Significance of Grain/Straw Ratio in Rice Breeding

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In the breeding works aiming at high yielding varieties, there are three important factors to be taken into consideration for the strain selection procedure. The first one is to find out what plant character should be taken up as an essential criterion for the selection under the existing environment from the crop-ecological standpoint. Secondly, the character must be genetically stable, and thirdly, the character must easily be measured.

The author had engaged for many years in the rice breeding work in Kanto district (central part of Japan), and during that period he had made a number of investigations to identify a critical plant character to be used in the selection for high yields. As a result, grain/straw ratio was found to be the character which can satisfy the three requirements mentioned above in this district*. The present paper attempts to prove the rationality of selecting rice strains by means of grain/straw ratio, based on the crop-ecological investigation and genetical study.

Crop-ecological study on grain/straw ratio of rice varieties

The experiment was designed on the following hypothesis related to the plant type of rice best suited to Kanto district.

Low productivity of rice in Kanto district is attributable to the less amount of solar radiation during ripening period against the comparatively vigorous vegetative growth until heading which often causes a luxuriant growth of plant. In other words, the rice grown in this district has a small value of I at the ripening period in the formula $I=I_0e^{-KF}$ presented by Monji et al.

Where I : Intensity of light after it passed through the leaf layer
I_0: Incident light intensity
F : Total leaf area
K: Light transmission coefficient

The small value of I at the ripening period implies that lower leaves of plant population are being exposed to a lower light intensity due to the luxuriant increase of leaf area, resulting in a reduced net carbon assimilation during the ripening period, and consequently a reduced ratio of grain to straw. Therefore, under such conditions as in Kanto, a large value of I is required for high yields, and this can be attained by reducing values of F and K. A rice variety with small leaf area shows less vigorous vegetative growth and smaller straw weight. Besides, small and erect leaves are desirable to make K small. Rice plants of such plant type have generally short culm and less vegetative growth, and consequently smaller straw weight.

On the other hand, however, there is a general tendency that varieties with less vegetative growth are apt to be small in

* This study was undertaken during the period from 1954 to 1960 when the author was working as a rice breeder in the Kanto-Tozan Agricultural Experiment Station (now renamed Central Agricultural Experiment Station), Konosu.

Table 1. Coefficients of rank correlation between grain yield and other characters by varieties (by Spearman's method)

	Year	1954					1955					2 years pooled
	Place	K	KS	S	T	4 places pooled	K	KS	S	T	4 places pooled	
Grain yield	—Grain/straw ratio	0.67*	0.72*	0.83*	0.40*	0.77**	0.25	0.55*	0.79*	0.70*	0.66*	0.70*
〃	—Stem length	−0.45*	−0.44*	−0.56*	−0.24	−0.48*	0.25	−0.22	−0.23	−0.40*	−0.24	−0.43
〃	—Number of tillers	−0.48	0.14	0.26	0.15	−0.11	0.38*	−0.23	0.25	0.01	0.06	−0.04
〃	—Total weight	0.46*	0.18	0.23	0.55*	0.18	0.61*	0.56*	0.13	−0.37*	−0.29	−0.02
〃	—Straw weight	−0.15	−0.25	−0.56*	0.24	−0.51*	0.29	−0.54*	−0.60*	−0.49*	−0.55*	−0.21

Note: K: Dry paddy field
KS: Semi-wet paddy field
S: Wet paddy field
T: Fertile wet paddy field

grain weight. Therefore, it is necessary to break this correlation in order to develop a plant type with large grain weight and less vegetative growth, that is, with high grain/straw ratio. Such a plant type might be best suited to Kanto district. Several results to verify the hypothesis were obtained by crop-ecological experiments as follows.

(1) In Kanto district the correlation between grain yield and grain/straw ratio by rice varieties is found to be always high. This phenomenon is more conspicuous in wet paddy field than in dry paddy field (Table 1). The past rice varieties grown in the district have long culms and low grain/straw ratio, whereas the ones presently grown have short culms, high grain/straw ratio and are high yielding (Fig. 1).

(2) Varieties with high grain/straw ratio give high rate of yield increase under heavy fertilization. Degree of grain/straw ratio seems to indicate the degree of nitrogen response.

(3) Relationship between vegetable growth and grain yield is given in Fig. 2. Grain yields plotted against the straw weight exhibited a symmetrical curve with a single peak. When vegetative growth is extremely small, the grain yield is also very low. With the increase of vegetative growth, grain yield also increases, reaching a peak at a certain point of straw weight, and the further increase in straw weight beyond that point results in decrease of yield.

(4) Therefore, from the standpoint of the relationship between environmental conditions and suitable varieties, it can be said that under the condition where vegetative growth is a limiting factor to the yield, varieties with large vegetative growth are suited to that condition, whereas under the condition where luxuriant growth tends to occur, varieties with high grain/straw ratio are best suited to that condition. In order to prove it, data of the performance tests at the rice breeding centers throughout the country are compiled. The result was as follows:

In case when plants were more or less luxuriant in growth and a total of sunshine hours in the ripening period (during 30 days after heading) was small, high correlations between yield and grain/straw ratio were observed (Fig. 3), indicating the suitability of varieties with high grain/straw ratio to that condition. On the contrary, when plant growth was not luxuriant and a total of sunshine hours at the ripening period was large, high correlations were found between the yield and straw weight, showing that variety with large straw weight is better (Fig. 4).

(5) To clarify further the relation between general environment with special reference to solar radiation and adaptability of rice varieties, several varieties with different grain/straw ratios were grown under limited solar radiation which was experimentally

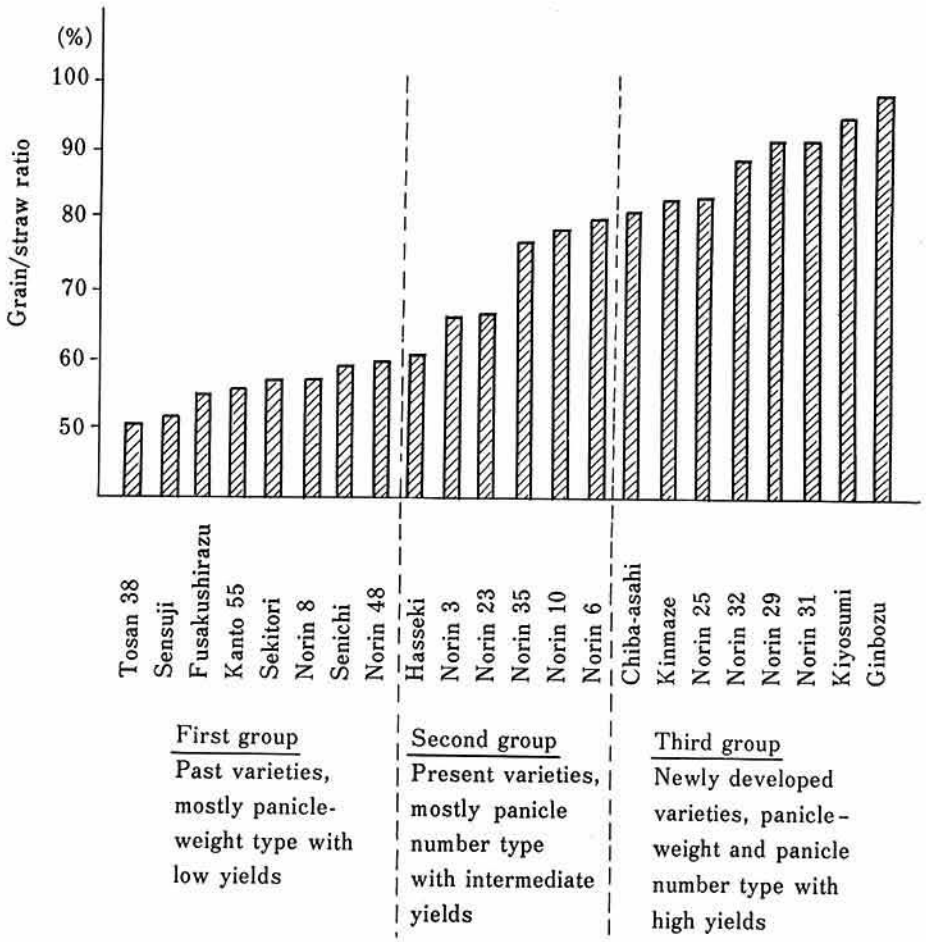


Fig. 1. Classification of varieties by grain/straw ratio

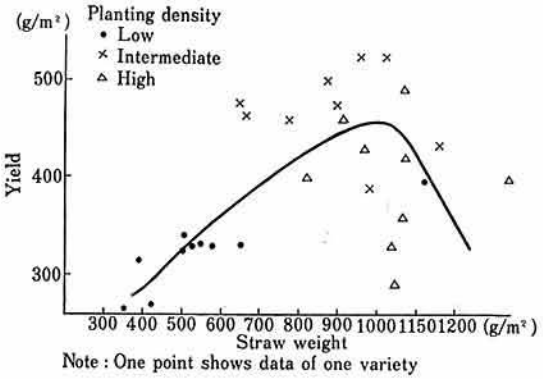
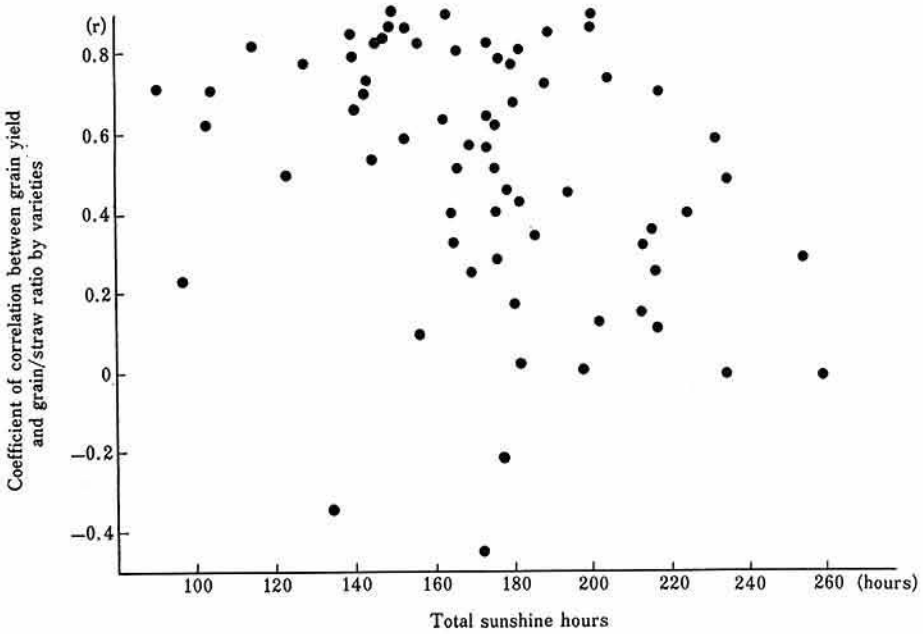
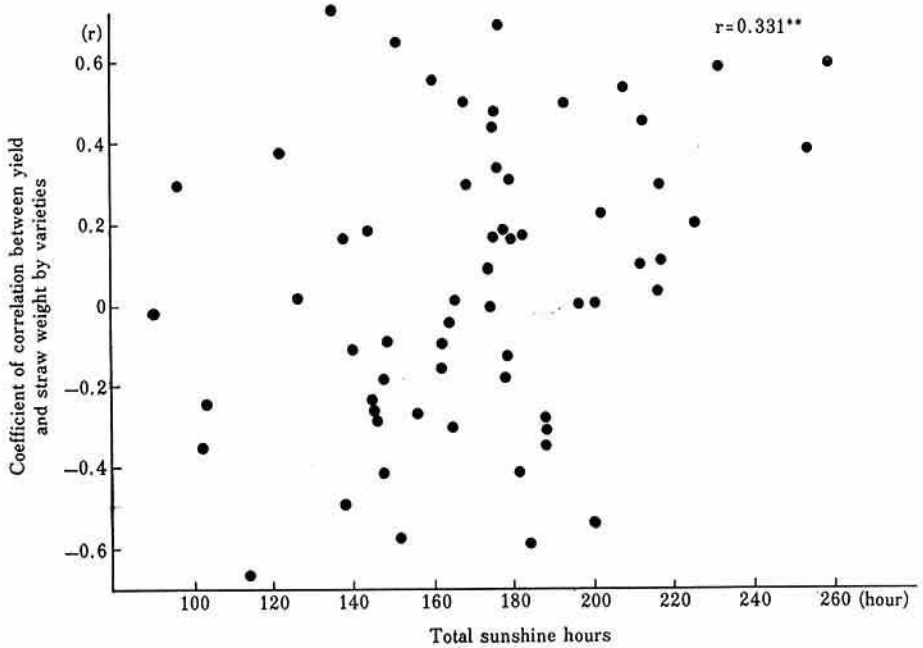


Fig. 2. Relationship between yield and straw weight under different planting densities by varieties



Note: One dot represents a result of performance test at one place.

Fig. 3. Coefficient of correlation between yield and grain/straw ratio by varieties as related to total sunshine hours at the ripening stage (during 30 days after heading).

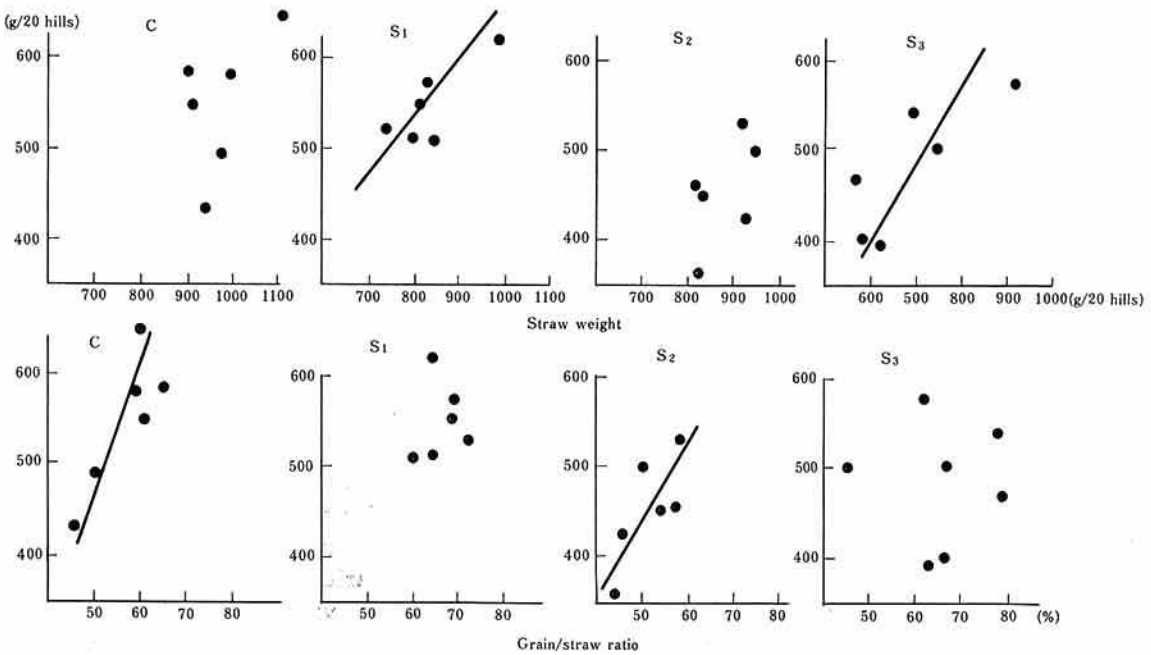


Note: One dot represents a result of performance test at one place.

Fig. 4. Coefficient of correlation between yield and straw weight by varieties as related to total sunshine hours at the ripening stage (during 30 days after heading).

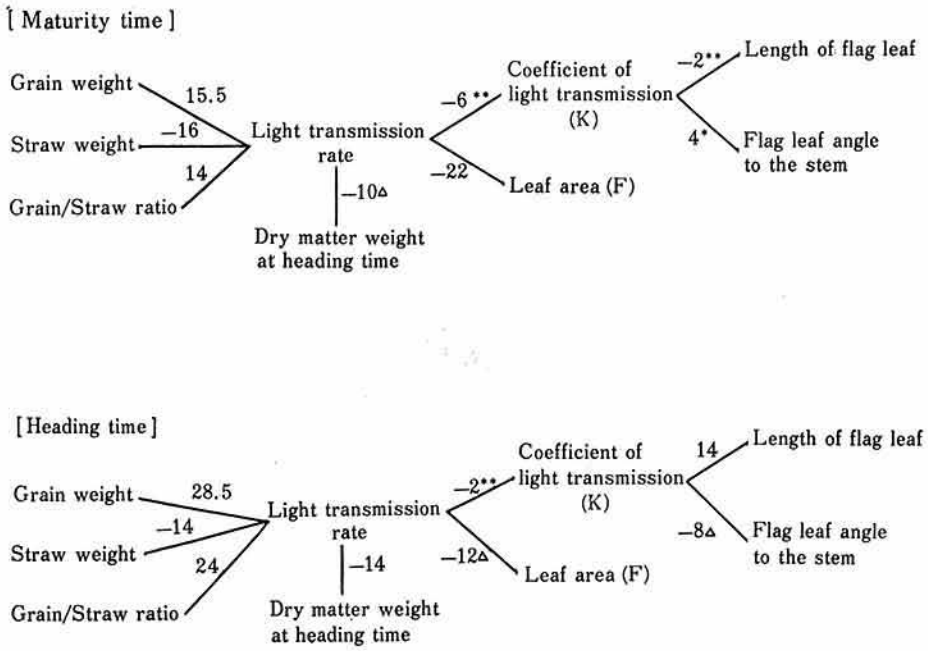
controlled at different growth stages. The result showed that the correlation between yield and straw weight was high when the solar radiation was limited at the vegetative growth stage, whereas correlation between yield and grain/straw ratio was high when solar radiation was limited at the ripening stage (Fig. 5). In other words, the suitability of varieties depends upon the difference in solar radiation received at different growth stages. This result indicates that in a district like Kanto where plants tend to grow luxuriantly and solar radiation is usually less at the ripening stage, an ideal plant type must be the one with less vegetative growth and high grain/straw ratio. However, even in this district when the solar radiation was happened to be limited at the vegetative growth period varieties with large straw weight are desirable.

(6) The following results were obtained as to the relationships between light transmission rate and straw weight, grain/straw ratio, and plant characters like leaf area and the leaf angle to the stem. The higher the light transmission rate at the ripening stage was, the higher the yield and grain/straw ratio. The smaller the leaf area at the heading stage, and the better the plant structure in receiving sun light at the heading and ripening stages, (in other words, the smaller the K is,) the higher the light transmission rate at the ripening stage (Fig. 6). In the case of the varieties with short culms and higher grain/straw ratio, the role of lower leaves was more important in increasing dry matter weight at the ripening stage as compared to the varieties with low grain/straw ratio. (This was proved by cutting lower leaves experimentally at the heading



Note:
C — Control under natural solar radiation
S1 — Shaded by screen cloth from 15 days after transplanting to heading
S2 — Shaded by screen cloth from heading to maturity
S3 — Shaded by screen cloth from 15 days after transplanting to maturity

Fig. 5 Relationship between grain yield and straw weight or grain/straw ratio under experimentally limited solar radiation



Notes : (1) Numbers in the figure show sum of square of rank difference between two characters by varieties

(2) △ Significant at 20% level

* Significant at 10% level

** Significant at 5% level

Fig. 6. Relationship between light transmission rate and other characters by varieties.

stage). Therefore, varieties with higher grain/straw ratio manifested a large amount of carbon assimilation even under the adverse condition of low intensity of solar radiation at the ripening stage.

These results verified the author's hypothesis that rice varieties with higher light transmission rate at the ripening stage would be well fitted to the environmental condition of Kanto district where plant growth is often luxuriant in relation to the low solar radiation during ripening stage, and that such character would give a favorable influence on the grain/straw ratio.

Genetic study of gain/straw ratio of rice varieties

It is a fact generally accepted that in the selection of strains the yield itself is low in heritability and unstable. In practices of breeding work it is important to seek characters which have high heritability and high genetic correlation with yield. Such characters had not been found so far in rice. However the following points were clarified from the investigation on grain/straw ratio of rice varieties.

(1) By the investigation conducted on the existing varieties it was confirmed that the heritability value of grain/straw ratio was lower than that of stem length, but higher than those of the grain yield, the total weight, the panicle length and of the number of panicles (Table 2). The study also confirmed the stability of grain/straw ratio as a genetic character.

(2) The investigation made by using F_3

Table 2. Heritability values of each characters estimated by varieties

Year	1954		1955	
Place	K	S	K	S
Grain yield	60.5%	68.9	42.8	56.6
Grain/straw ratio	82.0	78.9	62.5	77.4
Stem length	94.6	85.4	91.0	96.2
Total weight	75.2	51.9	43.1	37.7
Number of panicles	58.3	44.8	48.2	30.4

Note: K—Dry paddy field
S—Wet paddy field

Table 3. Heritability values of each characters of rice estimated at F_3 and F_5

Generation	Stem length	Panicle length	Number of panicles	Total weight	Grain yield	Grain/straw ratio
F_3	0.70	0.74	0.48	0.47	0.50	0.85
F_5	0.85	0.84	0.69	0.41	0.56	0.88

and F_5 strains of hybrids also proved higher heritability of grain/straw ratio and lower heritability of grain yield, total weight and number of panicles (Table 3). The reason for the higher heritability of grain/straw ratio than that of yield may be attributed to the fact that grain/straw ratio represents the plant type related to the proportion of grain yield to vegetative growth. It is known that in general plant type is a character which does not usually show changes in relation to year and place of cultivation. This seems to be one of the reasons why plant breeders have long been placing emphasis on plant types in selecting high yielding strains. In addition, the grain/straw ratio is a character which has a high genetic correlation with the grain yield (Table 4, Table 5). Consequently, grain/straw ratio can be regarded as an important character in strain selection for breeding high yielding variety.

(3) An experiment designed to compare the efficiency of two different methods of

Table 4. Phenotypic and genetic correlations between characters in F_3 strains

		Stem length	Panicle length	Number of panicles	Total weight	Grain yield	Grain/straw ratio
Stem length	Phe. corr.	1.000	0.150	0.143	0.606**	0.385**	0.214
	Gen. corr.	1.000	0.229	0.061	0.753	0.435	0.228
Panicle length	Phe. corr.		1.000	0.238	0.086	0.653	0.665**
	Gen. corr.		1.000	0.342	0.016	0.885	0.780
Number of panicles	Phe. corr.			1.000	0.548**	0.326*	0.231
	Gen. corr.			1.000	0.394	0.025	0.360
Total weight	Phe. corr.				1.000	0.600**	0.404**
	Gen. corr.				1.000	0.300	0.574
Grain yield	Phe. corr.					1.000	0.480**
	Gen. corr.					1.000	0.606
Grain/straw ratio	Phe. corr.						1.000
	Gen. corr.						1.000

Table 5. Phenotypic and genetic correlations between characters in F_5 strains

		Stem length	Panicle length	Number of panicles	Total weight	Grain yield	Straw weight	Grain/straw ratio
Stem length	Phe. corr.	1.000	−0.058	0.097	0.524**	0.022	0.500**	−0.380**
	Gen. corr.	1.000	−0.081	0.114	0.731	−0.078	0.571	−0.444
Panicle length	Phe. corr.		1.000	−0.505**	−0.127	0.335**	−0.311*	0.411**
	Gen. corr.		1.000	−0.630	−0.285	0.426	−0.413	0.469
Number of panicles	Phe. corr.			1.000	0.431**	−0.059	0.457**	−0.375**
	Gen. corr.			1.000	0.340	−0.446	0.462	−0.495
Total weight	Phe. corr.				1.000	0.253	0.843**	−0.512**
	Gen. corr.				1.000	−0.335	0.891	−0.748
Grain yield	Phe. corr.					1.000	−0.307*	0.696**
	Gen. corr.					1.000	−0.726	0.871
Straw weight	Phe. corr.						1.000	−0.890**
	Gen. corr.						1.000	−0.966
Grain/straw ratio	Phe. corr.							1.000
	Gen. corr.							1.000

selection was conducted during F_3–F_5 of hybrid generation. The first method was a direct selection for yield and the second one was an indirect selection for yield by mean of grain/straw ratio. In this experiment, correlation coefficient between yield of the preceding generation and that of the following generation was compared with correlation coefficient between grain/straw ratio of the preceding generation and the yield of the following generation.

The result showed that the efficiency of the indirect selection was greater than that of the direct selection conducted at F_3–F_4 generation, and no difference was found between these two selections at F_4–F_5 generation (Table 6). The result justified that, in breeding for high yielding, strain selection should be made to obtain higher grain/straw ratio at an early generation. In the case of strains obtained without repetition in the actual strain selection, there appears greater difference between the heritability of grain/straw ratio and that of yield (Table 7), and the heritability of yield is extremely lowered. This fact shows the importance of grain/straw ratio when selecting high yielding strains in the case of strain planted without repetition for the purpose of practical varietal improvement. The above was the fact proved from the standpoint of statistic genetics.

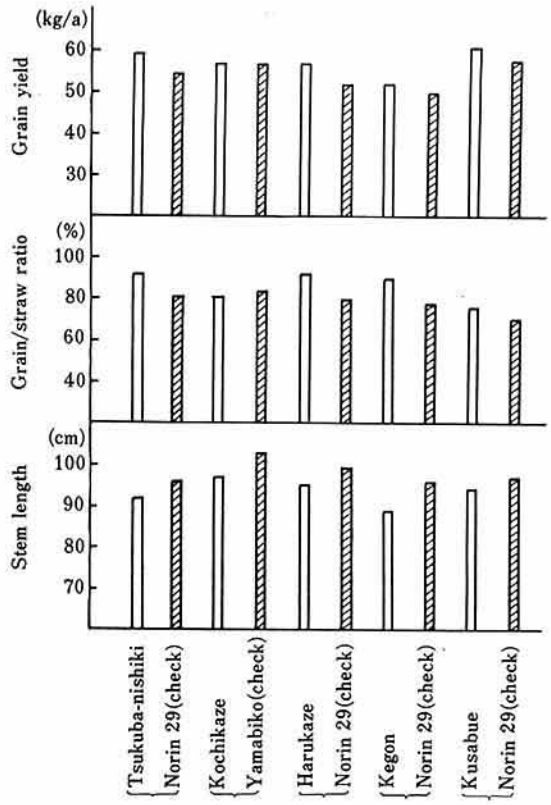
Table 6. Coefficient of correlation between F_3 characters and F_4 grain yield, and that between F_4 characters and F_5 grain yield

	F_3L*–F_4GL*	F_4L–F_5GL
Grain yield–grain yield	0.298*	0.356**
Grain/straw ratio–grain yield	0.483**	0.359**

Note: L shows strain, GL shows family

Table 7. Heritability values, with and without repetition, estimated with F_3 strains and F_5 families

	Heritability value with repetition		Heritability value without repetition	
	Grain yield	Grain/straw ratio	Grain yield	Grain/straw ratio
F_3 strain	0.50	0.85	0.25	0.65
F_5 family	0.56	0.88	0.24	0.65



Note: ☐ new variety, ▨ check variety

Fig. 7 Three characters of newly developed varieties as compared to check varieties.

Conclusion

All the results mentioned above furnished a clear evidence for the rationality of selecting strains on the basis of grain/straw ratio in improving rice varieties. One of the reasons why statistic genetics has rarely been applied in the actual breeding work may be due to the fact that the statistic genetics deals with analytical research mainly on individual character, and not enough analysis was made on plant type like grain/straw ratio, which has high genetic stability as well as important meaning in crop ecology, though plant breeders have been paying much attention to it based on their practical experiences.

The present study suggests that it is most desirable to identify a major plant character which can be most effective in selecting suitable varieties under a given environmental condition, based on crop-ecological and genetic research.

In this sense, the present study gives an example of an application of statistic genetics on the actual selection work of rice strains by combining breeding work and the science of genetics.

As a result of practical application of the present study, five new rice varieties were bred by the author since 1953. They had higher grain/straw ratio and higher grain yield than the check varieties in most cases (Fig. 7). These records again confirmed the effectiveness of selection for higher grain/straw ratio in the breeding of high yielding varieties of Kanto district.

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