Directional Change of Quantitative Characters in Trisomics

Studies on the Trisomics in Rice Plants (*Oryza sativa* L.) II.

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Changes of six quantitative characters in the trisomic rice plants identified by the morphological features were studied by the principal component analysis. The application of this analysis proved to be effective in grouping the respective single trisomics, double trisomics and disomics. Lines identified as different types of the trisomics composed different groups in the scatter diagram allowing a little overlapping. Disomic plants segregated from the progenies of trisomics, which had been derived from four different cultivars, tended to form different groups, showing the difference in their genetic backgrounds.

Some types of double trisomics under investigation demonstrated to have been typically changed to the direction synthesized by the characters of two single trisomics with respective chromosomes. This fact indicates that the addition of an extra chromosome has an independent specific effect on the expression of characters not only of single but also of double trisomic plants.

Introduction

Although trisomics in rice plants (*Oryza sativa* L.) have been reported by many workers (ICHIJIMA 1934, KATAYAMA 1963, NAKAMORI 1949, NISHIMURA 1961, YUNOKI and MASUYAMA 1945 and WATANABE *et al.* 1969), a complete set of primary trisomics—there should be twelve types corresponding to each of twelve chromosomes—has not been established.

In 1968, HU classified 98 trisomic lines of an *indica* cultivar into twelve types based on morphological features. More recently, IWATA, OMURA and NAKAGAHRA (1970) classified trisomic plants obtained from *japonica* cultivars into twelve types primarily by observing quantitative as well as qualitative characters. They confirmed the results cytogenetically by crossing their trisomics with reciprocal translocation lines and also genetically by observing mode of segregation for some marker genes. WATANABE and KOGA (1975) reported another new trisomic series obtained from a *japonica* cultivar, Norin 8.

In the present study, the principal component analysis was adopted for characterization of trisomic rice plants. Attention was focused on 1) whether or not twelve morphological types of trisomics are discriminated each other by this method, 2) how specifically characteristics of double trisomics shift from original single trisomic or disomic plants.

Materials and Methods

Trisomics used in the present study were obtained from the progenies of triploids

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originated in four different Japanese cultivars, Aikoku, Asakaze, Benisengoku and Norin 39. One of the triploid plants was artificially established by crossing diploid with tetraploid Aikoku (KOGA *et al.* 1967), and the others were spontaneous triploids found in fields.

Twelve types of trisomics were designated as follows: A (*Pale*), B (*Awned*), C (*Small grain*), D (*Erectoides*), E (*Spreading*), F (*Rolled leaf*), H (*Large grain*), I (*Late heading*), J (*Spotted leaves*), K (*Pseudonormal*), and L (*Short panicle*). Their characteristics are given in Table 1. The L type obtained from one of the progenies of the hybrid between reciprocal translocation lines was not used in the present experiment.

The following six quantitative characters were observed at maturity: culm length, panicle length, number of spikelet per panicle, length and width of spikelet, and seed fertility. The mean values of five trisomic or three disomics which segregated from single and double trisomic lines were used for analysis.

Table 1. Type and characteristics of trisomics compared with diploid and identification of extra chromosome

Type	Characteristics used in principal component analysis	Characteristics excluded from principal component analysis	Extra chromosome	Linkage group
A	Slightly short in height, long spikelets, fertile	Pale green leaves at heading stage		
B	Low fertility	Relatively coarse culm and leaves, somewhat rough and lax panicle, awned spikelet	6	I
C	Small grain	Fine stature, more or less bushy, bent uppermost internode		
D	Short grain	Dark green and wide leaves, erect and dark brown panicle		
E	Narrow grain	Slightly long and narrow leaves, drooped leaf blades, opening tiller	11	II
F	Long and narrow grain, low fertility	Semi-rolled leaves, imperfect panicle emergence	10	IV
G	Fertile	Somewhat dark green leaves, late heading, a little coarse and bright yellowish grain, easy threshing	9	VIII
H	Slightly short in height, large grain, fertile	Dark green leaves, horizontal stretch of flag-leaves, more or less imperfect panicle emergence	1	VII
I	Short in height	Very late heading		
J	Normal characteristics like as disomics	Fine stature, brownish discoloration of culm, appearance of brown leaf spots in adult stage		
K	Normal characteristics like as disomics	Somewhat late heading		
L*	Slightly short in height, short panicle, small grain		2	VI

Abbr.: Type A : Pale, B : Awned, C : Small grain, D : Erectoides, E : Spreading, F : Rolled leaf, G : Coarse, H : Large grain, I : Late heading, J : Spotted leaves, K : Pseudo-normal, L : Short panicle

* : L type was not computed in the present study, but it has a specific characteristics compared with the other trisomic types.

Table 2. Mean value of six characters in single trisomics, double trisomics and disomics used in the principal component analysis

C. N.	Variety	Chromosomal type*	Culm length (cm)	Panicle length (cm)	Number of spikelets per panicles	Fertility of seed (%)	spikelet length (mm)	Spikelet width (mm)
An 1	Aikoku	Tri. (A)	65.2	17.9	91.9	90.1	8.26	3.47
		Dis.	90.7	20.2	149.8	92.2	7.45	3.67
An 2	"	Tri. (B)	77.8	18.9	94.1	67.8	7.99	3.56
		Dis.	98.3	19.1	135.0	89.5	7.48	3.60
An 4	"	Tri. (B)	81.4	16.7	90.7	66.6	7.49	3.34
		Dis.	105.7	18.6	143.2	95.5	7.17	3.44
An 5	"	Tri. (C)	81.0	17.1	90.7	72.2	7.16	3.19
An 6	"	Tri. (G)	95.0	19.8	119.8	86.0	8.14	3.44
An 7	"	Tri. (I)	64.0	16.3	102.3	66.6	7.59	3.47
		Dis.	94.0	19.3	126.1	84.6	7.50	3.63
An 8	"	Tri. (C)	78.6	16.3	78.0	75.4	6.91	3.06
		Dis.	102.7	18.6	120.0	94.6	7.12	3.49
An 9	"	Tri. (J)	78.0	18.8	96.0	67.9	7.14	3.45
		Dis.	89.3	19.3	126.5	90.0	7.27	3.48
An 10	"	Tri. (F)	68.0	17.1	82.3	58.0	7.61	3.40
		Dis.	89.7	21.1	132.7	88.3	7.40	4.02
An 11	"	Tri. (F)	66.4	16.9	89.1	62.9	7.72	3.15
		Dis.	88.3	19.4	135.4	88.8	7.59	3.76
An 13	"	Tri. (D)	78.7	15.5	95.1	76.2	6.75	3.71
		Dis.	92.3	19.1	135.6	94.1	7.46	3.79
An 16	"	Tri. (C)	79.0	17.1	100.3	68.2	6.92	3.11
		Dis.	103.3	17.9	130.7	93.1	7.32	3.79
An 19	"	Tri. (D)	86.0	16.2	105.9	75.3	6.59	3.84
		Dis.	97.7	19.3	139.1	96.2	7.37	3.94
An 20	"	Tri. (D)	87.0	15.9	97.7	75.8	6.63	3.90
		Dis.	101.0	19.3	156.8	93.0	7.25	3.92
An 21	"	Tri. (D)	82.0	16.7	109.6	80.5	6.57	3.78
		Dis.	92.3	17.6	115.2	76.1	7.20	3.90
An 48	"	Tri. (K)	102.0	18.7	131.8	87.3	7.39	3.51
		Tri. (D)	92.2	17.4	122.9	77.2	6.54	3.65
		D. Tri. (K+D)	91.3	16.3	110.3	27.6	6.70	3.58
		Dis.	98.7	20.1	150.4	94.7	7.27	3.71
An 23	Norin 39	Tri. (A)	68.2	19.2	98.3	92.7	8.38	3.44
		Tri. (G)	85.7	20.9	132.0	94.0	8.22	3.72
		D. Tri. (A+G)	63.3	19.6	90.8	44.1	8.77	3.40
		Dis.	90.7	21.5	144.1	95.0	7.77	3.72
An 30	"	Tri. (E)	76.6	20.3	104.3	73.5	7.87	3.43
		Tri. (G)	88.2	21.2	141.6	92.6	8.03	3.72
		D. Tri. (E+G)	83.0	19.9	116.8	35.6	8.12	3.37
		Dis.	90.3	20.6	123.1	96.0	7.86	3.79
An 42	"	Tri. (C)	70.6	18.6	84.9	85.3	7.57	3.42
		Dis.	87.3	17.7	109.0	91.9	7.77	3.97
An 25	Benisengoku	Tri. (D)	69.0	14.9	83.3	76.9	6.92	3.64
		Dis.	78.0	18.0	121.6	95.4	7.47	3.80
An 28	"	Tri. (H)	61.2	18.5	111.3	75.7	8.01	3.98
		Dis.	80.7	18.2	118.2	70.2	7.44	3.76
An 29	"	Tri. (D)	66.0	15.0	76.9	73.5	7.01	3.85
		Dis.	94.0	17.9	120.2	93.3	7.45	3.88
An 32	Asakaze	Tri. (G)	65.0	22.9	151.7	92.9	7.85	3.70
		Tri. (H)	61.5	21.4	122.7	92.9	8.11	3.99
		Dis.	86.7	21.4	143.0	94.0	7.50	3.94
An 33	"	Tri. (B)	71.6	20.0	84.4	27.0	8.11	3.68
		Dis.	94.0	21.9	131.1	96.5	7.75	3.81
An 37	"	Tri. (E)	77.5	19.0	120.6	71.4	7.46	3.37
		Tri. (A)	61.4	18.4	96.0	84.7	7.94	3.47
		D. Tri. (E+A)	65.5	18.2	82.3	23.4	8.01	3.11
		Dis.	82.3	20.3	144.4	92.4	7.30	3.57
An 39	"	Tri. (G)	80.5	21.5	131.4	89.1	8.06	3.51
		Tri. (E)	78.2	18.8	86.0	70.6	7.84	3.50
		D. Tri. (G+E)	76.0	20.4	112.0	39.8	8.16	3.36
		Dis.	88.0	20.9	128.0	95.3	7.67	3.69
An 40	"	Tri. (H)	71.4	20.5	101.2	91.4	8.37	3.99
		Dis.	91.7	20.8	122.3	95.5	7.86	3.65
An 41	"	Tri. (G)	70.0	22.5	134.2	94.5	7.82	3.76
		Tri. (A)	58.7	18.0	85.2	78.6	7.96	3.51
		D. Tri. (G+A)	52.0	19.1	81.9	21.5	8.28	3.47
		Dis.	79.0	20.5	132.8	95.3	7.49	3.99
An 44	"	Tri. (F)	70.4	20.8	120.3	59.1	7.99	3.27
		Dis.	89.3	21.3	137.4	92.6	7.56	3.70
An 45	"	Tri. (G)	92.2	21.2	137.6	90.8	8.17	3.60
		Tri. (E)	86.5	20.3	117.5	64.6	7.84	3.38
		D. Tri. (G+E)	83.7	20.3	121.1	34.4	8.04	3.34
		Dis.	97.0	21.8	144.1	96.1	7.69	3.66

Note: *, Tri.; Trisomics (Type), Dis.; Disomics, D. Tri.; Double trisomics (Types)

C. N., Cultivated No. of trisomics ($2n=25$) or double trisomics ($2n=26$)

Results

Table 2 shows line means for six characters. The mean values of 73 lines were treated simultaneously in the principal component analysis for explaining the traits of both trisomic and disomic plants.

1. Classification of single trisomics and disomics

The correlation between six characters and principal components are given in Table 3. Eigen values and proportion of cumulative contribution to the total variation are also shown

Table 3. Correlation of six characters and components

Character or item	Principal component				
	1st	2nd	3rd	4th	5th
Culm length	0.753	-0.361	-0.424	-0.165	-0.296
Panicle length	0.631	0.721	-0.114	-0.061	0.172
Number of spikelets per panicle	0.932	0.081	-0.162	-0.147	0.166
Fertility	0.808	-0.123	0.141	0.559	-0.027
Spikelet length	-0.073	0.950	0.086	0.043	-0.272
Spikelet width	0.565	-0.159	0.769	-0.242	-0.068
Eigen value	2.812	1.600	0.838	0.429	0.224
Proportion of total variance	0.469	0.266	0.140	0.071	0.037
Cumulative contribution	0.469	0.735	0.875	0.946	0.984

Fig. 1. Scatter diagram of 66 lines of single trisomics and disomics in the (Z_1 - Z_2) plane
 Z_1 : First principal component
 Z_2 : Second principal component
A-K: Type of single trisomics in Table 1.

for each component in the same table. More than 70 percent of the total variation was attributable to the first and second principal components.

The first component showed high positive correlations with all the characters other than spikelet length. This suggests that the first component represents the size of plants and seed fertility.

The second component was positively correlated with panicle length and spikelet length, and negatively correlated with culm length. This suggests that the second component axis expresses the shape of plants.

Fig. 1 gives a scatter diagram of 66 lines of single trisomics and disomics in the plane defined by the first and

second components. All trisomics were widely scattered. Single trisomic plants belonging to different types tended to form different clusters, although some overlapping occurred.

By contrast, all disomics appear to form a cluster scattered mainly in the first and fourth quadrants. However, when the disomic lines were grouped according to their original cultivars, each reflected differences in genetic background. Lines obtained from Asakaze and Norin 39 had higher values than those from Aikoku and Benisengoku in the second component, and those from Benisengoku had lower values than the others in the first component as shown in Fig. 2. These results suggest that disomics and trisomics can be distinguished on the plane, though four different genetic backgrounds are involved.

It now appears that the trisomic plants, regardless of original cultivars, can be classified into the chromosomal types by adopting principal component analysis using only six quantitative characters. It should be noted that qualitative characters used in the previous studies were not used in the present study.

2. Directional change of characters in trisomics

Double trisomics ($2n=26$) segregate two types of single primary trisomics, disomics and parental double trisomics in the self-fertilized progenies. Fig. 3 shows four chromosomal types, A and G type of trisomics, disomics and their double trisomics scattered by the first and second component scores for self-fertilized progenies of double trisomic lines from Asakaze and Norin 39. These plants were taken randomly from the population of selfed offsprings of the double trisomic lines possessing the extra chromosomes of A and G types. The scatter diagram suggests that the scores of double trisomics are synthesized from those of the composite single trisomics of A and G type.

The above phenomenon was confirmed in other chromosomal types (Fig. 4, 5 and 6). In Fig. 4, three double trisomic plants are proved to have combined values of single trisomics of E and G type, respectively. Fig. 5 shows that the double trisomics possessing the extra chromosome of A and G type gives a similar result. In Fig. 6 the position of the double trisomics of K and D type in the scatter area is shown to have been synthesized by the composite single trisomics.

The above results clearly demonstrate that the plant type of double trisomics is determined by the additive effect of two extra chromosomes. An extra chromosome exerts independently specific effect on the expression of the characters not only of single but also of double trisomics.

Fig. 2. Scatter diagram of each disomics derived from four cultivars in the (Z_1 - Z_2) plane. Ak, Nr, As, and Bs shows disomics segregated from the trisomics of Aikoku, Norin 39, Asakaze and Benisengoku, respectively.

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 3~6. Relationship between disomics ($2n=24$), single trisomics ($2n=25$), and double trisomics ($2n=26$) in scatter diagram in the (Z_1 - Z_2) plane for extra chromosome A and G (Fig. 3), for E and G (Fig. 4), for A and E (Fig. 5), and for D and K (Fig. 6)

● : Disomics, ■▲ : Single trisomics, × : Double trisomics

Each double trisomic plant can thus be clearly classified by the application of the principal component analysis.

Discussion

The trisomic plants, upon their completion, are supposed to be effectively used to assign genes to linkage group. Unfortunately, all of the primary single trisomics in rice plants have not yet completely been identified to both linkage group and respective extra chromosome. The authors, however, had clarified the relationship between extra chromosomes and their linkage groups in six extra chromosomes using reciprocal translocation lines and marker lines as exemplified in Table 1.

Further studies are needed to investigate possible overall relationship existing between cytological changes and morphological features. IWATA *et al.* (1970) reported that the difference of morphological features caused by the addition of an extra chromosome in rice plants was larger than the difference caused by environmental effect and/or by genetic background. The spikelet size in particular showed relatively small environmental variation in the same type of trisomics. The results of the present study agree to the previous one in these respects. More, the expression of the quantitative characters of each type of trisomics differed from that of the disomic plant and shifted toward the directions spe-

cified by the extra chromosomes.

The disomic plants were widely distributed in the scattering area, probably because they were originated in four different *japonica* cultivars. Nevertheless, the present method for classifying trisomics and disomics was sufficiently practical. If the materials obtained from one cultivar are used, the distributing area of each type will be smaller than in the present case.

The change in phenotype of each of the single trisomics had a certain direction specified by an addition of individual extra chromosome. Moreover, each of the double trisomics maintained the characteristics synthesized by the two types of composite single trisomics. It means that phenotypic change in double trisomic plants is expressed as an additive effect of independent single trisomics. The specificity occurred in this additive effect strongly suggests that an extra chromosome independently influenced the metabolism of gene blocks of each bivalent chromosome. This finding together with previous other findings has thus proved that the phenotypic changes of both single and double trisomics occur not only in qualitative but also in quantitative genetic information by the addition of each chromosome.

The principal component analysis had been applied successfully for classification of cultivated rice plants by MORISHIMA *et al.* (1966), of maize by MOCHIZUKI (1968) and of wild rice plants by AKIHAMA and WATABE (1970). In the present case, the principal component analysis was used for characterizing chromosomal types of aneuploid plants, proving its effectiveness to realize the additive influence of chromosome.

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三染色体植物における量的形質の定方向変化

イネの三染色体植物に関する研究(II)

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先に作出し, 分類したイネ三染色体植物は主として質的形質を規準にしたものである。ここでは量的形質の特異的变化を明らかにする目的で, 主成分分析を適用し, その「総合特性」から分類の有効性と二染色体植物からの形質変化の様相を検討した。量的形質としては, 稈長, 穂長, 一穂粒数, 粒長, 粒幅および種子稈実歩合の6形質とした。

まず主成分のうち, 第1, 第2主成分でほとんどの分散が説明できたので, 第1, 第2主成分を軸として散布図を求めた。単純三染色体植物と二染色体植物は, 4つの異なる品種から派生したにもかかわらず, それぞれがかなりまとまった範囲に散布したため, 「総合特性」としての量的形質の変化は単純三染色体植物の種類ごとに特異的に起っていることが明らかとなった。

つぎに, 複三染色体植物とその自殖後代で分離する2種類の単純三染色体と二染色体植物相互の散布範囲を比較した。その結果, 複三染色体植物は2種類の単純三染色体植物が示す形質変化を同時に保有する範囲に散布し, いわば2種類の単純三染色体植物の特徴を合成した総合特性を表現した。

以上から, つぎのように結論される。

- 1) 各単純三染色体植物は二染色体植物とは明らかに区別でき, 単純三染色体植物間でもそれぞれの型ごとに比較的一定の特性を示す。
- 2) 単純三染色体植物の染色体添加は過剰染色体の種類によって特異的な形態形質の変化をもたらす。
- 3) 複数の過剰染色体が添加しても, 各過剰染色体の形質変化に及ぼす特異的な影響力は不変であり, しかも相加的である。