoro x Strain 252-1-2, Bollich (5) obtained the following correlation coefficients:

Yield in F_4 and spikelet length in F_3	0.023
Yield in F_4 and spikelet breadth in F_3	0.065
Yield in F_4 and spikelet weight in F_3	0.136

All $\underline{r}$ values of yield with spikelet length, breadth, weight and volume weight of grain were non-significant, indicating no association of these traits with yield.

Sane (45) selected a number of plants by the process of randomization from the rice variety No. 27 in order to determine the association of 16 pairs of characters. He worked out the correlations between yield and grain characters such as length of grain, breadth of grain, and the product of length and breadth which served as an index to grain size. The results are summarized as follows:

Yield per plant and grain length	-0.572**
Yield per plant and grain breadth	-0.329**
Yield per plant and grain size	-0.194 n.s.

Thus, there was a negative correlation between yield and the spikelet characters length and breadth. He concluded thus that an increase in length or breadth of grain or their product did not enhance the yield, but in some cases had a depressing effect on it. Theoretically, it is expected that when other yield attributes are constant, an increase in grain size should lead to an increase of yield.

In drill-strip tests, Jodon (22) observed that the average yield by groups of five long-grain varieties and 16 medium-grain varieties were practically the same. However, five of the medium-grain entries made higher average yields than the highest yielding long-grain variety. In date-of-seeding tests, six in a group of ten representative medium-grain varieties gave higher yields than any of ten representative long-grain entries. Three of the ten long-grain entries were lower in yield than any of the medium-grain entries. He concluded that medium-grain varieties tended to have greater ability to yield than long-grain varieties.

According to Jodon (23), rice growers in Louisiana usually obtain higher yield from Nato than from Bluebonnet 50. Experimental results indicate that medium-grain varieties in general outyield long-grain varieties of similar growing periods. However, yield of two long-grain selections compared well with higher yielding medium-grain varieties, indicating that equally high yielding long-grain varieties can be developed.

(4) Nature of inheritance of yielding ability.

In a yield trial of 79 F_4 lines of the cross Rexoro x Strain 252-1-2, Bollich (5) found the heritability of grain yield was very low.

Employing a Japanese rice cross, Tokaisenbon x Fujisaka No. 5, Toriyama and Futsuhara (53) grew the segregating generations by the bulk method up to F_5, in which generation selection of individual plants was made. They progeny-tested the selected plants in F_6 and conducted a yield trial of the selected lines in the F_7. They estimated the heritability in the F_5 by $h^2 = \frac{\Delta G}{i}$, where ΔG was the genetic grain, i.e., the mean difference between selected and nonselected line groups in the F_6, and $\underline{i}$ was the selection differential, i.e. the mean difference between selected groups of F_5 individuals and the nonselected original F_5 population. The heritability of grain yield estimated by this way was very low, varying from 0.070 to 0.115. They also estimated the heritability of grain yield in F_6 lines to be 0.69 by $h_B^2 = \frac{V\bar{F}_6 - E_2}{V\bar{F}_6}$, where, $V_{\bar{F}_6}$ was the variance among F_6 line means, and E_2 was the estimate of error variance for F_6 line means. Parent-offspring correlation coefficients of grain yield were estimated to be 0.211 for $\underline{r}\ F_5\bar{F}_6$ and 0.580 for $\underline{r}\ \bar{F}_6\bar{F}_7$. It should be noted that all of these heritability values and parent-offspring correlations were not significant. The heritability of panicle number, one of the important yield components, was 0.100 - 0.133 in the F_5, and 0.71 in the F_6 lines. Its parent-offspring correlation coefficient was 0.204 in $\underline{r}\ F_5\bar{F}_6$ and 0.128 in $\underline{r}\ \bar{F}_6\bar{F}_7$. The heritability of panicle length, being considered another important yield component, ranged from 0.182 to 0.219 in F_5, and 0.28

in F_6 lines. Its parent-offspring correlation coefficient was 0.060 in $\underline{r}\ F_5\bar{F}_6$ and 0.039 in $\underline{r}\ \bar{F}_6\bar{F}_7$. All above values were not significant.

Sakai (43) summarized the heritability of grain yield and its components, obtained mainly by Japanese workers as follows:

Characters	Number of estimations	0-0.1	0.1-0.2	0.2-0.3	0.3-0.4	0.4-0.5	0.5-0.6	0.6-0.7	Mean
Grain yield (wt. panicles)	10	3	4	1	2				0.17
Panicle length	13	4		5	1	2	1		0.25
Panicle number	13	9	3	1					0.09
1,000 grain wt.	1					1			0.45

He indicated that the phenotype for yield of a plant does not represent its genotypic value, because of the very low heritability of yield. According to his formulation, a character with 0.10 heritability in F_2 will have the heritability gradually increased as the advance of selfing generations. For example, the heritability of a character will increase from 0.57 in F_4 to 0.84 in F_7, if the estimation is based on lines having 20 plants each.

Oka (37) and Lin (28) obtained the heritability values for panicle number per plant and panicle length similar to those of Sakai. The material used by Oka was from a <u>japonica</u> x <u>indica</u> cross and that by Lin was from ponlai rice crosses.

Nei (36) chose at random 100 plants from the F_2 population of a Japanese rice cross, and grew F_3 lines, each having 30 plants, in a randomized block design with three replications. The same procedure was followed in F_4 and F_5, in which one plant was chosen at random from each line to obtain the seed for the next generation. The resulting heritability of ear weight per plant, ear length, number of ears, and ear weight per stem listed by him are shown as follows:

Estimated by	Generations	Ear wt. per plant	Ear length	Number of ears	Ear wt. per stem
Intergenerational correlation	$F_2 - \bar{F}_3$	-0.036	0.138	0.054	0.531**
"	$F_2 - \bar{F}_4$	0.019	0.162	0.165	0.427**
"	$F_3 - \bar{F}_4$	0.022	0.145	0.084	0.507**
"	$\bar{F}_3 - \bar{F}_4$	0.152	0.482**	0.100	0.628**
Analysis of variance	F_3	0.347**	0.711**	0.562**	0.794**
"	F_4	0.47**	0.811**	0.670**	0.854**
"	F_5	-	0.825**	0.727**	-

He concluded that an outstanding feature of heritability is the rise of its value in later segregating generations, and this agrees with the theoretical expectation as indicated by Sakai (43).

Bhide (4) worked on Kolamba rice in India and concluded that a type with a fairly high tillering capacity and a moderately large and heavy panicle was likely to give the highest yield. This conclusion is partly supported by the high correlation between tillering and yield per plant, $\underline{r}$ = 0.64 - 0.84 within 9 strains studied.

Iso (17) reported a positive significant association of grain yield with tillering capacity and several panicle characters, including panicle weight, panicle length, number of grain per panicle and grain density of panicle within seven Formosan native varieties, both in the first crop season and in the second crop season. An exception was found for panicle length in the first crop season, which was non-significant.

tillers (r = 0.671).

Using 50 lines of F_6 and F_7 derived from 25 rice variety crosses, Futsuhara, Toriyama, and Hashiguchi (13) obtained a significant phenotypic correlation of yield with panicle length, number of panicles and 500 grain weight of 0.335, 0.311 and 0.336, respectively. However, all genotypic correlations of yield with those characters were not significant.

Sakai and Suzuki (44) investigated X-rayed rice and estimated the degree of pleiotropy of polygenes by comparing genetic covariance in the X_4-lines with that in the control ones. They found that panicle length and number of panicles per plant were for the most part controlled by inversely operating pleiotropy of the genes.

According to Enyi (10), high positive correlations exist between shoot and panicle characters in rice. Panicle length and weight, number of spikelets and grains tended to depend more on stem diameter and shoot length than on any of the other shoot characters, while grain weight was more strongly influenced by leaf blade area and shoot length.

According to Ghose, Ghatge and Subrahmanyan (14), the Central Rice Research Institute, India, found that the percent contribution due to number of ears ranged from 10.39 to 43.69 percent within seven varieties, while that due to length of ear varied from 5.19 to 57.43 percent. Through a varietal trial consisting of 25 varieties, they generated several discriminal functions, one of which is $X_1 = X_2 + 0.54\ X_3 + 0.179\ X_4$, where X_1, X_2, X_3 and X_4 are yield per plant, number of ear bearing tillers, number of grain per acre and 1,000 grain weight, respectively. They conclude that selection based on yield components was not more efficient than selection based on yield along.

Employing seven crosses of ponlai rice, Lin (28) practiced selection for three characters, panicle weight, panicle number per plant, and plant height, in F_2. These characters were observed in F_3 and thus, were compared with panicle weight per plant in F_4 in terms of multiple regression analysis. The equation $X = W + 0.21564N - 0.08133H$ was found to have the highest precision, where W is panicle weight, N is number of panicle per palnt, and H is plant height.

In the report of rice breeding work in British Guiana, Poonai (39) presented a regression equation, $X_1 = -30.372 + 2.889\ x_2 - 0.1024\ x_3 + 0.019\ x_4 + 14.1909\ x_5 - 0.3234\ x_6$, where X_1, x_2, x_3, x_4, x_5 and x_6 were yield per plant, number of tiller per plant, number of grains per tiller, 100 grain weight, yield per tiller and ear length, respectively. He reduced this equation for practical purposes to provide that yield per plant is the product of number of tillers per plant and yield per tiller. This method led to the development of several high yielding varieties.

The International Rice Research Institute (60) estimated the path coefficient of panicle number per plant towards 20-plant grain yield in Chianung No. 242 in the dry season in the Philippines, to be 0.788 ($r = 0.931$), and that of grain number per panicle towards yield was 0.329 ($r = 0.688$). The effect of 100-grain weight and sterility were negligible in the same analysis. In another Formosan variety, Taichung No. 181, the same tendency was observed.

Chang (8) obtained the same tendency as reported by IRRI (60) in the F_2 population of a ponlai rice corss under ordinary spacing culture. However in the bunch-planted F_2 population of the same cross, the path coefficients of number of panicle per plant and number of grains per panicle towards grain yield were found to be 0.57 and 0.78, respectively. The number of grains per panicle is the predominant factor in bunch-planting, rather than number of panicles per plant as in ordinary spacing culture.

Using three American varieties, namely bluebonnet 50, Belle Patna and Calrose, Stansel, Bollich, Thysell and Hall (49) attempted to clarify the influence of light intensity and nitorgen fertilization on rice yields and components of yield. Through a multiple regression model, they concluded that filled florets per panicle, the interaction of panicles per unit x panicle weight, and the number of seedlings per unit area accounted for 88 percent of the yield variability. They found that low light intensity reduced yield by lowering the number of filled florets per panicle, individual kernel weight, and the number of panicle per unit area. Increased rates of nitrogen increased the filled florets per panicle except under reduced light intensity. High nitrogen levels lowered 1,000 kernel weight, but had no influence on panicles per unit area.

According to Simon (48), the percentage emergence and the number of grains per panicle each accounted for 47 percent of the intervarietal differences in yield for the first and fourth of five developmental phases of three varieties, while the other three developmental phases contributed 2, 1 and 4 percent, respectively.

From growing of three American varieties of midseason maturity under different row spacing and seedling rates, Scott (46) concluded that row spacings had no statistical influence on yield, probably due to the reduced panicle number compensated by a corresponding increased panicle weight in wide spaced plots. The increase in kernel weight was the factor responsible for increased panicle weight. A multiple regression analysis revealed that 78 percent of the yield was attributed to panicle weight, plus interaction of tillers x total filled florets and total florets x 1,000 kernel weight.

The idea that glutinous rices are less productive than non-glutinous rice was examined by Tsai (54) with a yield trial of glutinous and nonglutinous isogenic lines obtained after a series of back-cross experiments, in which Taichung No. 65 was the recurrent parent and a Japanese glutinous variety served as the donor. The result proved that the glutinous strains had the same yielding ability as non-glutinous ones, including the recurrent parent.

From selections made in the F_5 and yield-tested in F_6 of two crosses at Crowley, Louisiana, Jodon (24) found that normally liguled strains significantly outyielded the liguleless in both crosses. Normally short-glumed strains were significantly higher yielding than long-glumed in one cross but not in the other. Presence or absence of awns and pubescence were not related to yield. He found that significant interaction occurred between the pairs of characters, like awns and ligules, ligules and pubescence, and pubescence and glume length. The occurrence of significant interactions involving loci where there was significant difference between alleles, was attributed to epitatic or complementary gene action.

Probably Tsunoda and Kishimoto (56) were the first ones to emphasize the importance of leaf surface area in selecting high-yielding varieties, especially for early culture in Japan. After a series of studies on the developmental analysis of yielding ability in rice varieties, Tsunoda (55) concluded that a stem system of short culm—much tillering type brought about a well organized "gathering type" leaf arrangement favorable for uniform illumination of many leaves and consequently favorable for high yield under heavy manuring.

According to Jennings and Beachell (20) and Jennings (19), the traits most frequently considered to show association with and perhaps condition the level of fertilizer response were rate of nitrogen absorption and conversion to plant protein, short sturdy straw, leaf size, leaf color, leaf thickness, leaf angle, stage of senescence, plant maturity, temperature and photo-period sensitivity, and lower floret sterility at high levels of nitrogen. They recommended the following items as selection criteria for nitrogen responsiveness: (1) short stature of plants, (2) short relatively narrow, thick, erect, darkgreen leaves that remain functional until shortly before harvest, (3) maturity range of 115-130 days for a transplanted crop, (4) lower floret sterility with added nitrogen fertilizers.

In a panel discussion on Rice Breeding and Genetics at the Tenth Rice Technical Working Group (1), it was recommended that the factors contributing to straw strength, fertilizer response and yield components should be studied as a whole and emphasized the importance of these characters as related to grain yield in rice.

MATERIALS AND METHODS

(1) Source of experimental material

The experimental material used in this study was derived from a cross between two American varieties, Colusa and Nira, which was made in 1957. One thousand seeds from each of two F_1 plants of the cross were sown at the Rice Experiment Station at Crowley by Thullen (51) in 1963 under individual plant spacing culture. A total of 946 F_2 plants, derived from one of the F_1 plants, were harvested individually. On March 8, 1964, seeds from 297 of the F_2 plants were sown as F_3 lines at the Rice Experiment Station at Crowley in four adjacent blocks. The progeny of each F_2 plant formed a single plot containing 25 plants and constituting an F_3 line. The 297 F_3 lines were derived from randomly chosen F_2 plants, except for the provision that 183 were taken from early maturing F_2 plants and the other 114 lines came from late maturing F_2 plants.

Before harvest, the F_3 lines were classified for date of maturity. The lines were classified shortly after the early parent, Colusa, had reached maturity but before the later parent, Nira, was mature. The lines were classified into 3 categories: (1) lines widely segregating for date of maturity, (2) lines relatively homogeneous for early maturity and (3) lines relatively homogeneous for late maturity. Among the 297 F_3 lines, 32 were classified as widely segregating and the others were either in the second or in the third category. All 32 segregating lines were harvested. In addition, 40 lines from those in the second category and 61 lines from those in the third category were also harvested. The relatively homogeneous lines in respect to time of maturity were taken at random.

At harvesting time, the height of each plant was measured. The plants within lines were harvested separately and the panicles of each plant were put in an envelope, on which the line number, plant number within line, whether early or late in maturity and the plant height were written with a marker pencil. The early maturing plants were harvested when a reasonable number were mature, while the late plants were left in the field until they had all matured.

Within each of the 32 lines widely segregating for date of maturity, the greater proportion of plants were found to be early in maturity. Some segregating lines contained even fewer than 5 late maturing plants. Based on the number of late maturing plants within lines, 23 lines having at least 6 late plants each were selected from the 32 lines segregating for date of maturity. From each of these 23 segregating lines, one group of 5 or more plants which were early in maturity and a second group consisting of at least 5 plants late in maturity were established. A similar number of seeds were taken from each plant in the 2 groups and the seeds from all plants within each group were bulked to form a subline seed lot.

Thus, for each of the 23 F_3 lines there was a pair of subline lots, in which one member of the pair was composed from early maturing F_3 plants and the other was made up from late maturing plants. Seed of the 23 pairs of subline lots plus the 2 parents as controls, were used as the material of the first experiment. Including the 2 parents, these constituted 48 seed lots. Forty-eight grams of seeds were taken from each of the 48 seed lots, for use in planting a yield trial.

From among the 101 F_3 lines which were relatively homogeneous for early or late maturity, 66 were taken at random for the second phase of the study, dealing with the relationship between plant height and yield. Approximately half of these lines, 35, appeared to breed true for early maturity and half, 31, appeared to breed true for late maturity. Using a frequency distribution table for plant height of the 66 lines, 23 lines were selected which showed the widest range in height of plant. These 23 lines were assumed to be segregating for plant height. Seventeen of the 23 lines chosen were relatively homogeneous for early maturity and 6 lines were relatively homogeneous for late maturity.

Within each of the 23 lines, at least 5 of the shortest plants were chosen to represent a short plant population and all seed of these plants were bulked. The same procedure was followed for the tallest plants in each line to form a tall plant population. Thus, 2 subline lots, one made up from short plants and the other from tall plants, were created from each of the 23 F_3 lines involved. A seed lot of each of the 2 parents was added to provide 48 entries for a second yield trial.

(2) Field plot technique and cultural management.

Two field experiments were conducted in this study. One was yield trial of the 23 pairs of subline lots selected for date of maturity plus the parents. The parents were paired to form 24 pairs of entries. The other field experiment was a yield trial of 23 pairs of subline lots selected for plant height plus the parents. As in the first experiment the parents were paired to form 24 pairs of entries. In both field experiments, a split-plot design in randomized complete blocks was employed. The pairs were main plot treatments and the members of each pair were subplot treatments. Consequently a complete replication of each experiment contained 24 main-plots, and each main plot contained 2 sub-plots. Four complete replications were used in both experiments. Each randomized block was divided into 24 main plots, on which the 24 main plot treatments were assigned at random. The sub-plots within a main-plot consisted of 2 adjacent rows. The seeds of each subline lot were sown in a sub-plot, which was a single row 16 feet long. Both experiments were planted on May 5, 1965.

A complete fertilizer at the normal rate used for variety yield trials at the Rice Experiment Station was applied to the soil. The spacing between rows was 18 inches. Two border lines were planted along the sides of the experimental areas. The soil type of the experimental field is Crowley silt loam. The water management and other culture practices were those used customarily at the Rice Experiement Station. On the day after sowing, the experimental areas were irrigated and were kept under flooded condition for several days, after which the water was drained off.

Classification of the 48 entries in the date of maturity experiment was begun on August 23 and completed on September 13. Classification for date of maturity was by observation. On the first date, August 23, any sub-plot in which it appeared that in most of the panicles at least two-thirds of the grains were ripe was recorded as having reached maturity on that date. The decision as to whether the grains were ripe or unripe was based on their color. The writer returned to the Rice Experiment Station at 3 or 4 day intervals and repeated the classification procedure each time.

Plots of the date of maturity experiment were harvested 3 dates, August 30, September 7 and September 13. On each harvest date all plots in which the grain was fully ripe were harvested. Each sub-plot was harvested separately. Hurricane Betsy caused lodging of all late maturing plots on September 11 but, since it occurred only 2 days before final harvest, there did not appear to be appreciable damage. In harvesting, all plants in a sub-plot were cut, tied in a bundle and identified with a tag.

The height of plant experiment was classified before harvest by measurement. In each sub-plot of the first and second replications, 5 representative culms were chosen and their lengths from ground level to tip of the panicle were measured in inches. The length of each culm was recorded to the nearest 1/4 inch.

The procedure described earlier for harvesting the plant material for the date of maturity experiment was also used for the height of plant test.

After harvest, the bundles were allowed to dry then were threshed with threshing equipment of the Rice Experiment Station. The threshed grain from each sub-plot was put into a paper bag, with proper identification.

(3) Measurement of spikelet length, spikelet breadth and grain yield.

In order to determine a suitable size of sample for the measurement of spikelet length and spikelet breadth, samples consisting of 3, 5, 10, and 20 grains with 20 replications each were taken from 4 entries, including the two parents, and their mean lengths and breadths were measured. Based on the results, 4 samples of 10 spikelets each were taken at random from each subline plot in the first replication of both experiments. The 10 spikelets of a sample were placed end to end on a scale graduated in millimeters for the measurement of spikelet length.

The total length of 10 spikelets was observed with the aid of a hand lens. Spikelet breadth was measured as the mean distance from the keel of the lemma to the keel of the palea, across the spikelet at approximately its widest point. The 10 spikelets of a sample were placed side by side along the graduated scale and total breadth was observed.

About one month after harvest, the grain in each bag was cleaned separately. (During the time of storage, about 10 bags were damaged by mice. The damage was not serious, however). The cleaning of seeds was performed satisfactorily by use of the Bates aspirator seed cleaner made by Ricetown Sample Device Company, using window 0.75, feed dial No. 4. Each bag was cleaned twice and the trash was passed through the cleaner once again with the same window and dial number. After cleaning, the grain in each bag was weighed in grams with an ordinary balance.

(4) Methods of statistical analysis.

In order to know whether real differences in yield of grain occurred among lines and between subline lots as well as whether interaction occurred between lines and sublines, analysis of variance for grain yield was carried out for each experiment according to the split-plot design as follows:

Sources of variation	Degrees of freedom
Total	rpq-1
Replications	r-1
Among lines	q-1
Error (a)	(r-1))q-1)
Between sublines	(p-1)
Lines X sublines	(q-1)(p-1)
Error (b)	q(r-1)(p-1)

Where r, p and q represent the number of replications, the number of sublines within lines and the number of lines, respectively. If the replications, sublines and lines are denoted by i, j and k, the sums of squares were calculated by:-

Sum of squares, total = $\sum_i \sum_j \sum_k X^2_{ijk} - (\sum_i \sum_j \sum_k X_{ijk})^2/rpq$

Sum of squares, replications = $\sum_i \left\{(\sum_j \sum_k X_{ijk})^2/qp\right\}$ - C.F.

Sum of squares, lines = $\sum_k \left\{(\sum_i \sum_j X_{ijk})^2/rp\right\}$ - C.F.

Sum of squares, error (a) = $\sum_i \sum_k \left\{(\sum_j X_{ijk})^2/p\right\}$ - C.F. - S.S. replications - S.S. lines

Sum of squares, sublines = $\sum_j \left\{(\sum_i \sum_k X_{ijk})^2/rq\right\}$ - C.F.

Sum of squares, lines x sublines = $\sum_j \sum_k \left\{(\sum_i X_{ijk})^2/r\right\}$ - C.F. - S.S. lines - S.S. sublines

Sum of square error (b) = Subtract S.S. of all other sources of variation from total S.S.

The standard error for a line mean as an average of two sublines was calculated by $\sqrt{s^2E(a)/rp}$, where $s^2E(a)$ is variance of main plot treatments. The standard error for the mean of a subline within line was calculated by $\sqrt{s^2E(b)/r}$, where $s^2E(b)$ is variance of subplot treatments.

The same type of analysis was made on plant height and date of maturity as on grain yield. However, only data from two replications were available for these analyses.

As for spikelet length and breadth, since only one replication with four samples per plot was investigated, the analysis of variance was made as follows:

Sources of variation	Degrees of freedom
Total	rpq-1
Among lines	q-1
Between sublines	p-1
Lines x sublines	(p-1)(q-1)
Error	pq(r-1)

where,

Sum of squares, total = $\sum_i \sum_j \sum_k X_{ijk}^2 - (\sum_i \sum_j \sum_k X_{ijk})^2/rpq$

Sum of squares, lines = $\sum_k \{(\sum_i \sum_j X_{ijk})^2/rp\}$ - C.F.

Sum of squares, sublines = $\sum_j \{(\sum_i \sum_k X_{ijk})^2/rq\}$ - C.F.

Sum of squares, lines x sublines = $\sum_j \sum_k \{(\sum_i X_{ijk})^2/r\}$ - C.F. - S.S. lines - S.S. sublines

Sum of squares, error = Subtract S.S. of all other sources of variation from total S.S.

The correlation coefficient between any 2 of the characters was calculated by:

$$r_{x_y} = \frac{\text{Sum of products of deviations from mean between x and y}}{\sqrt{(\text{Sum of squares of } \underline{x}) \times (\text{Sum of squares of } \underline{y})}}$$

RESULTS AND DISCUSSION

(1) Association of grain yield with date of maturity

The method used to determine the date of maturity in this study is described in the "Materials and Methods" section. The date of maturity was defined as the date when the majority of panicles within a row had approximately two-thirds of the grains that had reached the color typical of ripe grain. Maturing period is the duration from the date of sowing of seed to the date of maturity.

Relatively early maturity of rice varieties is generally listed as one of the important breeding objectives. One reason for its importance is the possible association with high yielding capacity. For this reason, a considerable amount of data has been accumulated on the association of grain yield with maturing period, as described in "Review of Literature". Two opinions can be summarized from the review. One is that the grain yield is positively associated with maturing period (Bhide, 4; Nei, 36; Sethi, 47; Tsai, 54), and the other is that grain yield is negatively associated with maturing period (Bollich, 5; Jacobson, 18; Toriyama and Futsuhara, 53). A positive association means that late maturity is associated with high yield while a negative association means that early maturing forms have highest yield.

The purpose of this part of the present work is to evaluate further the relationship between grain yield and date of maturity by use of pairs of subline lots in the F_4 generation in which each pair of subline lots was derived from an F_3 line which was segregating for time of maturity. As described in "Materials and Methods", the seeds of five or more plants which were relatively early in maturity were bulked to form an early subline lot and the seeds of another five or more plants of the same F_3 line which were later in maturity were bulked to form a late subline lot.

It is recognized that the early and late maturing plants in the F_3 lines were not homogygous. Furthermore, there were genetic differences among the early or among the late maturing plants within a line in respect to other characteristics which might influence yield of grain. However, by bulking the seed from at least 5 plants to form each subline lot, it was felt that the 2 subline lots derived from any particular F_3 line should be reasonably similar in respect to other characteristics, except for those governed by genes which were linked with time of maturity genes. Thus, if there should prove to be a consistent superiority of either the early or the late maturing subline lot over its counterpart, this can be accepted as reasonably reliable evidence of an association between yield of grain and time of maturity. However, this evidence would not indicate whether the association was due to a direct influence of time of maturity on yield or to linkage between yield genes and those governing time of maturity.

Experiment 1 was a yield trial in which the subline lots within a line were derived from plants that differed in date of maturity. As mentioned earlier, a plot containing a subline lot was classified as mature when in a majority of the panicles approximately two-thirds of the grains appeared to be mature on the basis of color. The average days to maturity of each subline lot in the experiment is shown on Table 1. The parents, Colusa and Nira, were also included in the experiment and days to maturity for them are given at the bottom of the table.

Table 1. Average number of days required to reach maturity for the 23 pairs of subline lots and the parents in experiment 1

Line number or parents	Early sub-lines (E) (days) 1/	Late sub-lines (L) (days) 1/	Means of lines (days)	Indication of significance (α=0.05)	Mean differences (E-L) (days)
1	123.25	128.75	126.00	h	- 5.50**
2	121.00	125.50	123.25	cdefgh	- 4.50**
3	119.00	127.00	123.00	cdefgh	- 8.00**
4	119.50	124.25	121.88	bcdef	- 4.75**
5	116.50	129.00	122.75	bcdefg	-12.50**
6	124.25	125.25	124.75	fgh	- 1.00
7	119.75	123.75	121.75	bcdef	- 4.00**
8	121.25	128.75	125.00	gh	- 7.50**
9	116.50	125.00	120.75	abc	- 8.50**
10	122.00	125.75	123.88	defgh	- 3.75*
11	121.75	127.50	124.63	efgh	- 5.75**
12	117.50	124.50	121.00	bcd	- 7.00**
13	117.50	123.75	120.63	abc	- 6.25**
14	117.00	123.50	120.25	abc	- 6.50**
15	118.50	120.50	119.50	ab	- 2.00
16	116.00	119.75	117.88	a	- 3.75**
17	118.00	124.75	121.38	bcde	- 6.75**
18	117.50	126.75	122.13	bcdef	- 9.25**
19	123.25	121.25	122.25	bcdef	2.00
20	121.00	125.00	123.00	cdefgh	- 4.00**
21	119.50	124.00	121.75	bcdef	- 4.50**
22	116.50	126.50	121.50	bcdef	-10.00**
23	119.75	126.00	122.88	cdefgh	- 6.25**
Colusa	110.00				
Nira		128.75			-18.75

[1]Presumed to be early or late in maturity on the basis of behavior of F_3 plants which were selected and bulked to form the subline lots.

**Significant at α=0.01

*Significant at α=0.05

The classification "Early subline" and "Late subline" in the table heading is based on the classification of F_3 plants used in forming these lots and not based on the actual maturity dates of the subline lots in 1965.

It is clear from the table that the Colusa parent is an early maturing variety with an average maturing period under these conditions of about 110 days, while the other parent, Nira, is a midseason variety with an average maturing period of about 129 days. This classification of the parents for maturity is based on the system commonly used in the United States.

Apparently none of the "early" subline lots was as early as the Colusa parent. The nearest were "early" sublines in lines 5, 9, 16, and 22, which matured in about 116 days.

Differences between "early" and "late" sublines within lines in number of days to reach maturity are shown in the last column of Table 1. In all lines except one, line 19, the presumably early subline lot was numerically earlier than its presumably late counterpart. However, in 2 other lines, numbers 6 and 15, the difference between subline lots within lines was not significant. Thus, in the 3 lines, 6, 15 and 19, the classification of early and late for the sublines based on maturity of the F_3 plants, proved to be erroneous. Any difference in yield between subline lots within these 3 lines cannot be due to the effect of date of maturity on yield. Only the remaining 20 lines can be useful in studying the relationship between days required to reach maturity and grain yield.

Size of the mean differences in days required to reach maturity between sublines within lines appeared to be continuous. Most of the differences were in the range of 4 to 7 days. The maximum difference was 12.50 days, in line number 5. One line, number 22, had a 10 day difference between sublines.

The range among the "early" sublines was from 116.0 to 124.25 days. However, the subline with 124.25 days was in line 6, where there was no difference between the so called "early" and "late" sublines. Otherwise, the latest of the so called early sublines was 123.25 days in line 1. Thus, many of the so called early sublines were actually not early in maturity. In fact, among the 20 lines, excluding 6, 15 and 19, 6 of the "early" subline components required more than 120 days to mature.

On the other hand, 3 "late" sublines were fully as late as Nira. These were the "late" sublines within lines 1, 5 and 8. In addition, the "late" sublines within lines 3 and 11 were essentially as late as Nira. The range among the "late" sublines was from 119.75 to 129.00 days.

However, there was a strong tendency, despite the variation among "early" and among "late" sublines, for the so called early sublines to be earlier in maturity than the so called late sublines.

There were significant differences among the 23 lines as an average of sublines. As shown by Table 1, the means of the 23 lines ranged from 117.88 days to maturity for line number 16 to 126.00 days for line number 1. Thus, line 1 was almost as late as the later parent, Nira. However, none of the lines were early in maturity. All lines, except 15 and 16, had means of 120 days or longer to reach maturity.

Four lines, 9, 13, 14 and 15, were not significantly different from the earliest line, number 16, but the remaining 18 lines were significantly later. The 9 latest maturing lines were not significantly different from one another.

In order to evaluate the relationship between date of maturity and grain yield, statistical evidence of real differences in date of maturity among lines and between sublines is necessary. Using the data obtained from the first and second replication of the experiment, the analysis of variance for date of maturity, excluding the parents, was made as shown on Table 2.

Table 2. Variance analysis on date of maturity in experiment 1

Sources of variation	Degrees of freedom	Mean squares	F-values
Total	91		
Replications	1	1.56	
Among lines	22	14.19	3.96**
Error (a)	22	3.58	
Between sublines	1	743.78	377.55**
Lines x sublines	22	9.14	4.64**
Error (b)	23	1.97	

The variance analysis shows there exists highly significant differences in date of maturity among lines and between sublines, even though only two replications were used in the analysis.

One point of interest that the experiment was intended to provide information about is whether the procedure of forming pairs of subline lots by bulking seed from early and from late plants within segregating F_3 lines would prove effective in forming strains which would differ considerably in time of maturity in the direction anticipated. The fact that in 20 of the 23 lines tested, the subline lot formed from early maturing F_3 plants was significantly earlier than its counterpart formed from later maturing F_3 plants indicates that the procedure was at least partially successful. However, in many lines the difference between the early and late sublines was small, less than one week, while the parents differed by almost 3 weeks. Failure to produce subline lots within a line which differ as greatly as the parents in time of maturity was due primarily to a scarcity of F_3 plants which were as early as Colusa. This suggests that the difference between the parents in time of maturity is controlled by several pairs of genes. Undoubtedly, the procedure used would have been more effective if a larger number of plants per F_3 line had been grown and classified.

The grain yield of each subline was obtained by weighing in grams the clean dry rough rice which was harvested from a 1.5 x 16 foot plot. The yield in grams per plot was used during the statistical analysis; however, it will be more useful to present the data in pounds per acre. The correction factor for this purpose was computed as:

$$0.0022046 \times 43{,}560 \;/\; 1.5 \times 16 = 4.00135$$

Table 3 shows the average grain yield of each subline and the mean differences between the 2 sublines within lines as well as between parents in experiment 1, in which the selection was made on date of maturity. One of the parents, Colusa, showed an average grain yield of 2,995.4 lbs/A, while the other parent, Nira, showed an average yield of 2,200.0 lbs/A. Thus, there was a difference of 795.5 lbs/A in favor of the early Colusa parent.

The mean differences between early and late subline lots within lines are given in the last column of Table 3. All mean differences were obtained by subtracting the yield for the late subline lot from

Table 3. Average grain yield of the 23 pairs of subline lots and the parents in experiment 1 in lbs/acre

Line number or parents	Early sub-lines (E) 1/	Late sub-lines (L) 1/	Means of lines	Indication of significance (α=0.05)	Mean differences (E-L)
1	2,744.1	1,502.5	2,123.3	a	1,241.6**
2	2,756.1	1,669.4	2,212.8	abc	1,086.7**
3	3,099.0	2,009.9	2,554.5	abcdefg	1,089.1**
4	3,262.7	2,526.1	2,894.4	ghi	736.6**
5	3,107.4	2,125.1	2,616.3	cdefg	982.3**
6	2,763.3	1,905.4	2,334.4	abcde	857.9**
7	2,701.7	2,389.2	2,545.5	abcdefg	312.5
8	2,832.2	2,474.8	2,653.5	defgh	357.4
9	2,433.6	2,147.9	2,290.8	abcd	285.7
10	2,306.0	1,935.1	2,120.6	a	370.9*?
11	3,263.9	2,611.3	2,937.6	ghi	652.6**
12	2,782.1	2,196.3	2,489.2	abcdef	585.8**
13	2,919.8	2,293.2	2,606.5	bcdefg	626.6**
14	2,315.2	2,383.2	2,349.2	abcde	- 68.0
15	3,115.9	3,159.1	3,137.5	i	- 43.2
16	3.084.2	3,031.8	3,058.0	hi	52.4
17	2,930.6	2,747.7	2,839.2	fghi	182.9
18	3,027.0	2,441.6	2,734.3	fghi	585.4**
19	2,055.5	2,296.8	2,176.2	ab	-241.3
20	3,148.3	2,312.0	2,730.2	efghi	836.3**
21	2,321.6	1,953.9	2,137.8	a	367.7
22	3,320.7	2,824.6	3.072.7	i	496.1*
23	2,812.1	1,755.8	2,284.0	abcd	1,056.3**
Colusa	2,995.4				
Nira		2,200.0			795.4
Means2/	2,858.4	2,266.6			591.8

1/Classification based on date of maturity of F_3 plants used in forming subline strains.

2/Excluding 6, 15, 19 and parents

**Significant at α=0.01

*Significant at α=0.05

*?Approaching to significant level α=0.05, but did not reach

that of the early subline counterpart within a line.

Fourteen of the mean differences between sublines were significant and the remaining 9 were non-significant. Twenty of the mean differences, including all significant ones, were positive.

There were wide differences among the early subline lots in yield, with yields ranging from 2,055.5 lbs/A for the early subline in line 19 to 3,320.7 lbs/A in line 22. A similar wide variation in yield occurred among the late sublines with yields ranging from 1,502.5 to 3,159.1 lbs/A.

Means of the 23 lines varied from 2,120.6 lbs/A for line 10 to 3,137.5 lbs/A for line 15. As shown in Table 3 many of the differences between lines were significant. Lines, 1, 2, 3, 6, 9, 10, 12, 14, 19, 21 and 23 constituted a group of the lowest yielding lines which were not significantly different from one another. Lines 4, 11, 15, 16, 17, 18, 20 and 22 made up a group of highest yielding lines which did not differ significantly from one another. These 2 groups of lines were significantly different in yield.

Three of the lines, 15, 16 and 22, appeared to be outstanding in yield of grain. In these 3 lines both subline lots were as high in yield as was the higher yielding Colusa parent.

Considering that the lines were taken at random, it is remarkable that several of the subline lots, particularly among the early group, were as high, possibly higher, in yeild than the Colusa parent. Several subline lots in the late group appeared to be lower in yield than the midseason Nira parent.

The primary purpose of the experiment was to determine the relationship between time of maturity and yield by comparing the yields of early and late subline strains derived from the same F_3 line, on the assumption that such paired strains would differ only in genes for time of maturity.

It was found, however, that for 3 of the 23 lines there was not a significant difference between sublines within lines in time of maturity. These were lines 6, 15, and 19. Only the other 20 lines can be used for this study. For these 20 lines, the early subline lot was significantly higher in yield than its late counterpart in 13 of the lines. For the other 7 lines, the early subline produced a numerically higher yield than its late counterpart in 6 lines although the differences were not significant.

Thus, among the 20 lines involved, the yield of the early subline lot was numerically higher than that of the late member of the pair in 19 cases. In the one exception, the difference was very small and clearly due to chance.

The results provided strong evidence that in the cross of Colusa x Nira high yielding ability was associated with early maturity. The lines which did not show any evidence of an association were 14 and 16. Failure of the "early" subline to yield more than the "late" in line 16 is not surprising. In this line, the so called late subline reached maturity in approximately 120 days, a relatively short period for the material in this study.

In some lines, such as 1, 2 and 23, even small differences in time of maturity of less than one week were associated with very large differences in yield.

Despite the strong association between early maturity and high yield within most of the lines, there was no apparent tendency for size of the mean difference between early and late subline lots within lines in time of maturity to be associated with the size of the mean difference between the sublines in yield. The correlation coefficient of the mean differences between sublines within lines for time of maturity, in Table 1, and the mean differences between sublines within lines for yield, in Table 3, was calculated and found to be only -0.11. This is very low and non-significant. Lack of association is also shown by the fact that in 2 of the lines, 5 and 22, the sublines differed by 10 to 12 days in time of maturity but the differences between sublines in yield were not exceptionally large, although both were significant. The reason for this lack of association is not known.

It has been pointed out earlier that the 23 early sublines differed appreciably in both time of maturity and yield of grain. For these sublines the correlation coefficient between time of maturity and yield was -0.285. Although the r value is negative, as expected if early maturity is associated with high yield, it is not significant.

However, for the 23 late sublines the correlation coefficient between time of maturity and yield was not only negative but a significant value of -0.483. This indicates that among the late sublines there was a moderate tendency for the less late ones to produce the highest yield. This is shown by the fact that the 4 latest maturing sublines, 1, 3, 5 and 8 produced yields of 1,502.5, 2.009.9, 2,125.1 and 2,474.8 lbs/A, respectively, while the 2 earlier sublines, 15 and 16, had yields of 3,159.1 and 3,031.8, respectively.

For the entire 46 early and late sublines as a whole the correlation between time of maturity and yield was -0.650, a moderately high, significant value.

The correlation coefficients suggest that for time of maturity periods up to 120 days, the range found among the "early" sublines, there was no marked association between time of maturity and yield. Many of the early sublines that matured in about 120 days were as high in yield as those which matured in 116 days. However, these 116 to 120 day sublines tended to be distinctly higher in yield than those which required 127 to 128 days to mature. Whether sublines as early as Colusa, 110 days, would have outyielded those that required 120 days cannot be answered by this experiment, since there were none earlier than 116 days. However, the data suggest that extremely early sublines would not have yielded more than the 120 day ones, because several of the 116-120 day sublines yielded as much as Colusa.

It is also significant that the 2 earliest lines as an average of the early and late subline components, lines 15 and 16, were also the highest in mean yield (Table 3). The mean yields of these 2 lines were 3,137.5 and 3.058.0 lbs/A, respectively, in contrast to the mean yields of the 3 latest lines, 1, 6 and 8, which were 2,123.3, 2,334.4 and 2,653.5, respectively.

Analysis of variance of the yield data is presented in Table 4. There were significant differences in grain yield among the 23 lines and between early and late subline lots within lines. There was also a significant interaction between lines and sublines. Differences required for significance were calculated for the means of the lines and for the mean differences between sublines within lines. These values were used in determining and indicating significant differences in the last 3 columns of Table 3.

Table 4. Analysis of variance of grain yield of experiment 1, in which selection was made on date of maturity

Sources of variation	Degrees of freedom	Sums of Squares	Mean squares	F-values
Total	183	3,500,376.01		
Replications	3	141,779.45	47,259.82	
Among lines	22	1,163,623.36	52,891.97	6.15**
Error (a)	66	567,399.46	8,596.96	
Between sub-lines	1	836,474.55	836,474.55	175.65**
Lines x sub-lines	22	462,524.35	21,023.83	4.41**
Error (b)	69	328,574.84	4,761.95	

(2) Association of grain yield with plant height

Experiment 2 consisted of 23 pairs of subline strains which were selected on the basis of plant height. In this experiment, the two subline strains within a line were relatively short and relatively tall in plant stature.

The heterozygous nature of the F_3 lines possibly induced genetic differences among the short or the tall plants within a line in respect to other characteristics which might influence yield of grain. However, as indicated in the previous section, bulking the seed of several plants within each subline lot should cause any two subline counterparts to be reasonably similar in respect to other characteristics, except for those governed by genes which were linked with plant height. The evidence of an association between yield of grain and plant height can be shown by whether there exists a consistent superiority of either the short or tall subline lot over its counterpart. However, this evidence would not indicate whether the association was due to a direct influence of plant height on yield or to linkage between yield genes and those governing plant height.

The average plant height of each of the subline lots and the parents as well as the mean differences between the two subline lots within lines is shown on Table 5. As controls, the Colusa parent was 43.88 inches tall while the other parent, Nira, was 59.75 inches tall. The mean difference between parents was about 16 inches. The plant height of Colusa can be considered short in relation to the height of most United States varieties, while the height of Nira can be considered as relatively tall.

As indicated in Table 5, all so called "short" sublines were numerically shorter than their "tall" subline counterparts. This is shown by the negative mean differences between subline lots of all 23 lines since the mean differences were obtained by subtracting a "short" subline mean from a "tall" subline mean. For the 23 lines, 4 lines had non-significant mean differences between so called short and tall subline lots. They are lines 19, 20, 21 and 23. In each of these 4 lines, the classification of short and tall for the sublines proved to be erroneous. Any difference in yield between sublines within these 4 lines cannot be due to the effect of height of plant on yield. Only the remaining 19 lines can be useful in studying the relationship between height of plant and grain yield. Line 6 gave the biggest mean difference (9.50 inches) of plant height between so called short and tall subline lots. The mean differences of a majority of the other lines were in the range of 3-6 inches.

The range among the presumably short sublines was from 44.78 to 54.90 inches. The shortest one, which was essentially as short as the

Table 5. Average plant height in inches for the 23 pairs of subline lots and the parents in experiment 2

Line number or parents	Short sub-lines[1] (S)	Tall sub-lines[1] (T)	Means of lines	Indication of significance (α=0.05)	Mean differences (S-T)
1	47.78	51.33	49.56	ab	-3.55**
2	54.90	61.38	58.14	d	-6.48**
3	50.53	57.40	53.97	cd	-6.87**
4	49.70	54.75	52.23	bc	-5.05**
5	53.20	56.63	54.92	cd	-3.43**
6	49.98	59.48	54.73	cd	-9.50**
7	49.08	53.93	51.51	abc	-4.85**
8	51.70	57.25	54.48	cd	-5.55**
9	49.68	52.78	51.23	abc	-3.10**
10	51.45	55.25	53.35	bc	-3.80**
11	53.60	56.20	54.90	cd	-2.60*
12	51.48	54.65	53.07	bc	-3.17**
13	49.00	53.85	51.43	abc	-4.85**
14	44.78	50.80	47.79	a	-6.02**
15	51.05	55.33	53.19	bc	-4.28**
16	51.10	54.23	52.67	bc	-3.13**
17	49.05	52.88	50.97	abc	-3.83**
18	49.93	55.73	52.83	bc	-5.80**
19	52.83	54.25	53.54	bc	-1.42
20	53.18	54.98	54.08	cd	-1.80
21	53.63	54.13	53.88	bcd	-0.50
22	49.48	53.10	51.29	abc	-3.62**
23	53.65	54.53	54.09	cd	-0.88
Colusa	43.88				
Nira		59.75			15.87

[1]Classification based on behavior of F_3 plants used in forming each subline strain.

** Significant at α=0.01

*Significant at α=0.05

Colusa parent (43.88 inches) was in line 14. Several of these sublines were more than 50 inches in plant height, which is considerably taller than Colusa.

The plant height of so called tall sublines varied continuously from 50.80 to 61.38 inches. The 2 tallest sublines, in lines 2 and 6, were fully as tall as the taller parent, Nira. The plant height of most of the other "tall" sublines was in the range of 52-56 inches.

Despite the variation among early and among late sublines, there was a strong tendency for the so called short subline lots to be shorter in height of plant than the so called tall subline plots.

The average plant height of each line as an average of two sublines is also shown in Table 5. There were significant differences among these 23 line means, which ranged from 47.79 inches for line 14 to 58.14 inches for line 2. The two extremes were relatively close to, but did not reach, the parent limits.

Six lines, 1, 7, 9, 13, 17, and 22, were not significantly different from the shortest line 14, but the remaining 16 lines were significantly taller. The 9 tallest lines were not significantly different from one another in height of plant. They were lines 2, 3, 5, 6, 8, 11, 20, 21, 23.

In order to obtain statistical evidence of differences in plant height existing among the lines and between sublines, variance analysis was carried out based on data obtained from the first and second replications of the experiment. The parents were not included in the analysis. The results are shown in Table 6. The differences among lines and between sublines within lines were highly significant. The interaction between lines and sublines was also highly significant.

Table 6. Variance analysis on plant height in experiment 2.

Sources of variation	Degrees of freedom	Mean squares	V-values
Total	91		
Replications	1	111.87	
Among lines	22	17.83	2.773**
Error (a)	22	6.43	
Between sublines	1	385.20	345.499**
Lines x sublines	22	4.34	3.895**
Error (b)	23	1.12	

The experiment was intended to provide information about whether the procedure of forming pairs of subline lots by bulking seed from short and from tall plants within segregating F_3 lines would prove effective in forming strains which differed considerably in height of plant in the direction anticipated. The results presented earlier indicate that the procedure was at least partially successful because in 19 of the 23 lines tested the subline lot formed from short F_3 plants was significantly shorter than its counterpart formed from tall F_3 plants in the same line. According to Caldwell (6) and Poonai (40), the height of plant by which the parents, Colusa and Nira, differed was controlled by several pairs of genes. For this reason, the procedure used would have been more effective if a larger number of plants per F_3 line had been employed.

The grain yield of each subline and parent expressed in pounds per acre is presented in Table 7. One of the parents, Colusa, gave an average grain yield of 3,696.8 lbs/A, while the other parent, Nira, showed an average yield of 1,853.4 lbs/A. The mean difference of grain

Table 7. Average grain yield of the parents and 23 pairs of subline lots in experiment 2 in lbs/acre

Line number or parents	Short sublines[1] (S)	Tall sublines[1] (T)	Means of lines	Indication of significance (α=0.05)	Mean differences (S-T)
1	2,948.6	2,840.2	2,894.4	bcde	108.4
2	3,115.1	2,873.0	2,994.1	bcdefg	242.1
3	2,394.8	2,792.5	2,593.7	bc	-397.7*
4	3,390.0	3,031.0	3,210.5	efg	359.0
5	3,053.8	2,940.6	2,997.2	bcdefg	113.2
6	2,712.1	2,865.0	2,788.6	bcd	-152.9
7	2,840.2	3,057.0	2,948.6	bcde	-216.8
8	3,011.8	2,558.9	2,785.4	bcd	452.9*
9	3,069.0	3,070.2	3.069.6	cdefg	- 1.2
10	3,428.4	3,035.8	3,232.1	efg	392.6
11	3,390.3	3.360.7	3.375.5	fg	29.6
12	2,822.6	2,856.2	2,839.4	bcde	- 33.6
13	2,913.4	3.033.4	2,973.4	bcdef	-120.0
14	2,439.2	2,977.4	2,708.3	bcd	-538.2**
15	2,793.3	3.419.2	3.106.3	defg	-625.9**
16	3,338.7	3,603.6	3.471.2	g	-264.9
17	3,111.8	3,237.9	3,174.9	defg	-126.1
18	1,818.2	2,086.7	1,952.5	a	-268.5
19	2,481.2	2,560.9	2,521.1	b	- 79.7
20	2,871.0	2,909.4	2,890.2	bcde	- 38.4
21	2,848.6	2,983.0	2,915.8	bcde	-134.4
22	2,143.1	1.790.2	1,966.7	a	352.9
23	3,055.0	2,801.7	2,928.4	bcde	253.3
Colusa	3,696.8				
Nira		1,853.4			1,843.4
Mean[2]	2,880.8	2,917.3			26.5

[1]Classification based on height of F_3 plants used in forming subline strains.

[2]Excluded 19, 20, 21, 23 and parents

**Significant at α=0.01

*Significant at α=0.05

yield between the two parents was 1,843.4 lbs/A. Thus, the short Colusa parent was much higher in yield than the tall Nira parent.

The mean differences between sublines within lines for yield are in the last column of the table. All mean differences were obtained by subtracting the yield for the tall subline lot from that of the short subline counterpart within a line.

As pointed out previously, the sublines within 4 lines, 19, 20, 21 and 23, were not significantly different in plant height and have to be ignored in evaluating the relationship between height of plant and yield. For the remaining 19 lines, the mean difference was positive within 8 lines and negative within 11 lines. This suggests that no distinct association occurred between sublines within lines for yield and plant height. Furthermore, only 4 of the 19 mean differences between sublines within lines were significant, 3 being negative and one positive. This provides additional evidence of a lack of association between yield and plant height. It is obvious that there was no evidence that high yield was associated with either short or tall plant height.

The grain yield of the "short" subline lots varied from 1,818.2 lbs/A, in line 18 to 3,428.4 lbs/A in line 10. The tall subline lots showed essentially the same range in yield, from 1,790.2 lbs/A in line 22 to 3,603.6 lbs/A in line 16. This is additional evidence that no association occurred between yield and plant height. The means of the short and tall sublines were almost identical, 2,880.8 and 2,917.3 lbs/A, respectively.

Mean yields of the 23 lines as averages of the 2 subline lots within lines varied from 1,952.5 lbs/A for line 18 to 3,471.2 lbs/A for line 16. No line numerically exceeded the parent limits in yield. Lines 18 and 22 made up a group of the lowest yielding lines which were not significantly different from one another. Lines 2, 4, 5, 9, 10, 11, 15, 16 and 17 constituted a group of the highest yielding lines which did not differ significantly from one another. These two groups of lines were significantly different in yield.

The correlation coefficient between plant height and yield of grain for the 23 "short" sublines was a non-significant value of +0.312. For the "tall" sublines, the correlation coefficient was -0.042, very low and non-significant. For the entire 46 sublines, the correlation coefficient between height of plant and yield of grain was +0.127. This value is not only non-significant but very low and provides further strong evidence that no association occurred between these 2 traits.

Plant height is considered the major characteristic responsible for lodging (Chang 7). According to Jennings et al (21), lodging is the primary cause of yield loss. Thus, plant height could affect yield through its primary effect, lodging. Since no lodging which could induce yield damage was observed in the experiment, this was not the limiting factor in this study.

The variance analysis of grain yield for the experiment was carried out in order to obtain the statistical evidence existing among lines and between sublines. The parents were not included in the analysis. The results are shown in Table 8. As Table 8 indicates, the differences of grain yield among lines were highly significant. The effect of sublines was not significant; however, the interaction between lines and sublines was significant. This indicates that the differences of grain yield between sublines within lines were significant, but in both positive and negative directions. These two directions of differences between sublines within lines compensated each other and led to the non-significant F-value of sublines in Table 8. When the lines

Table 8. Variance analysis of grain yield in experiment 2.

Sources of variation	Degrees of freedom	Sums of squares	Mean squares	F-values
Total	183	2,981,794.00		
Replications	3	211,547.38	70,515.79	
Lines	22	1,498,809.00	68,127.68	6.48**
Error (a)	66	694,218.45	10,518.46	
Sublines	1	2,619.10	2,619.10	0.52 n.s.
Lines x sublines	22	230,935.55	10,497.07	2.11*
Error (b)	69	343,664.52	4,980.64	

having non-significant mean differences between sublines in plant height were dropped in the variance analysis, the effect of lines was still highly significant; the effect of sublines was also not significant, and lines x sublines interaction became highly significant.

Differences required for significance were calculated for the mean differences of the lines and for the mean differences between sublines within lines. These were used in determining and indicating significant differences in Table 7.

(3) Association of grain yield with spikelet length and spikelet breadth.

Although no consideration was given to spikelet dimensions in choosing the lines and forming the subline strains in the 2 experiments conducted in this study, it appeared probable that through chance the lines would differ appreciably in length and breadth of spikelet and provide some evidence concerning the association of yield with these spikelet dimensions. Consequently, spikelet length and spikelet breadth were determined for each of the 46 subline lots in experiment 1 and those in experiment 2.

A considerable amount of work has been done by earlier investigators with spikelet length and breadth in which suitable techniques for measuring these traits were devised. However, almost all of this earlier work was done with individual plants, in which variation among spikelets within a sample was environmental. Since in the present study involving subline strains as units the variation among spikelets will be genetic as well as environmental in nature, it was necessary to conduct a preliminary experiment to determine the minimum number of spikelets needed per sample in order to provide a reliable indication of spikelet length and breadth.

For the size of sample experiment, the grain harvested from 4 plots of the 2 yield trials was utilized. Two of these plots represented subline strains and the other 2 plots represented the Colusa and Nira parents. For each of the 4 strains or varieties, 4 sizes of samples were measured. The sample sizes were 3, 5, 10 and 20 spikelets each. For each size of sample, 20 measurements were made. For example, from one plot of the Colusa parent 20 lots of 3 spikelets each were taken at random. Each lot was measured separately for length and breadth of spikelet.

The results of the size of sample experiment are given in Table 9. For each sample size the mean, standard deviation and coefficient of variation of spikelet length and of spikelet breadth were calculated and are presented in the table.

Within each of the 4 strains, the means from different sizes of sample were very similar. However, this probably is not very significant since each mean was based on a minimum of 60 spikelets. This number

Table 9. Means ($\bar{x}$), standard deviation(s) and coefficients of variation ($CV_{(Xi)}$) for length and breadth of spikelets in Colusa, Nira and two sublines, as estimated from samples of 3, 5, 10 and 20 spikelets.

No. of spikelets within sample	Spikelet length			Spikelet breadth		
	$\bar{x}$(mm)	s	$CV(X_i)$%	$\bar{x}$(mm)	s	$CV(X_i)$%
Row No. 37 (Colusa)						
3	7.38	0.128	1.74	3.72	0.119	3.19
5	7.45	0.119	1.59	3.70	0.065	1.75
10	7.36	0.088	1.19	3.71	0.050	1.35
20	7.35	0.043	0.58	3.69	0.057	1.54
Row No. 38 (Nira)						
3	10.06	0.197	1.95	2.71	0.082	3.29
5	10.08	0.182	1.81	2.70	0.046	1.69
10	10.07	0.134	1.33	2.72	0.039	1.41
20	10.04	0.082	0.82	2.74	0.024	0.86
Row No. 40 (11-L)						
3	9.07	0.335	3.69	3.30	0.120	3.64
5	9.17	0.185	2.01	3.25	0.056	1.72
10	9.14	0.121	1.32	3.33	0.059	1.76
20	9.13	0.092	1.01	3.33	0.030	0.91
Row No. 235 (8-S)						
3	8.44	0.179	2.12	3.09	0.118	3.81
5	8.47	0.169	1.99	3.10	0.085	2.74
10	8.48	0.091	1.07	3.06	0.082	2.67
20	8.49	0.021	1.10	3.08	0.009	1.32

is undoubtedly adequate for obtaining a reliable mean of spikelet length and breadth.

The coefficient of variation is probably the most suitable expression of the amount of variation which each sample size is subject to. As expected, the coefficient of variation tended to decrease with increase in sample size, tending to be highest for 3 spikelet samples and lowest for 20 spikelet samples. However, the coefficients of variation were surprisingly low, less than 4 percent, for all sample sizes.

It was concluded that although 20 spikelet samples would prove more reliable, measurements based on 10 spikelet samples would be satisfactory and could be done more rapidly. It can be noted that for 10 spikelet samples the coefficient of variation was usually between 1 and 2 percent.

Based on the results in the table, 10 spikelets were taken at random from the grain harvested from each plot of the first replication of the 2 yield experiments and used to determine spikelet length and breadth.

(A) Association between grain yield and spikelet length

The average spikelet length of each subline as well as parent in experiments 1 and 2 is shown in Tables 10 and 11, respectively. The Colusa parent had a mean of about 7.30 mm. in spikelet length for the 2 experiments, while Nira averaged about 10.00 mm. (Tables 10 and 11). Colusa is classified as a short grain variety and Nira as long grained. The difference between the parents is relatively large, approximately the maximum found in cultivated rice of the species *Oryza sativa*.

Through chance, considerable variation occurred for spikelet length among the 46 subline strains in each experiment. In experiment 1,

Table 10. Average spikelet lengths for the 23 pairs of subline lots and the parents in experiment 1.

Line number or parents	Early sub-lines mm.	Late sub-lines mm.	Means of lines mm.	Indication of significance (α=0.05)
1	8.95	9.20	9.08	e
2	8.79	8.89	8.84	bcd
3	8.57	8.57	8.57	a
4	8.89	8.53	8.71	b
5	8.59	8.86	8.73	b
6	8.91	8.63	8.77	bc
7	8.81	8.64	8.73	b
8	9.03	8.79	8.91	cd
9	9.34	8.84	9.09	e
10	9.46	9.52	9.49	gh
11	9.09	9.17	9.13	e
12	9.21	9.41	9.31	f
13	7.52	7.50	7.51	
14	8.39	8.59	8.49	a
15	8.79	8.89	8.84	bcd
16	9.44	9.33	9.39	fg
17	8.98	8.87	8.93	d
18	8.51	8.52	8.52	a
19	9.30	9.21	9.25	f
20	8.77	9.00	8.89	cd
21	8.30	8.40	8.35	
22	9.20	9.32	9.26	f
23	9.58	9.60	9.59	h
Colusa	7.32			
Nira		10.15		

Table 11. Average spikelet lengths for the 23 pairs of subline lots and the parents in experiment 2

Line number or parents	Short sub-lines mm.	Tall sub-lines mm.	Means of lines mm.	Indication of significance (α=0.05)
1	8.06	8.69	8.38	d
2	8.79	9.10	8.95	j
3	8.71	9.00	8.86	ij
4	8.73	9.16	8.95	j
5	8.24	8.90	8.57	fg
6	8.47	9.25	8.86	ij
7	8.21	8.49	8.35	cd
8	8.44	8.69	8.57	fg
9	8.62	9.00	8.81	i
10	8.53	9.41	8.97	j
11	8.04	8.11	8.08	b
12	8.01	8.46	8.24	c
13	8.85	8.97	8.91	ij
14	7.72	7.70	7.71	
15	8.63	8.67	8.65	h
16	8.66	9.02	8.84	ij
17	8.57	8.33	8.45	de
18	8.40	8.85	8.63	gh
19	8.33	8.45	8.39	de
20	8.35	8.58	8.47	def
21	7.81	8.03	7.92	a
22	8.47	8.52	8.50	efg
23	8.02	7.93	7.98	ab
Colusa	7.28			
Nira		9.97		

the range was from 7.50 mm. in the late subline of line 13 to 9.60 mm. for the late subline in line 23. In experiment 2, the range was from 7.70 mm. for the tall subline in line 14 to 9.41 mm. for the tall subline in line 10.

In each experiment, there were significant differences among lines in spikelet length (Table 12). Means of the lines for spikelet length and indication of significant differences between lines are shown in the last column of Tables 10 and 11.

In experiment 1, line 13, with a mean of 7.51 mm., was significantly shorter in spikelet length than all other lines. Line 21 was the second shortest line in this experiment, being significantly shorter than the remaining lines. Lines 3, 14 and 18 represented the third shortest group. Lines 10, 16, 19, 22 and 23 had the longest spikelets in experiment 1.

In experiment 2, lines 11, 14, 21 and 23 were the shortest in spikelet length while lines 2, 3, 4, 6, 10, 13 and 16 had the longest spikelet length.

Table 12. Variance analyses of spikelet length in experiments 1 and 2.

Sources of variation	Degrees of freedom	Mean squares (Exp. 1)	F-values (Exp. 1)	Mean squares (Exp. 2)	F-values (Exp. 2)
Total	183				
Among lines	22	1.5958	97.36**	1.0273	67.94**
Between sublines	1	0.0012	0.07n.s.	3.7878	250.52**
Lines x sub-lines	22	0.0811	4.95**	0.1536	10.16**
Error	138	0.0164		0.0151	

The correlation coefficients between spikelet length and yield among all sublines in the 2 experiments were -0.038 and -0.008. These are non-significant and extremely low, indicating that in both experiments there was no association between yield of grain and length of the spikelets.

In experiment 1, the shortest spikelet line, number 13, was average in yield. The second shortest line, number 21, was low in yield. The relatively short group of lines, 3, 14 and 18, were all intermediate in yield. Among the long spikelet lines, 10, 16, 19, 22 and 23, there was a range in yield from very low (2,120.6 lbs/A) to very high (3,072.7 lbs/A).

Lines 16 and 22 of experiment 1 are of special interest. These 2 lines had mean spikelet lengths of 9.39 mm. and 9.26 mm., respectively, in comparison with a spikelet length of 10.15 mm. for the Nira parent. Thus these 2 lines had relatively long spikelets. However, they were also high in yield of grain, averaging 3,058.0 and 3,072.7 lbs/A, respectively, and at least equal to the yield of the short grained, high yielding Colusa parent.

There was a similar lack of association between yield of grain and spikelet length among the lines in experiment 2.

Although experiments 1 and 2 were not designed specifically to measure association between spikelet length and grain yield, the results were highly consistent and suggest strongly that no association exists between these traits in the Colusa x Nira hybrid material.

This apparent lack of association is surprising. In Louisiana, varieties of medium grain length generally yield more than long grain varieties. For example, Jodon[1] showed that the average yield of 8 medium grain varieties was 4,466 lbs/A, while that of 8 long grain varieties of comparable maturity range was only 3,939 lbs/A. The broad significance of the lack of association between spikelet length and grain yield in the present study is uncertain. However, it is of considerable interest and indicates a need for more critical research on this subject. Apparently a critical study of this association has not been made.

(B) Association between grain yield and spikelet breadth.

The average spikelet breadth of each subline strain and parent in experiments 1 and 2 is shown in Tables 13 and 14, respectively. In experiment 1, Colusa had an average breadth of 3.70 mm. and Nira an average of 2.72 mm. In experiment 2, the Colusa and Nira parents averages 3.74 mm. and 2.70 mm., respectively. For the 2 experiments, Colusa was 3.72 mm. and Nira was 2.71 mm. in average. The difference between the parents was about 1.00 mm. Colusa is classified a broad grained Japonica type and Nira as a narrow grained Indica form. The difference between the parents was relatively large.

In experiment 1, the 46 sublines varied in spikelet breadth from 2.73 mm. to 3.37 mm. Several of the sublines were essentially as narrow as Nira, but none approached the breadth of Colusa. However, the range among the 46 sublines in spikelet breadth was appreciable.

In experiment 2, the 46 sublines varied in spikelet breadth from 2.94 mm. to 3.41 mm. In this experiment none of the sublines was

[1]Fifty-seventh Annual Progress Report, Rice Experiment Station, Crowley, Louisiana, 1965, p. 11.

Table 13. Average spikelet breadth in mm. for the 23 pairs of subline lots and the parents in experiment 1

Line number or parents	Early sublines	Late sublines
1	3.20	3.31
2	2.94	2.91
3	3.12	3.22
4	3.37	3.33
5	3.03	3.06
6	3.36	3.34
7	3.00	3.05
8	3.17	3.15
9	3.37	3.28
10	2.99	3.01
11	3.31	3.33
12	2.73	2.80
13	3.35	3.29
14	2.98	2.99
15	3.11	3.19
16	3.15	3.08
17	3.11	3.00
18	2.97	2.91
19	3.21	3.23
20	3.23	3.24
21	3.25	3.31
22	3.07	3.12
23	3.05	3.14
Colusa	3.70	
Nira		2.72

Table 14. Average spikelet breadth in mm. for the 23 pairs of subline lots and the parents in experiment 2.

Line number or parents	Short sublines	Tall sublines
1	3.05	3.11
2	3.04	3.13
3	3.15	3.09
4	3.15	3.15
5	2.98	2.94
6	3.37	3.41
7	3.10	3.11
8	3.03	3.05
9	3.13	3.19
10	3.00	3.00
11	3.18	3.16
12	3.08	3.10
13	3.07	3.12
14	3.32	3.33
15	2.95	3.03
16	2.96	2.96
17	3.18	3.14
18	3.18	3.41
19	3.21	3.32
20	3.19	3.40
21	3.10	3.11
22	3.04	3.06
23	3.06	3.13
Colusa	3.74	
Nira		2.70

as narrow as Nira or as broad as Colusa. However, the range among the sublines large enough to represent appreciable genetic variability in spikelet breadth.

Analysis of variance showed significant differences among the lines in each experiment (Table 15).

Table 15. Variance analyses of spikelet breadth in experiments 1 and 2.

Sources of variation	Degrees of freedom	Mean squares (Exp. 1)	F-values (Exp. 1)	Mean squares (Exp. 2)	F-values (Exp. 2)
Total	183				
Among lines	22	0.1972	52.31**	0.1089	45.38**
Between sub-lines	1	0.0035	0.93 n.s.	0.0666	27.75**
Lines x sub-lines	22	0.0081	2.15*	0.0105	4.38**
Error	138	0.00377		0.0024	

For experiment 1, the correlation coefficient between yield of grain and breadth of spikelet was a very low, non-significant value of +0.013, indicating no association. However, in experiment 2, the correlation coefficient between these traits was a significant value of -0.300. This suggests that in experiment 2, high yield was associated with narrow grain types. This association is not in the direction that would be expected. The higher yielding parent, Colusa, had broad grains.

In view of all data from the 2 experiments and the nature of the characters in parents, it is concluded that there was probably no real association between yield of grain and breadth of spikelet.

SUMMARY

Two field experiments were carried out in order to determine association of grain yield with date of maturity and height of plant. Some evidence was also obtained on the relationship of yield to spikelet length and breadth.

Experiment 1 consisted of 23 pairs of subline strains derived from 23 F_3 lines segregating for date of maturity in a cross between 2 rice varieties, Colusa and Nira. The parents were also included as controls. In each pair of strains, one member was made up by bulking seed from at least 5 early maturing plants of an F_3 line. The other was made up from bulked seed of at least 5 late maturing plants of the same line.

Variance analyses in experiment 1 showed significant differences among lines, between subline strains within lines and a significant lines x sublines interaction in respect to date of maturity as well as in grain yield.

In 20 of the 23 lines of experiment 1, the subline strain formed from early maturing F_3 plants was found to be significantly earlier in maturity than its counterpart formed from late maturing F_3 plants of the same line. In 13 of these 20 lines, the early maturing subline strain significantly outyielded its late counterpart. Furthermore, in 6 of the other 7 lines the early subline strain produced a numerically higher yield than its late counterpart, although the difference was not statiscally significant. The correlation coefficient between time of

maturity and yield among the 46 early and late subline strains as a whole was -0.650, a significant value. The results provided strong evidence that in the corss of Colusa x Nira high yielding ability was associated with early maturity.

Experiment 2 consisted of 23 pairs of subline strains derived from 23 F_3 lines which were segregating for height of plant. As in experiment 1, the F_3 lines of experiment 2 came from the Colusa x Nira cross and the parents were included in the experiment as controls. The strains of experiment 2 were formed in the same manner as those in experiment 1 except that selection of F_3 plants for use in forming the strains was based on plant height instead of date of maturity.

In experiment 2, variance analysis showed significant differences among lines and between subline strains within lines in height of plant. In grain yield there was evidence of significant differences among lines but the difference between sublines within lines was not signficant.

The presumably short subline strain in 19 of 23 lines in experiment 2 was significantly shorter in height of plant than its presumably tall counterpart. In 8 of these 19 lines, the short subline strain yielded numerically more than its tall counterpart, while in the other 11 lines the short subline strain yielded numerically less than its tall counterpart. The correlation coefficient between height of plant and yield of grain among the 46 short and tall subline strains was +0.127, a low and non-significant value. It is obvious that there was no evidence that high yield was associated with either short or tall plant stature.

The correlation coefficients between spikelet length and grain yield in the 2 experiments among all subline strains were non-significant values, -0.038 and -0.008, although the sublines were significantly different in spikelet length in both experiments.

The correlation coefficients between spikelet breadth and grain yield in the 2 experiments among all sublines were +0.013 and -0.300. The latter one was significant; however, the association between the two traits was not in the direction which would have been expected. It appeared doubtful that any real association occurred between breadth of spikelet and yield of grain.

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VITA

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He entered the Taiwan Provincial College of Agriculture, Taiwan, China, where he graduated in Agronomy in July 1952. After one year's service in the Chinese Army, 1952-1953, he has been employed by the Taiwan Agricultural Research Institute, Taiwan, China. In 1959, he was sent to the National Institute of Genetics, Japan, for one year under the fellowship offered by the International Atomic Energy Agency. In May 1963, he joined his research work with the International Rice Research Institute, the Philippines, as a research scholar. At the same time he enrolled at the University of the Philippines for graduate study.

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EXAMINATION AND THESIS REPORT

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Major Field: Agronomy

Title of Thesis: Association Between Grain Yield and Several Other Plant Characteristics In Rice

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