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Citation	Journal of the Faculty of Agriculture, Hokkaido University, 61(1), 73-88
Issue Date	1982-11
Doc URL	http://hdl.handle.net/2115/12973
Type	bulletin (article)
File Information	61(1)_p73-88.pdf

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CLASSIFICATION OF NINETEEN KINDS OF NEAR-ISOGENIC DWARF LINES DUE TO THE CHARACTERS OF INTERNODES

—Genetical studies on rice plant LXXXIV*—

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Received March 17, 1982

Introduction

There are about fifty kinds of dwarf genes described in the various reports[12]. Among them, the genes for semi-dwarf such as d_{47} (Taichung Native 1 dwarf) and d_{49} (Reimei dwarf) are extensively utilized for the breeding of lodging resistance and fertilizer responsive varieties[1,2,3].

In the previous paper[5,10], the junior authors carried out the genic identification by the crossings between dwarf lines and produced the near-isogenic lines by the successive backcrossing procedure. These lines were grown in water culture and the character expressions of the dwarf genes were investigated. In the present paper, the authors examined the similar characters of the nineteen kinds of near-isogenic dwarf lines in the condition under the paddy field and classified them into the four groups according to the demarcation standard which is based on the relation between the compound characters of the internodes.

Materials and Methods

Nineteen kinds of near-isogenic dwarf lines which were produced by the backcrossing method[5,10] were used in the experiment as shown in Table 1. The near-isogenic lines and the recurrent parent, Shiokari were grown in the paddy field in 1979 and 1980. Seeds were sown on May 3rd, 1979

[J. Fac. Agr. Hokkrido Univ., vol. 61, Pt. 1, 1982]

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TABLE 1. List of the near-isogenic dwarf line used in the experiment

No. of isoline	Gene symbol	Name of dwarf type	Dwarf donor	Number of backcrossing times
ID- 1	d_1	Daikoku dwarf	H-86	8
- 2	d_2	Ebisu dwarf	H-85	7
- 3	$d_3 d_4 d_5$ [1]	Tillering dwarf of Bunketsu-waito	H- 2	4
- 6	d_6	Ebisumochi dwarf	H-126	6
- 7	d_7	Cleistogamous dwarf	N- 7	8
-10	d_{10}	Tillering dwarf of Toyohikari-bunwai	N-70	8
-11	d_{11}	Norin 28 dwarf	N-58	6
-12	d_{12}	Yukara dwarf	N-62	5
-13	d_{13}	Short grained dwarf	M-51	5
-14	d_{14}	Tillering dwarf of Kamikawa-bunwai	H-147	7
-17	d_{17}	Slender dwarf	I -71	5
-18h	d_{18}^h [2]	Hosetsu dwarf	N-71	8
-18k	d_{18}^k [2]	Kotake-tamanishiki dwarf	Fl-26	8
-27	d_{27}	Tillering dwarf of Bunketsu-to	Fl-86	6
-30	d_{30}	Waisei-shirasasa dwarf	Fl- 3	5
-35	d_{35}	Tanginbozu dwarf	N-77	7
-47	d_{47}	Taichung Native-1 dwarf	I -120 (IR-8)	4
-51	d_a [3]	M-290 dwarf	M-290	4
-52	d_b [4]	Hiroba dwarf	N-100	4

1) Triplicate genes[8].
2) Multiple allelles in the order of $+ > d_{18}^k > d_{18}^h$ (SHINBASHI *et al.*[9]).
3), 4) Single recessive genes named tentatively.

and April 25th, 1980, respectively. Seedlings grown in the vinyl-house were transplanted to the paddy field on May 31th, 1979 and May 29th, 1980, respectively, with single plant per hill spaced at 30.2 cm × 14.5 cm. The amount of fertilizers were applied with N; 7.2 kg, P_2O_5; 7.2 kg and K_2O; 4.5 kg per 10 a in both years. In the field, the plots were arranged in the order of plant height to prevent mutual shading between lines in two replications. Each plot consisted of three rows and each row contained six plants. Eighteen characters shown in Table 2 were investigated on an individual basis. All of the characters except panicle number, 100 kernel weight and days to heading were measured on the main culm. The length of the fifth internode from the top was less than 10 mm in all of the

TABLE 2. Varince components estimated from the data both in 1979 and 1980, expressed by percentages to the total of variance components

Character	Percentage of variance component due to			
	Lines	Years	L×Y	Error
Panicle length	78.9**	2.1**	13.5**	5.5
Culm length	95.6**	0.9**	1.6**	1.9
1st internode length	89.3**	0.3*	6.0**	4.3
2nd "	93.5**	1.0**	1.6	4.1
3rd "	89.5**	2.2**	0.0	8.4
4th "	61.4**	4.6**	18.3**	15.8
1st leaf sheath length	93.9**	0.0	2.5**	3.6
2nd "	96.1**	0.0	1.1	2.7
3rd "	94.2**	0.7*	0.7	4.5
1st leaf blade length	84.0**	0.1	7.7**	8.1
2nd "	88.5**	5.0**	1.8	4.7
3rd "	85.5**	5.0**	6.3**	3.2
Width of flag leaf	56.6**	24.5**	2.4	16.6
Flag leaf angle	81.1**	0.0	7.7*	11.2
Panicle number[1)]	92.4**	4.9**	1.3**	1.4
Number of spikelets[2)]	91.5**	0.0	4.1**	4.4
100 kernel weight	96.1**	0.0	1.6**	2.3
Days to heading[3)]	75.9**	18.5**	4.7**	0.9

1) Per plant. 2) Per panicle of main culm. 3) Counted from sowing.
*, ** Significant at the 0.05 and 0.01 levels of probability, respectively.

Model of variance analysis

Source	df	Mean square expectation
Lines	l−1	$\sigma^2+ny\kappa_L^2$
Years	y−1	$\sigma^2+nl\kappa_Y^2$
L×Y	(l−1) (y−1)	$\sigma^2+n\kappa_{LY}^2$
Error	ly (n−1)	σ^2

κ_L^2 = variance component due to the lines.
κ_Y^2 = variance component due to the years.
κ_{LY}^2 = variance component due to the interaction between the lines and the years.
σ^2 = error mean square.
l, y, n = number of lines, years and replications, respecvively.

materials. The heading date was recorded when half of the plants in a plot initiated heading. The flag leaf angle was measured about one week before maturity from eight plants of each plot. The 100 kernel weight were sampled from two plants of each plot. The other characters were measured from four plants of the middle row in each plot. The measurement of flag leaf angle of d_{30}-line was omitted, since the fragile leaf collar caused the drooping leaf blade or the lack of leaf blade.

Principal component analysis was made by the use of SPSS (Statistical Package for Social Sciences) program in the Hokkaido University Computing Center.

Results

1. Estimation of variance components

The variance components for the eighteen characters are shown by percentages to the total of variance components in Table 2. The model of variance analysis for the near-isogenic lines and Shiokari is shwon in the foot note of Table 2. The percentages due to the lines were markedly greater than those of other componetnts in all characters, indicating a large variation due to the actions of dwarf genes. The relatively low percentages due to the lines for the fourth internode length and the width of the flag leaf are attributable to the magnitudes of other components such as error and the interaction between lines and years in the former, and error and years in the latter. These facts indicate that the fourth internode length is easily affected by field condition, and the order of the dwarf lines in this character may be altered with years.

2. The characteristics under the field condition

The lengths of panicle, culm, internodes, and leaf sheaths and blades of the near-isogenic lines in 1979 are expressed as percentages to those of Shiokari in Table 3. The panicle lengths of d_2-, d_{12}-, d_{14}-, d_{47}- and d_a-lines were not different significantly with that of Shiokari. Among the nineteen near-isogenic lines, d_{11}-line showed a significant increase from Shiokari. This is caused by the elongation of the lower part of the panicle axis accompanying with the occurrence of the additional neck leaf. It is noticed that the culm length of d^h_{18}-line was the shortest and d_1-line followed. On the contrary, d_7-line and d_{30}-line showed relatively long culm lengths, 87% and 79% respectively, and the other lines ranged from 41% to 64%. The first internode lengths of d_6- and d_{12}-lines were similar to that of Shiokari, while those of d_a- and d^h_{18}-lines decreased prominently. The second internode

TABLE 3. The lengths of panicle, culm, internodes, and leaf sheaths and blades of the nineteen near-isogenic dwarf lines and Shiokari in 1979; expressed as percentages to those of Shiokari in dwarf lines

Name of isoline	Panicle length	Culm length	Internode length				Leaf sheath length			Leaf blade length		
			1st	2nd	3rd	4th	1st	2nd	3rd	1st	2nd	3rd
d_1-	37	32	64	3	25	8	65	54	60	55	63	59
d_2-	94^{ns}	59	75	42	60	20	86	78	76	88	88	69
$d_{3,4,5}$-	72	41	59	35	22	20	71	60	64	55	66	59
d_6-	64	46	102^{ns}	6	8	8	107	96^{ns}	101^{ns}	92^{ns}	99^{ns}	84
d_7-	81	87	74	99^{ns}	90^{ns}	70	91	91	93^{ns}	91^{ns}	96^{ns}	91^{ns}
d_{10}-	80	55	68	60	28	28	79	79	84	76	79	81
d_{11}-	112	52	58	2	109^{ns}	85^{ns}	93	88	89	85	90^{ns}	83
d_{12}-	106^{ns}	63	100^{ns}	59	23	13	106^{ns}	98^{ns}	98^{ns}	91^{ns}	103^{ns}	83
d_{13}-	70	58	68	49	58	50	76	62	79	66	85	76
d_{14}-	91^{ns}	54	80	46	23	20	90	83	92	93^{ns}	98^{ns}	84
d_{17}-	84	60	74	56	39	53	77	75	90	78	93^{ns}	82
d_{18}^{h}-	40	13	26	5	3	5	33	23	23	24	25	23
d_{18}^{k}-	79	53	68	51	42	10	70	65	56	53	66	56
d_{27}-	86	64	80	60	43	53	81	78	88	87	91^{ns}	88
d_{30}-	79	79	65	85	97^{ns}	85^{ns}	88	98^{ns}	115	83	100^{ns}	84
d_{35}-	83	61	54	76	66	20	88	74	60	78	73	52
d_{47}-	93^{ns}	59	74	60	42	15	101^{ns}	90	84	86	96^{ns}	72
d_a-	90^{ns}	54	35	71	69	25	79	85	94^{ns}	75	109^{ns}	96^{ns}
d_b-	89	54	64	60	33	10	89	82	71	88	78	62
Mean	81	55	68	49	46	31	83	77	80	76	84	73
Shiokari (Actual measurement, cm)	16.0	64.6	26.0	21.7	13.0	4.0	23.3	21.7	17.9	26.0	28.9	30.3
L. S. D.$_{(0.05)}$ (cm)	1.8	3.7	2.3	1.0	2.8	1.1	1.5	1.0	1.4	2.7	3.2	2.7

ns.... non-significant difference with Shiokari, the other values showed a significant difference with Shiokari at the 0.05 or 0.01 levels of probability.

lengths of d_1-, d_6-, d_{11}- and d_{18}^h-lines were extremely reduced. The third internode lengths of d_7-, d_{11}- and d_{30}-lines were similar to that of Shiokari, while those of d_6- and d_{18}^h-lines were extremely reduced. Furthermore the reduction of the fourth internode length was more prominent in most of the lines. As shown in the table, the mean of the nineteen near-isogenic lines decreased in the order of the panicle, the first, second, third and the fourth internode. These facts indicate that most of the dwarf genes insert their actions to shorten the lower internodes more remarkably than the panicle and the upper internodes. As to the lengths of leaf sheaths and

TABLE 4. Yield components and two leaf characters of the nineteen near-isogenic dwarf lines and Shiokari in 1979

Name of isoline	Panicle number[1)]	No. of spikelets[2)]	100-kernel weight (g)	Days to heading[3)]	Width of flag leaf (mm)	Flag leaf angle (degree)
d_1-	19.7	93**	0.99**	88.0	12.4**	12.2**
d_3-	16.7	101*	1.82	89.0	10.2	13.8**
$d_{3,4,5}$-	82.8**	43**	1.72	91.5**	7.6*	29.7**
d_6-	22.7	82**	1.92	89.0	9.9	24.4**
d_7-	18.3	137*	1.67	89.0	10.3	34.1**
d_{10}-	85.9**	62**	1.71	100.0**	9.2	23.2**
d_{11}-	15.8	93**	1.20**	98.0**	11.5*	13.8**
d_{12}-	17.3	110	1.82	86.5**	9.7	22.5**
d_{13}-	19.7	85**	1.75	108.5**	10.5	18.5**
d_{14}-	112.4**	81**	1.66	103.0**	9.8	19.4**
d_{17}-	81.3**	82**	1.66	104.0**	8.9	23.5**
d_{18}^h-	31.1*	26**	1.82	98.5**	8.6*	23.5**
d_{18}^k-	25.8	64**	2.13**	89.5	9.4	20.3**
d_{27}-	88.2**	80**	1.74	105.0**	9.2	27.8**
d_{30}-	16.1	125	1.59*	91.0*	9.4	—
d_{35}-	19.2	84**	1.88	89.0	9.8	36.6*
d_{47}-	16.4	76**	2.06**	91.5**	11.3*	14.1**
d_a-	16.7	156**	1.81	92.5**	11.4*	17.2**
d_b-	17.8	75**	2.12**	91.0*	10.1	16.6**
Shiokari	19.2	120	1.79	89.0	9.9	48.2
L. S. D.$_{(0.05)}$	9.7	16	0.16	1.5	1.1	8.8

1) Per Plant. 2) Per panicle of main culm. 3) Counted from sowing.
*, ** Difference from Shiokari was significant at the 0.05 and 0.01 levels of probability, respectively.

blades, each dwarf line did not show a marked difference, indicating that each dwarf gene affects the characters in a similar proportion though the degrees of reduction are different among the dwarf genes.

The survey on yield components and two leaf characters in 1979 are shown in actual measurement in Table 4. In the panicle number per plant, the different tillering dwarfs, $d_{3,4,5}$-, d_{10}-, d_{14}-, d_{17}- and d_{27}-lines were over four times as compared with Shiokari, and delayed the heading from eleven to sixteen days with the exception of $d_{3,4,5}$-line. It is implied that the excessive production of tillers caused a delay in the initiation of panicle primordium. The number of spikelets per panicle did not exceed that of Shiokari except d_7- and d_a-lines. In 100 kernel weight, d_1- and d_{11}-lines were inferior to the others owing to short round grains. It is noted that the two lines also showed a striking reduction of the second internode length (Table 3). On the contrary, d_{18}^k-, d_{47}- and d_b-lines were significantly increased to Shiokari

TABLE 5. Characteristics of the nineteen near-isogenic dwarf lines

Name of isoline	Characteristics
d_1-	Striking reduction of the second internode length and short round grain.
d_2-	Semi-dwarf type showing striking reduction of the second internode length sometimes.
$d_{3,4,5}$-	Tillering dwarf.
d_6-	Prominent reduction of the second and lower internode lengths.
d_7-	Cleistogamous and short round grain.
d_{10}-	Tillering dwarf showing delayed heading.
d_{11}-	Striking reduction of the second internode length, small grain and occurrence of neck leaf.
d_{12}-	Semi-dwarf (resemble to Shiokari except short lower internodes and erect leaf type).
d_{13}-	Yellowish leaf and delayed heading.
d_{14}-	Tillering dwarf showing delayed heading.
d_{17}-	do.
d_{18}^h-	Extreme dwarf.
d_{18}^k-	Semi-dwarf (panicle-number type).
d_{27}-	Tillering dwarf showing delayed heading.
d_{30}-	Moderate dwarf and shattering.
d_{35}-	Semi-dwarf (responsible to gibberellin).
d_{47}-	Semi-dwarf.
d_a-	Extreme reduction of the first internode length.
d_b-	Semi-dwarf.

TABLE 6. Correlation coefficients among panicle, culm and leaf characters in 1979 (below diagonal) and 1980 (upper diagonal)

	Panicle length	Culm length	Internode length				Leaf sheath length			Leaf blade length			Width of flag leaf	Flag leaf angle
			1st	2nd	3rd	4th	1st	2nd	3rd	1st	2nd	3rd		
Panicle length		.37	.28	.11	.59**	.12	.54*	.47*	.41	.56*	.46*	.46*	.18	−.10
Culm length	.61**		.70**	.86**	.71**	.50*	.72**	.77**	.71**	.72**	.67**	.65**	−.03	.30
1st internode length	.40	.54*		.40	.21	.04	.84**	.69**	.55*	.72**	.55*	.42	−.14	.21
2nd "	.41	.84**	.21		.50*	.34	.45*	.54*	.48*	.42	.42	.44	−.14	.37
3rd "	.53*	.70**	−.01	.50*		.62**	.40	.53*	.55*	.59**	.54*	.55*	.28	.11
4th "	.40	.72**	.19	.45*	.84**		.12	.31	.50*	.19	.45*	.61**	−.02	−.01
1st leaf sheath length	.72**	.66**	.74**	.37	.34	.27		.89**	.71**	.86**	.69**	.55*	−0.9	.06
2nd "	.75**	.77**	.66**	.52*	.49*	.44*	.94**		.91**	.92**	.90**	.77**	−.03	.01
3rd "	.60**	.72**	.61**	.46*	.46*	.56**	.79**	.91**		.84**	.97**	.91**	−.02	.03
1st leaf blade length	.75**	.75**	.70**	.49*	.42	.41	.92**	.93**	.84**		.83**	.66**	.12	.03
2nd "	.71**	.70**	.58**	.49*	.45*	.43	.84**	.91**	.94**	.88**		.94**	.11	−.08
3rd "	.62**	.73**	.57**	.48*	.50*	.60**	.71**	.84**	.93**	.80**	.92**		.11	−.11
Width of flag leaf	.23	.03	−.02	−.14	.33	.04	.27	.23	.18	.22	.29	.24		−.50*
Flag leaf angle	.03	.58**	.27	.58**	.29	.47*	.15	.19	.14	.20	.06	.20	−.46*	

*, ** Significant at the 0.05 and 0.01 levels of probability, respectively.

in 100 kernel weight. The flag leaf of d_1-line was the broadest among the all dwarf lines, while that of $d_{3,4,5}$-line was the narrowest. The flag leaf angles of the dwarf lines were generally smaller than that of Shiokari. In other words, the dwarf genes affected canopy structures, producing erect plant types.

The similar results as mentioned above were obtained in 1980. The morphological features of the near-isogenic lines are described in Table 5 and figures of the Plate. It may be concluded that the dwarf genes not only reduce culm length but also show manifold effects to various parts of the plant.

3. Interrelations among panicle, culm and leaf characters

The correlation coefficients among the 14 characters related to panicle, culm and leaves were calculated from the data of the nineteen kinds of near-isogenic dwarf lines and Shiokari in 1979 and 1980 as shown in Table 6. The culm length showed highly significant correlations with the lengths of internodes and leaf sheaths and blades, respectively. Among the internode lengths, the highest correlation was indicated between the third and fourth internode lengths. The lengths of leaf sheaths and blades were correlated very closely one another. The first internode length was closely correlated with the lengths of the flag (first) leaf sheath and blade. The flag leaf angle was correlated with the lengths of culm and the second and fourth internodes in 1979. A negative correlation was found between the width and angle of the flag leaf in both years.

4. Principal component analysis

Principal component analysis was attempted to explain the interrelationship among the lengths of panicle, internodes and leaf sheaths and blades using the nineteen kinds of near-isogenic dwarf lines and Shiokari. As shown in Table 7, in the analysis containing the lengths of panicle, internodes and leaf sheaths and blades, the first component was loaded positively for all chracters. The second component was loaded negatively for the first internode length and positively for the third and fourth ones. The third component was loaded for the second internode length in 1979 and for the lengths of panicle and the second internode in 1980. Similar components were detected from the analysis containing the first to fourth internode lengths (Table 8). In the analysis for the lengths of the first to third leaf sheaths and blades (Table 9), the first component contributed more than 85% of the total variation. The second component was loaded positively for the lengths of the first leaf sheath and blade and negatively for the lengths

TABLE 7. Factor loadings of the first three principal components analyzed by the use of the lengths of panicle, internodes, leaf sheaths and blades

Length of	Factor (1979)			Factor (1980)		
	I	II	III	I	II	III
Panicle	.78	.04	.24	.58	−.05	.76
1st internode	.66	−.54	−.16	.69	−.54	−.22
2nd "	.58	.37	.57	.58	.15	−.46
3rd "	.59	.74	−.04	.68	.46	.31
4th "	.59	.68	−.34	.47	.78	−.14
1st leaf sheath	.89	−.33	.09	.85	−.44	.01
2nd "	.96	−.13	.06	.96	−.16	−.08
3rd "	.93	−.05	−.20	.94	.10	−.12
1st leaf blade	.94	−.20	.08	.91	−.26	.10
2nd "	.94	−.11	−.02	.93	.07	−.05
3rd "	.91	.03	−.21	.86	.29	−.04
Eigen value	7.27	1.63	0.63	6.79	1.53	0.98
Contribution (%)	66.1	14.8	5.8	61.7	13.9	8.9
Cumulated (%)		80.8	86.6		75.6	84.5

TABLE 8. Factor loadings of the first three principal components analyzed by the use of internode lengths

Length of	Factor (1979)			Factor (1980)		
	I	II	III	I	II	III
1st internode	.25	.95	.19	.48	.79	.38
2nd "	.73	.16	−.66	.78	.29	−.54
3rd "	.91	−.30	.16	.85	−.26	.07
4th "	.91	−.10	.32	.73	−.52	.25
Eigen value	2.25	1.02	0.60	2.10	1.05	0.50
Contribution (%)	56.3	25.4	15.0	52.6	26.2	12.4
Cumulated (%)		81.7	96.7		78.8	91.2

of the third leaf sheath and blade, though its contribution was relatively small.

Thus, the variation of the internode lengths among the nineteen near-isogenic dwarf lines and Shiokari may be explained by following three aspects : 1) the total size indicated by the culm length, 2) the relative elongation pattern of the upper (first) and the lower (third and fourth) internodes, and

TABLE 9. Factor loadings of the first two principal components analyzed by the use of the lengths of leaf sheaths and blades

Length of	Factor (1979)		Factor (1980)	
	I	II	I	II
1st leaf sheath	.92	.37	.84	.49
2nd "	.97	.14	.97	.15
3rd "	.95	−.22	.97	−.20
1st leaf blade	.95	.22	.92	.27
2nd "	.97	−.13	.96	−.23
3rd "	.92	−.36	.87	−.45
Eigen value	5.37	0.40	5.13	0.63
Contribution (%)	89.5	6.7	85.6	10.6
Cumulated (%)		96.2		96.1

3) the reduction of the second internode length.

As to the lengths of the first to third leaf sheaths and blades, each dwarf gene affected them in a similar proportion though the degrees were different among the dwarf genes.

5. The internode distribution pattern

Two kinds of indices were employed to examine the internode distribution pattern of each line, namely, the arctangent of the ratio of the first internode length to the third one and the percentage of the second internode length to the total culm length. The former index indicates the relative elongation pattern of the upper and the lower internodes named as "uper

TABLE 10. Variance components estimated for the compound characters of internodes, expressed by percentages to the total of variance components

Compound character	Percentage of variance component due to			
	Lines	Years	L×Y	Error
Upper internode elongation index	87.6**	2.3**	5.0*	5.1
Percentage of the second internode length to culm length[1)]	92.5**	0.2	0.0	7.3
Ratio of the first internode length to the third internode length	70.8**	5.0**	18.1**	6.1

1) Arcsine transformation was carried out before the estimation.

*, ** Significant at 0.05 and 0.01 levels of probability, respectively.

internode elongation index". The fourth internode was not included in the calculation, because of the remarkable fluctuation by environmental conditions and the small contribution to culm length. The variance components of both indices and the ratio of the first to the third internode lengths were estimated as shown in Table 10. The variance component due to the lines was the largest in both indices showing the strong effects of the dwarf genes. The variance component due to the lines in the upper internode elongation index was larger than that in the ratio of the first to the third internode lengths. Therefore, the former may be more stable than the latter. The scatter diagram by both indices in 1979 and 1980 are shown in Fig. 1-a and 1-b, respectively. The nineteen kinds of near-isogenic lines were divided into two groups; the upper and lower internode elongation type in comparison with the index of Shiokari. The results of two years were consistent except d_{13}-line. It was also noticed that in the percentage of the second internode length to culm length, d_1-, d_6-, d_{11}- and d^h_{18}-lines were remarkably small,

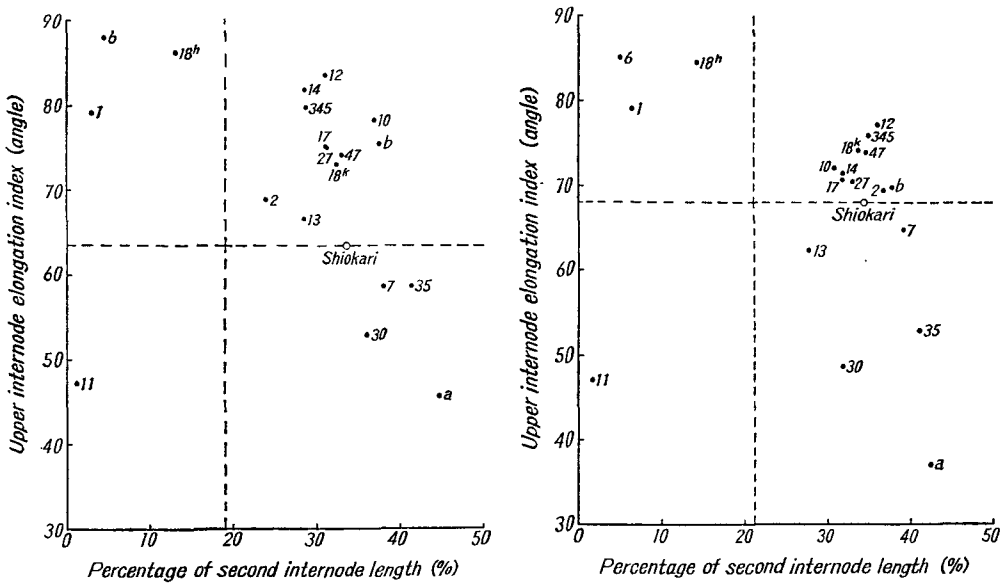

Fig. 1. Scatter diagram of the nineteen near-isogenic dwarf lines and Shiokari according to the upper internode elongation index and the percentage of the second internode length to culm length in 1979 and 1980.

LSDs of the upper internode elongation index and the percentage of the second internode length to culm length at the 0.05 probability level were 6.5° and 9.3% in 1979, and 6.1° and 6.2% in 1980, respectively.

while the other dwarf lines distributed around Shiokari.

As the result, all of the lines except d_{13}-line were grouped into four classes by using the two indices. Namely, group I comprising d_{2}-, $d_{3,4,5}$-, d_{10}-, d_{2}-, d_{14}-, d_{17}-, d^{k}_{18}-, d_{27}-, d_{47}- and d_{b}-lines was characterzed by the upper internode elongation type with the normally elongated second internode. Group II consisting of d_{1}-, d_{6}- and d^{h}_{18}-lines showed not only the conspicuous depression of the lower internode elongation but also possessed the extremely reduced second internode. In these three lines, the first internode occupied more than 70% of culm length. Group III comprising d_{7}-, d_{30}-, d_{35}- and d_{a}-lines was regarded as the lower internode elongation type accompanied with the normally elongated second internode. Group IV of d_{11}-line alone was characterized by the striking reduction of the second internode and belonged to the lower internode elongation type.

Discussion

The nature of the nineteen kinds of near-isogenic dwarf lines was investigated in the condition under the paddy field. In order to clarify the genic action of various dwarfs, principal component analyses were attempted using the near-isogenic lines under the genetic background of the variety Shiokari. The present study indicated that the interrelationship of plant type characters due to the action of various dwarf genes is characterized by the following three aspects; the reduction of total size, the relative elongation pattern of the upper and lower internodes and the extreme reduction of the second internode length. It was shown that each dwarf gene reduced the lengths of the first to third leaf sheaths and blades in a similar proportion though the degree of reduction was attributed to the individual dwarf gene.

MORISHIMA and OKA[7] analyzed two kinds of principal components from the variation of the mutant lines, *i. e.*, the first component which was loaded positively for the lengths of panicle and the first to fifth internodes, and the second component which was loaded positively for the lengths of panicle and the first internode and negatively for the lengths of the third to fifth ones. They were called "isometric" and "allometric" phases of variation. The upper and lower elongation pattern of internodes was also examined in the oat varieties[13] and the dwarf mutants of barley[6], though the classification between the upper and the lower internodes was different with that in rice. Thus, it is noted that the upper and lower elongation patterns of internodes showed a parallel relation in rice and other cereal crops.

Factor scores have been employed to examine the upper and lower

elongation pattern in rice[4,7]. In addition, the authors devised a new index called "upper internode elongation index" which is associated with the actual measurements of internode lengths more intimately than scores obtained through factor loadings. Therefore, this index can be employed in the similar way for the cultivated varieties. However, when the index is applied for late maturing varieties which possess more than five elongated internodes, it is needed to take one or two additional internodes below the third internode into the calculation. TODA[14] reported that the degree of lodging in rice was negatively correlated with the percentage of the first internode length to culm length, while it was positively correlated with culm length and the percentages of the third to fifth internode length to culm length. HU[3] suggested the internode distributing pattern as a major factor of lodging resistance in rice. Therefore, "upper internode elongation index" as well as culm length may be appropriate for evaluating the lodging resistance. In most of the dwarf lines examined in this study, the indices were larger than that of Shiokari. MORISHIMA and OKA[7] reported that most of the mutant lines belonged to "upper internode elongation type" in comparison with the original variety. Hence, it is postulated that most of the dwarf genes insert their actions to reduce the lower internode lengths more strongly than the upper internodes.

Eight kinds of dwarfs out of the nineteen kinds of dwarf types used in this study were used for the classification of internode distribution pattern by TAKAHASHI and TAKEDA[11], the strains bearing d_2 show the features of either dm- or dn-type in the internode distribution pattern. In 1979, each plant of d_2-line contained a small number of tillers showing extremely reduced second internodes (less than 0.5 cm) besides the normally developed internodes (longer than 12 cm), while in 1980, all tillers of the plants from the same d_2-line possessed normally developed second internodes alone. Therefore, the fluctuation of the second internode length in the d_2-line may be affected by environmental factors. TAKAHASHI and TAKEDA[11] indicated that the dwarf strains possessing $d_3d_4d_5$, d_7 and d_{14} were included to the dn-type thogether with some of the strains bearing d_2. In this experiment, the authors decided that d_7-line belongs to the lower internode elongation type and the other three lines involving d_2-line enter to the upper internode elongation type. Thus, the author's classification by the new standard of demarcation was appropriate to characterize the genic actions of various kinds of dwarfness. It is also pointed out that the genic action under the near-isogenic background made possible to make the classification due to the elongation pattern of the internodes.

Summary

The lengths of internodes and leaf sheaths and blades were examined in the nineteen kinds of near-isogenic dwarf lines developed by the back-crossing procedure. Principal component analyses indicated that the variation of internode lengths due to the dwarf genes may be characterized by three aspects, *i. e.*, 1) the reduction of total size indicated by the culm length, 2) the relative elongation pattern of the upper (first) and the lower (third and fourth) internodes, and 3) the extreme reduction of the second internode length. As to the lengths of the first to third leaf sheaths and blades, each dwarf gene affected them in a similar proportion though a wide range of variation existed among different dwarf genes. Two kinds of indices were employed to compare the internode elongation patterns of the lines, *i. e.*, the percentage of the second internode length to culm length and the arctangent of the ratio of the first to the third internode length named as "upper internode elongation index". All of the near-isogenic dwarf lines except d_{13}-line were classified into four groups by using the two indices. Group I, which was regarded as the upper internode elongation type in comparison with the recurrent parent, Shiokari and possessed the normally elongated second internode, comprised d_{2}-, $d_{3,4,5}$-, d_{10}-, d_{12}-, d_{14}-, d_{17}-, d^{k}_{18}-, d_{27}-, d_{47}- and d_{b}-lines. Group II, in which the second and lower internodes were conspicuously reduced, contained d_{1}-, d_{6}- and d^{h}_{18}-lines. Group III comprising d_{7}-, d_{30}-, d_{35}- and d_{a}-lines was characterized as the lower internode elongation accompanied with the normally elongated second internode. Group IV consisting of d_{11}-line alone was characterized by the striking reduction of the second internode length and belonged to the lower internode elongation type.

Acknowledgement

The authors wish to express their sincere gratitude to Dr. M. TAKAHASHI Professor Emeritus, Hokkaido University, for his guidance and encouragement. They thank Dr. K. TAKEDA, Assistant Professor of Okayama University, for his valuable advice and critical reading of the manuscript.

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Explanation of Plate

Legend for figures

Fig. 1. Shiokari, the representative cultivar in Hokkaido

2. d_1-line, Daikoku dwarf

3. d_2-line, Ebisu dwarf

4. $d_{3,4,5}$-line, tillering dwarf of Bunketsu-waito

5. d_6-line, Ebisumochi dwarf

6. d_7-line, cleistogamous dwarf

7. d_{10}-line, tillering dwarf of Toyohikari-bunwai

8. d_{11}-line, Norin-28 dwarf

9. d_{12}-line, Yukara dwarf

10. d_{13}-line, short grained dwarf

11. d_{14}-line, tillering dwarf of Kamiikawa-bunwai

12. d_{17}-line, slender dwarf

13. d_{18}^{h}-line, Hosetsu dwarf

14. d_{18}^{k}-line, Kotake-tamanishiki dwarf

15. d_{27}-line, tillering dwarf of Bunketsu-to

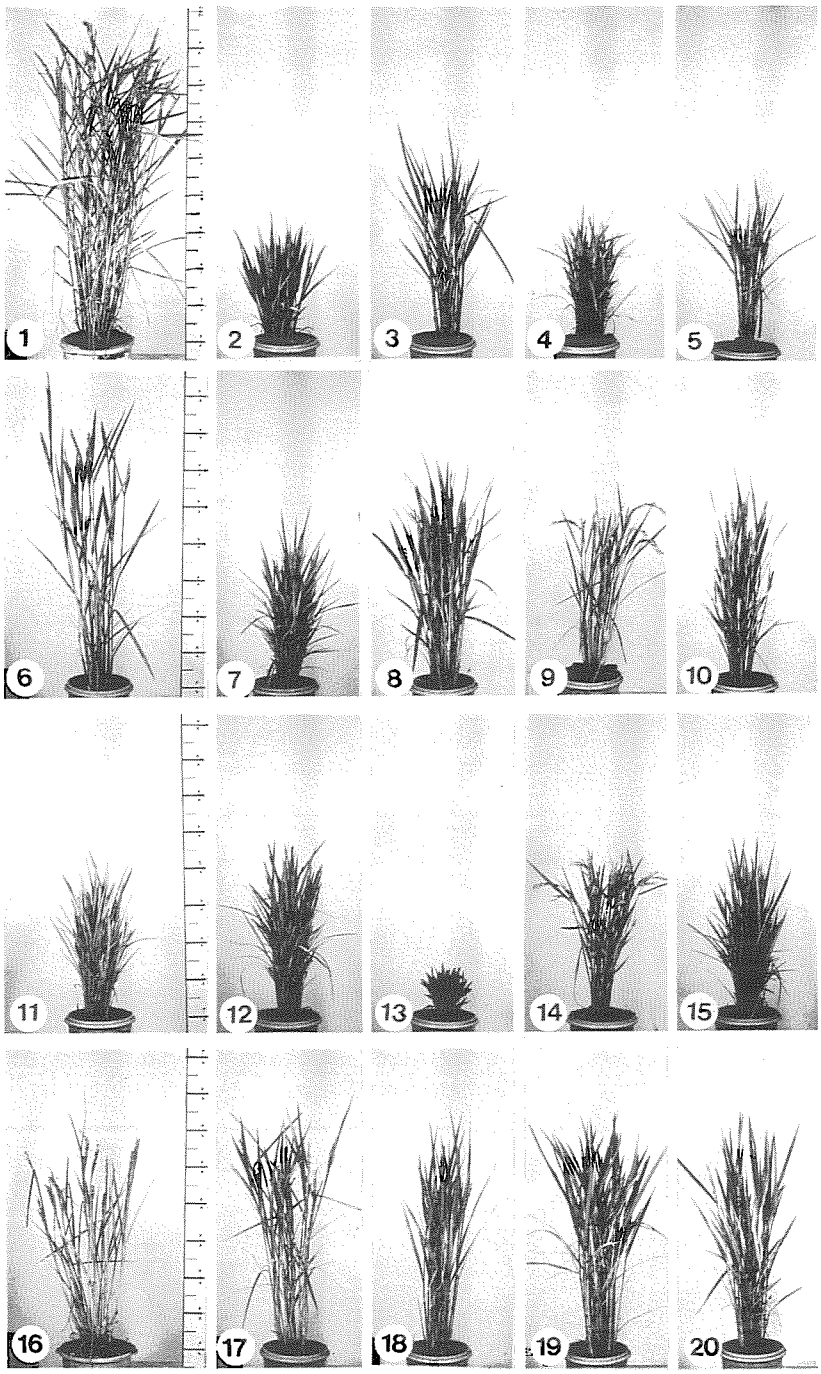
16. d_{30}-line, Waisei-shirasasa dwarf

17. d_{35}-line, Tanginbozu dwarf

18. d_{47}-line, Taichung Native-1 dwarf

19. d_a-line, M-290 dwarf

20. d_b-line, Hiroba dwarf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