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GENETIC ANALYSIS AND CHARACTER EXPRESSION OF SEMIDWARF MUTANTS INDUCED IN *INDICA* RICE (*ORYZA SATIVA* L.)

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Introduction

Short stature mutants, induced in native rices, are often associated with more efficient partitioning of the dry matter resulting in high harvest index and lodging resistance besides increased grain yields[7,13]. Induction of semidwarf (SD) mutants in tall rices with special adaptations, such as resistance to salinity and drought, aroma etc., is highly desirable[10,11]. As most of the high yielding SD cultivars are derived from Dee-geo-woo-gen (DGWG) source, it is worthwhile to generate new versions of SDs for broadening the genetic base of semidwarfism[12].

A total of about fifty reduced height mutants, induced in diverse indigenous lines, were field-tested for their performance and other morphometric characters during 1982 and 1983. After preliminary evaluation, a set of eleven SD mutants with desirable yield potential and agrobotanical traits were selected for further evaluation and genetic analysis. This report deals with (i) the performance of SD mutants at four levels of nitrogen (N) fertilizer; (ii) internode-pattern of SD mutants; (iii) genetic analysis of certain SD mutants; and (iv) physiological characterization of various SD mutants.

Materials and Methods

The SD mutants, their tall parents and two semidwarf checks, IR 8 and DGWG (Table 1), were grown during 1982 and 1983, on Plant Genetics Experimental Farm of Department of Genetics, O. U., Hyderabad, in a randomized block design with three replications. One-month old seedlings

TABLE 1. List of semidwarf mutants and other stocks used

Mutant/Cultivar	Parent	Mutagen used	Source
Basmati 370 (SD_1)	Basmati 370	E.M.S.	C.R.R.I., Cuttack, India
Basmati 370 (SD_2)	Basmati 370	γ-rays+E.M.S.	Panthnagar Agricultural University, U.P., India
Basmati 370 (SD_3)	Basmati 370	γ-rays	Department of Genetics, O.U., India
TCA_2 (SD)	Tilakchandan	E.M.S.	Rajendra Agricultural University, Bihar, India
TCA_3 (SD)	Tilakchandan	X-rays	do.
$TCAP_2$-5 (SD)	Tilakchandan	γ-rays	do.
T 141 (SD)	T 141	X-rays	University of Agriculture and Technology, Orissa, India
NZD_3 (SD)	Nizulu	E.M.S.	Department of Genetics, O.U., India
NZD_{13} (SD)	Nizulu	γ-rays	do.
Mahsuri (SD_2)	Mahsuri	γ-rays	do.
YV (SD)	Yedagaru Vadlu	spontaneous	do.
IR 8 (EMD)	IR 8	γ-rays+E.M.S.	do.
DGWG (*sd-1*)	Woo-gen	spontaneous	I.R.R.I., Manila, Philippines,
cv. IR36 (*sd-1*)	—	—	do.
D24 (*sd-2*)	Calrose	γ-rays	University of California, Davis, U.S.A.
D 66 (*sd-4*)	Calrose	γ-rays	do.
cv. Bala (*sd-1*)	—	—	A.I.C.R.I.P., India

were transplanted in five-row plots, at a spacing of 15×20 cm, and were raised under standard culture conditions (60 kg N : 20 kg P_2O_5 : 20 kg K_2O/acre) of the region. Data were recorded on plant, panicle, grain and other agro-botanical characters. At maturity, ten random plants from each stock were uprooted and measurements were noted on the longest culm for number and length of internodes. During the winter season of 1983–1984, eleven SD mutants were further evaluated at four levels of nitrogen, viz., N_0=0 kg ; N_1=50 kg ; N_2=100 kg ; and N_3=150 kg N/ha. The seedlings were transplanted in six-row plots, at each N level, in a randomized design with three replications. Uniform doses of 50 kg/ha each of P_2O_5 and K_2O were incorporated before transplantation. N-fertilizer, urea, was applied in split doses at seedling and panicle initiation stages. Data were recorded on days to maturity, culm length, panicle number, panicle length, No. of grains/panicle, grain weight and grain yield/20 plants. Observations were noted at maturity on plant habit and lodging index (LI). Also, the total dry matter produced/plant and harvest index (HI) were estimated in each replication at four N levels. Duncan's new multiple range test revealed significant varietal differences for different characters at each dose of N.

Investigations on inheritance mode and allelism, with reference to DGWG (*sd-1*) locus, were made on semidwarf and dwarf mutants. The F_2 progenies together with their respective parents were raised under paddy field conditions during the monsoon season of 1984. Culm lengths were measured before maturity in parents and F_2 populations. Chi-square (χ^2) analysis was used to test the goodness of fit of observed segregations with expected ratios.

In SDs and talls, the fresh and dry weights were measured on ten day old seedlings. Adopting the method of ARNON[1], chlorophyll "a" and "b" were estimated from the leaf tissues of ten-day old seedlings. The beta-amylase activity was assayed on five-day old seedlings following the method of BERNFELD[2]; amylase activity was expressed in maltose units per gram fresh weight. The nitrate reductase (NR) activity was measured in the flag leaf, after anthesis, adopting the method of SCOT and NEYRA[15]. NR activity was expressed in terms of nitrite (NO_2) formed per hour per gram leaf-tissue. These estimations were repeated twice under identical conditions.

Results and Discussion

Performance of SD mutants: The yield potential of eleven SD mutants, four tall parents and two semidwarf (DGWG) checks was evaluated at four levels of N fertilizer. The objective was to identify morphometric traits influencing grain-yield response to increased N among SD mutants. Data recorded on grain yield and yield components are given in Table 2. In semidwarfs and talls, days to maturity and culm length tended to increase with increasing dose of N fertilizer. In certain SD mutants, viz., Basmati 370 (SD_2) and (SD_3), TCA_2 (SD), TCA_3 (SD), $TCAP_2$-5 (SD), T 141 (SD) and YV (SD), consistent increases were observed in panicle number, panicle length, grains/panicle and grain yield with increasing dose of N applied. Likewise, three tall SD mutants, NZD_3, NZD_{13} and Mahsuri (SD_2), also disclosed similar positive responses at higher levels of N. Especially three mutants, $TCAP_2$-5 (SD), T 141 (SD) and NZD_{13} (SD), exhibited N-response patterns similar to that of IR 8. Whereas, in both SDs and talls, the grain weight tended to decrease with increasing dose of N applied. The superior grain yields of SDs at higher rates of N are mainly associated with their favourable responses for number of panicles, number of grains/panicle and panicle length. On the other hand, in tall Basmati 370 (C), TCA, T 141,

TABLE 2. Grain yield and ancillary characters of SD mutants at different levels of N fertilizer

Mutant	N-level	Days to maturity	Culm length (cm)	Panicle number/20 plants	Panicle length (cm)	No. of grains/ panicle	1000 Grain weight (g)	Grain yield/ 20 plants (g)
	N 0	127	99.8	120	21.7	76	22.9	216
Bas 370	N 1	131	106.5	146	24.5	93	21.2	261
(C)	N 2	134	111.9	155	25.1	95	20.7	278
	N 3	136	113.5	136	25.6	92	20.5	224
	N 0	126	72.3	138	19.9	88	22.1	242
Bas 370	N 1	132	74.2	161	21.4	104	21.4	286
(SD_1)	N 2	135	76.4	183	21.8	108	20.3	338
	N 3	137	79.1	160	22.3	103	20.1	275
	N 0	125	61.2	149	20.8	108	22.5	258
Bas 370	N 1	127	65.4	178	22.3	121	22.2	321
(SD_2)	N 2	131	67.3	192	22.8	132	21.4	368
	N 3	133	70.2	198	23.4	135	21.1	385
	N 0	130	59.4	126	20.1	94	23.7	231
Bas 370	N 1	132	63.2	164	21.4	117	23.4	298
(SD_3)	N 2	135	64.8	182	22.1	124	22.1	342
	N 3	140	66.2	193	22.6	129	21.4	367
	N 0	117	87.4	121	18.4	72	23.6	226
TCA	N 1	121	98.2	143	19.1	88	24.2	272
(C)	N 2	122	102.7	151	20.6	97	23.1	289
	N 3	124	108.3	139	21.4	104	22.6	242
	N 0	116	67.2	135	.18.2	69	24.2	215
TCA_2	N 1	120	69.5	160	19.3	84	23.9	263
(SD)	N 2	122	72.6	182	20.8	98	23.3	318
	N 3	122	73.8	194	21.2	102	23.1	334
	N 0	120	65.3	128	17.7	66	24.5	209
TCA_3	N 1	123	68.1	156	18.8	87	23.8	258
(SD)	N 2	125	70.4	174	19.6	102	22.9	298
	N 3	128	71.7	186	20.8	105	22.3	321
	N 0	125	60.5	141	18.2	81	25.2	258
$TCAP_2$-5	N 1	128	62.6	178	19.4	93	24.3	356
(SD)	N 2	132	65.4	204	20.8	125	23.9	395
	N 3	134	68.3	218	21.6	128	23.1	432
	N 0	147	101.4	115	23.4	123	19.6	258
T 141	N 1	151	109.2	148	24.1	168	18.8	319
(C)	N 2	153	114.1	154	24.8	189	18.5	342
	N 3	155	116.3	133	24.6	151	18.1	294

Table 2. (Continued)

Mutant	N-level	Days to maturity	Culm length (cm)	Panicle number/20 plants	Panicle length (cm)	No. of grains/ panicle	1000 Grain weight (g)	Grain yield/ 20 plants (g)
	N 0	150	60.3	138	21.8	116	18.8	243
T 141	N 1	153	63.4	182	22.3	142	18.6	326
(SD)	N 2	155	65.3	196	23.1	158	18.2	381
	N 3	157	67.2	219	23.9	163	18.0	428
	N 0	134	72.2	121	23.6	102	25.3	261
NZD_3	N 1	137	75.1	158	23.9	124	24.6	329
(SD)	N 2	142	77.4	176	24.2	131	23.7	394
	N 3	145	78.2	184	24.4	134	23.1	423
	N 0	135	73.6	129	23.5	115	26.3	269
NZD_{13}	N 1	137	75.8	165	24.1	132	25.4	348
(SD)	N 2	143	78.2	183	24.3	141	25.1	403
	N 3	145	79.3	192	24.7	148	24.3	437
	N 0	139	94.2	126	23.4	135	18.6	269
Mahsuri	N 1	141	97.1	148	23.8	187	18.4	331
(C)	N 2	145	102.3	173	24.2	202	18.1	386
	N 3	147	103.1	152	24.6	201	18.2	339
	N 0	128	70.4	131	21.7	128	18.1	251
Mahsuri	N 1	132	74.8	162	22.3	176	17.8	322
(SD)	N 2	135	78.3	181	22.6	193	17.3	381
	N 3	137	80.4	194	23.2	198	17.5	392
	N 0	110	61.1	128	21.8	94	24.3	241
YV	N 1	113	63.4	164	22.6	115	24.1	305
(SD)	N 2	116	64.1	178	23.9	129	23.2	331
	N 3	117	65.7	193	23.2	143	22.7	368
	N 0	128	64.3	143	20.5	84	25.2	262
IR 8	N 1	132	67.2	169	21.6	102	24.3	345
(*sd-1*)	N 2	135	70.4	193	22.9	122	23.7	402
	N 3	137	71.6	221	23.2	134	23.2	428
	N 0	132	66.4	131	21.3	79	25.8	253
DGWG	N 1	135	69.5	158	22.6	97	25.1	322
(*sd-1*)	N 2	138	72.2	183	23.5	118	24.4	384
	N 3	140	73.5	196	23.9	126	23.8	416

Bas = Basmati ; C = Control ; N 0 = 0 kg ; N 1 = 50 kg ; N 2 = 100 kg ; N 3 = 150 kg N/ha.

TABLE 3. Agrobotanical traits of SD mutants at different levels of N fertilizer

Mutant	N-level	Plant habit	Lodging* index (LI)	Total dry matter/ plant (g)	Harvest index (HI)
	N 0	Normal	3	136	27.4
Bas 370	N 1	Spread	5	153	26.3
(C)	N 2	Spread	7	188	24.2
	N 3	Spread	7	192	22.6
	N 0	Erect	1	134	41.6
Bas 370	N 1	Erect	1	162	39.8
(SD_1)	N 2	Normal	3	171	38.7
	N 3	Normal	5	184	38.3
	N 0	Erect	1	128	45.3
Bas 370	N 1	Erect	1	146	44.2
(SD_2)	N 2	Erect	1	165	43.1
	N 3	Erect	1	181	42.7
	N 0	Erect	1	112	45.2
Bas 370	N 1	Erect	1	133	44.3
(SD_3)	N 2	Erect	1	154	43.8
	N 3	Erect	1	175	43.1
	N 0	Normal	3	124	31.6
TCA	N 1	Normal	3	157	29.4
(C)	N 2	Spread	5	182	27.7
	N 3	Spread	7	186	26.3
	N 0	Erect	1	115	42.8
TCA_2	N 1	Erect	1	146	40.2
(SD)	N 2	Erect	1	165	39.6
	N 3	Normal	3	173	39.4
	N 0	Erect	1	108	43.6
TCA_3	N 1	Erect	1	137	41.2
(SD)	N 2	Erect	1	161	40.4
	N 3	Normal	1	168	39.9
	N 0	Erect	1	122	43.8
$TCAP_2$-5	N 1	Erect	1	161	42.9
(SD)	N 2	Erect	1	184	42.8
	N 3	Erect	1	191	41.1
	N 0	Normal	1	138	33.7
T 141	N 1	Normal	1	168	31.3
(C)	N 2	Spread	3	196	28.4
	N 3	Spread	5	203	26.1

Table 3. (Continued)

Mutant	N-level	Plant habit	Lodging index (LI)	Total dry matter/ plant (g)	Harvest index (HI)
	N 0	Erect	1	116	44.7
T 141	N 1	Erect	1	142	42.5
(SD)	N 2	Erect	1	162	42.1
	N 3	Erect	1	181	41.8
	N 0	Erect	1	122	41.4
NZD_3	N 1	Erect	1	164	39.2
(SD)	N 2	Erect	1	189	38.4
	N 3	Normal	3	196	37.1
	N 0	Erect	1	128	43.5
NZD_{13}	N 1	Erect	1	168	41.2
(SD)	N 2	Erect	1	192	40.6
	N 3	Erect	1	201	40.3
	N 0	Erect	1	132	36.2
Mahsuri	N 1	Normal	1	161	33.4
(C)	N 2	Normal	3	183	31.3
	N 3	Spread	5	204	29.8
	N 0	Erect	1	123	42.6
Mahsuri	N 1	Erect	1	148	40.3
(SD_2)	N 2	Erect	1	172	38.2
	N 3	Normal	3	181	37.1
	N 0	Erect	1	109	44.3
YV	N 1	Erect	1	127	43.9
(SD)	N 2	Erect	1	142	42.3
	N 3	Erect	1	158	41.9
	N 0	Erect	1	126	44.6
IR 8	N 1	Erect	1	146	43.7
(*sd-1*)	N 2	Erect	1	171	41.2
	N 3	Erect	1	189	40.4
	N 0	Erect	1	121	43.1
DGWG	N 1	Erect	1	153	42.4
(*sd-1*)	N 2	Erect	1	172	40.8
	N 3	Erect	1	187	39.2

* 1=Strong ; 3=Moderately strong ; 5=Intermediate ; 7=Weak.

Mahsuri and Basmati 370 (SD_1), the panicle number and grain yields showed substantial decreases at the maximum dose of N used.

Observations recorded on certain agrobotanical traits of SDs and talls are summarized in Table 3. Basmati 370 (SD_1), though nonlodging at N_1, was found susceptible to lodging (LI=3 to 5) at higher doses of N used. Also, TCA_2 (SD), NZD_3 (SD) and Mahsuri (SD_2) were prone to slight lodging (LI=3) at the maximum dose of N applied. Whereas, Basmati 370 (SD_2) and (SD_3), TCA_3 (SD), $TCAP_2$-5 (SD), T 141 (SD), NZD_{13} (SD) and YV (SD), with erect habit, proved lodging resistant when cultured at the highest dose of N fertilizer. On the other hand, the amount of lodging in talls showed substantial increases with increasing dose of N applied.

In talls and semidwarfs, the quantum of total dry matter produced per plant increased with increments in the dose of N used. Whereas, the harvest index (HI) showed a consistent decrease with increasing dose of N applied. However, the decline in HI across N doses was relatively less among SD mutants when compared to tall parents. Certain of the SD mutants, viz., Basmati 370 (SD_2) and (SD_3), $TCAP_2$-5 (SD), T 141 (SD), YV (SD) and NZD_{13} (SD), showed relatively high HI (40.3 to 43.1) even at the maximum dose of N used. Especially three mutants, $TCAP_2$-5 (SD), T 141 (SD) and NZD_{13} (SD), were found on par with IR 8 in lodging resistance, dry matter productivity and harvest index. The grain-yield superiority of semidwarfs, at higher levels of N, is probably due to more efficient division of the biomass into grain and straw. Path-coefficient analysis in diverse rice mutants revealed harvest index as the major determinant of grain yield[16]. SD mutants exhibiting more favourable responses for one or more yield components and high HI should be included in crosses for developing superior semidwarfs suitable for high fertility conditions.

Internode pattern in SD mutants: Data on the number and length of internodes are listed in Table 4. A total of seven internodes were observed in tall Basmati 370 (C) and T 141 (C), while their SD mutants were characterized by six identifiable internodes. However, other tall lines and their SD mutants showed an identical number of six internodes. The SD mutants were classified into two groups based on percentage contribution of the panicle-bearing internode (IN 1) to the main culm length. In the first group, comprising Basmati 370 (SD_1) and (SD_2), TCA_3 (SD) and NZD_3 (SD), IN 1 contributed $<35\%$ to the main culm length. In the second group, consisting of other SDs and IR 8, IN 1 contributed $>35\%$ to the main culm length. In $TCAP_2$-5 (SD) and T 141 (SD), IN 1 alone contributed $>40\%$ to the main culm length.

TABLE 4. Number and length of elongated internodes (IN) in SD mutants, their parents and IR 8

Mutant/ Variety	IN 1 (cm)	IN 2 (cm)	IN 3 (cm)	IN 4 (cm)	IN 5 (cm)	IN 6 (cm)	IN 7 (cm)	Culm length' (cm)
Bas 370 (C)	37.9	27.8	21.2	11.5	4.8	2.3	1.8	107.3
Bas 370 (SD_1)	18.4	16.8	15.8	10.7	4.3	2.1	—	68.1
Bas 370 (SD_2)	21.5	17.6	16.7	6.3	1.9	0.9	—	64.9
TCA (C)	33.4	27.6	19.4	9.6	4.3	2.1	—	96.4
TCA_2 (SD)	27.6	21.3	12.1	5.3	2.2	1.0	—	69.5
TCA_3 (SD)	21.9	17.8	14.8	7.4	3.8	1.9	—	67.6
$TCAP_2$-5 (SD)	26.7	20.9	11.6	4.5	1.8	0.7	—	66.2
YV (SD)	26.3	19.8	13.2	5.4	2.5	1.1	—	68.3
NZD_3 (SD)	25.7	18.1	15.2	8.9	4.1	1.9	—	73.9
NZD_{13} (SD)	29.6	21.9	14.7	6.4	2.9	1.1	—	76.6
Mahsuri (C)	35.9	24.9	19.7	9.9	3.6	1.8	—	95.8
Mahsuri (SD_2)	28.9	20.7	16.9	8.8	2.9	1.2	—	79.4
T 141 (C)	36.2	27.1	19.7	13.4	5.9	2.4	1.5	106.2
T 141 (SD)	26.3	19.2	12.9	4.7	1.6	0.8	—	65.5
IR 8 (*sd-1*)	25.6	19.3	14.1	7.4	2.4	0.9	—	69.7

C = Control ; SD = Semidwarf ; Bas = Basmati.

The data on percentage reduction in the length of internodes in SDs, when compared to their tall parents or Basmati 370, are summarized in Table 5. Basmati 370 (SD_1), TCA_3 (SD) and NZD_3 (SD) were characterized by substantial reduction in the length of two top internodes, IN 1 and IN 2, while their basal internodes, IN 5 and IN 6, showed least reduction. Basmati 370 (SD_2) showed marked reduction in the lengths of all internodes though reduction is more drastic in IN 5 and IN 6. In T 141 (SD), $TCAP_2$-5 (SD), TCA_2 (SD), YV (SD) and NZD_{13} (SD), a pronounced reduction in the lengths of three basal internodes was observed. However, TCA_2 (SD), NZD_{13} (SD) and $TCAP_2$-5 (SD) showed least reduction in the lengths of IN 1 and IN 2. Mahsuri (SD_2) exhibited a more or less proportionate reduction in the lengths of all internodes except IN 6. Certain SD mutants, T 141 (SD), YV (SD), $TCAP_2$-5 (SD) and Basmati 370 (SD_2), revealed internode patterns similar to that of IR 8.

Based on the relative contribution of specific internodes to total culm length, the SD mutants were classified into three groups : (i) Top-shortening type — Basmati 370 (SD_1), TCA_3 (SD) and NDZ_3 (SD) are characterized by

TABLE 5. Percentage reduction in the length of internodes in SD mutants as compared to tall parents

SD mutants	IN 1	IN 2	IN 3	IN 4	IN 5	IN 6
Bas 370 (SD_1)	51.5	39.6	25.5	7.0	10.4	8.7
Bas 370 (SD_2)	43.3	36.7	21.2	45.2	60.4	60.9
TCA_2 (SD)	17.4	22.8	37.6	44.8	48.8	52.4
TCA_3 (SD)	34.4	35.5	23.7	22.9	11.6	9.5
$TCAP_2$-5 (SD)	20.1	24.3	40.2	53.1	58.1	66.7
YV (SD)*	30.6	28.8	37.7	53.0	47.9	52.2
NZD_3 (SD)*	32.2	34.9	28.3	22.6	14.6	17.4
NZD_{13} (SD)*	21.9	21.2	30.7	44.3	39.6	52.2
Mahsuri (SD_2)	19.5	16.9	14.2	11.1	19.4	33.3
T 141 (SD)	27.3	29.2	34.5	64.9	72.9	66.7
IR 8 (*sd-1*)*	32.5	30.6	33.5	35.7	50.0	60.9

* Compared to Basmati 370.

a marked reduction in the lengths of IN 1 and IN 2; (ii) Base-shortening type — T 141 (SD), $TCAP_2$-5 (SD), TCA_2 (SD), YV (SD) and NZD_{13} (SD) exhibited drastic reduction in the lengths of basal internodes; and (iii) Uniform type — Mahsuri (SD_2) showed proportionate reduction in the lengths of all internodes.

The reduced height mutants were generally observed to exhibit reduction in the length of specific internodes although decrease in the number of internodes is not uncommon[8]. The present observations indicate that reduction in the height is caused by decrease in the length and/or number of specific internodes. In cereals, straw stiffness and lodging resistance are generally associated with decrease in the length of basal internodes and increased length of top internodes, besides reduction in the number of internodes[6,9,14]. Path-coefficient analysis in divergent rice stocks revealed a strong negative correlation ($r=-0.742$) between plant height and lodging resistance[4]. In the present investigation, SD mutants belonging to base-shortening class exhibited erect plant habit with high lodging resistance and high yield potential.

Inheritance and allelism of SD mutants: The mode of inheritance and allelism of six SD mutants and one dwarf mutant were investigated based on F_2 segregation pattern.

The spontaneous semidwarf, YV (SD), when crossed to Basmati 370 (C), gave an F_2 segregation of 3 tall : 1 semidwarf indicating monogenic inheritance

TABLE 6. Inheritance and allelism of YV (SD) mutant

Cross combination	Total No. of F_2 plants	Talls (105–140 cm)	Semi-dwarfs (71–85 cm)	Double dwarfs (45–60 cm)	F_2 ratio	χ^2	p-value
YV (SD)/ Bas 370 (C)	427	325	102	—	3 : 1	0.282	0.50–0.60
YV (SD)/ DGWG (*sd-1*)	182	—	182	—	—	—	—
D 66 (*sd-4*)/ YV (SD)	204	113	79	12	9 : 6 : 1	0.153	0.90–0.95
D 24 (*sd-2*)/ YV (SD)	193	112	81	—	9 : 7	0.249	0.60–0.70

Bas = Basmati ; C = Control.

TABLE 7. Inheritance and allelism of Basmati 370 (SD) mutants

Cross combination	Total No. of F_2 plants	Talls (110–145 cm)	Semi-dwarfs (71–85 cm)	Double dwarfs (50–60 cm)	F_2 ratio	χ^2	p-value
Bas 370 (SD_1)/ Bas 370 (C)	216	166	50	—	3 : 1	0.395	0.50–0.60
IR36 (*sd-1*)/Bas 370 (SD_1)	295	170	107	18	9 : 6 : 1	0.229	0.80–0.90
Bas 370 (SD_1)/ cv. Bala (*sd-1*)	276	160	99	17	9 : 6 : 1	0.345	0.80–0.90
Bas 370 (C)/ Bas 370 (SD_3)	341	259	82	—	3 : 1	0.165	0.60–0.70
Bas 370 (SD_3)/ cv. Bala (*sd-1*)	217	130	87	—	9 : 7	1.180	0.20–0.30

Bas = Basmati ; SD = Semidwarf ; C = Control.

of its semidwarfism (Table 6). In the cross of YV (SD)/DGWG (*sd-1*), the F_2 progenies did not yield any tall or double-dwarf recombinants with all progenies being semidwarf. Obviously, the semidwarfism of YV (SD) is governed by a single recessive gene which is allelic to *sd-1* locus. However, when YV (SD) was crossed to two SD mutants, D 24 and D 66, induced in cv. Calrose, it proved nonallelic to both the mutant genes, viz., *sd-2* and *sd-4*.

Four induced SD mutants, viz., Basmati 370 (SD_1) and (SD_3), TCA_2 (SD) and TCA_3 (SD), when crossed to their respective parents, exhibited monogenic inheritance of 3 tall : 1 semidwarf in the F_2 progenies. In the crosses of SD mutants/semidwarfs (DGWG), the F_1 hybrids were tall indicating their nonallelism to *sd-1* gene. Further, the modified dihybrid F_2 ratios, viz., 9 tall : 6 semidwarf : 1 double-dwarf and/or 9 tall : 7 semidwarf, clearly suggest

TABLE 8. Inheritance and allelism of TCA (SD) mutants

Cross combination	Total No. of F_2 plants	Talls (100–120 cm)	Semi-dwarfs (71–85 cm)	Double dwarfs (45–60 cm)	F_2 ratio	χ^2	p-value
TCA_2 (SD)/ TCA (C)	316	240	76	—	3:1	0.152	0.60–0.70
TCA_2 (SD)/ DGWG (*sd-1*)	356	209	130	17	9:6:1	1.713	0.40–0.50
TCA_2 (SD)/ YV (SD)	372	216	135	21	9:6:1	0.581	0.70–0.80
TCA_3 (SD)/ TCA (C)	319	244	75	—	3:1	0.377	0.50–0.60
IR 36 (*sd-1*)/ TCA_3 (SD)	243	143	86	14	9:6:1	0.673	0.70–0.80
TCA_3 (SD)/ YV (SD)	287	170	102	15	9:6:1	1.229	0.50–0.60

TCA = Tilackhandan; DGWG = Dee-Geo-Woo-Gen; C = Control.

TABLE 9. Inheritance and allelism of $TCAP_2$-5 (SD)

Cross combination	Total No. of F_2 plants	Talls (100–120 cm)	Semi-dwarfs (71–85 cm)	Double dwarfs (45–60 cm)	F_2 ratio	χ^2	p-value
TCA (C)/ $TCAP_2$-5 (SD)	412	314	98	—	3:1	0.324	0.50–0.60
TCA_3 (SD)/ $TCAP_2$-5 (SD)	255	154	101	–	9:7	1.778	0.10–0.20

TCA = Tilakchandan; C = Control.

that the four SD mutants are nonallelic to *sd-1* locus (Tables 7 and 8).

Likewise, when $TCAP_2$-5 (SD) was crossed to its tall parent, the F_2 progeny showed a monogenic segregation of 3 tall : 1 semidwarf. The dihybrid segregation of 9 tall : 7 semidwarf, observed in the cross TCA_3 (SD)/$TCAP_2$-5 (SD), indicates that these mutants also are nonallelic to each other (Table 9).

An early maturing dwarf (EMD) mutant induced in cv. IR 8, when crossed to its parent, produced semidwarf F_1s and showed an F_2 segregation of 3 semidwarf : 1 dwarf indicating a monogenic difference between them. In the cross between IR 8 (EMD)/Basmati 370 (C), the F_1 hybrids were tall; in the F_2 generation, 9 tall : 6 semidwarf : 1 double-dwarf were observed (Table 10). The segregation pattern amply suggests that the EMD mutant is

TABLE 10. Inheritance and allelism of IR 8 (EMD) dwarf mutant

Cross combination	Total No. of F_2 plants	Talls (110–145 cm)	Semi-dwarfs (71–85 cm)	Double dwarfs (50–65 cm)	F_2 ratio	χ^2	p-value
IR8 (EMD)/ IR 8 (*sd-1*)	259	—	196	63	3 : 1	0.063	0.80–0.90
IR8 (EMD)/ Bas 370 (C)	561	320	209	32	9 : 6 : 1	0.339	0.80–0.90

EMD = Early maturing dwarf; C = Control; Bas = Basmati.

a double-dwarf comprising two nonallelic SD genes, namely, *sd-1* and a mutant SD gene. These SD genes probably act in an additive and/or cumulative fashion to cause further reduction in the height of EMD mutant.

The five nonallelic SD mutants, induced in *indica* background, seem promising as parents in cross-breeding and as alternative gene sources to guard against possible genetic vulnerability caused by the use of single *sd-1* gene.

Physiological characterization of SD mutants: The data recorded on four physiological parameters are given in Table 11. The SD mutants, when compared to tall lines, showed increased seedling fresh and dry weights. Especially five mutants, viz., Basmati 370 (SD_3), $TCAP_2$-5 (SD), T 141 (SD), NZD_3 (SD) and NZD_{13} (SD), exhibited high fresh and dry weights comparable to that of IR 8. Likewise, most of the SD mutants, with superior grain-yield potential, surpassed tall parents in their chlorophyll content. Four SD mutants, $TCAP_2$-5 (SD), T 141 (SD), NZD_{13} (SD) and YV (SD), were found on par with or superior to IR 8 in their chlorophyll content. Also the various SDs, when compared to talls, disclosed marked increases in their beta-amylase activity. The maximal values for amylase activity were noted in Basmati 370 (SD_2), $TCAP_2$-5 (SD), NZD_{13} (SD) and IR 8. These observations hold promise for early selection of productive semidwarfs in the segregating progenies by screening them for these parameters.

Nitrate reductase (NR) is the first enzyme involved in the metabolism of nitrates in higher plants[5]. In crop plants, NR catalyzes the reduction of nitrates to nitrites which is a rate-limiting step in the utilization of nitrates[3]. Genotypes exhibiting higher levels of NR activity possess increased potential for accumulating reduced N, resulting in increased grain and grain-protein yields[3,16]. In the present study, the various SD mutants, in general, showed enhanced NR activity when compared to tall parents (Table 11). In

TABLE 11. Physiological characteristics of SD mutants

Mutant	Seedling weight (mg/seedling)		Chlorophyll (mg/g)		β-amylase (mg maltose/g FW)	NR (μg NO_2/hr/g FW)
	Fresh	Dry	'a'	'b'		
Bas 370 (C)	49.7	4.6	0.81	0.36	66.1	5.0
Bas 370 (SD_1)	52.4	5.8	0.96	0.40	76.3	6.5
Bas 370 (SD_2)	53.2	6.4	1.20	0.49	101.2	14.5
Bas 370 (SD_3)	63.3	7.9	1.03	0.43	98.4	12.5
TCA (C)	55.1	5.2	0.97	0.36	62.7	10.0
TCA_2 (SD)	59.3	5.6	1.35	0.63	98.4	14.5
TCA_3 (SD)	61.8	5.5	1.05	0.56	100.2	12.0
$TCAP_2$-5 (SD)	69.8	7.2	1.71	0.69	103.8	25.0
T 141 (C)	46.2	4.6	0.98	0.57	91.3	13.5
T 141 (SD)	69.2	7.4	1.76	0.63	100.6	22.5
NZD_3 (SD)	71.5	8.2	1.25	0.68	97.2	—
NZD_{13} (SD)	74.7	8.7	1.82	0.64	102.3	26.5
Mahsuri (C)	56.2	5.7	0.99	0.48	89.6	14.0
Mahsuri (SD_2)	58.6	6.1	1.39	0.61	92.2	17.5
YV (SD)	62.8	7.3	1.81	0.67	96.1	—
IR 8 (*sd-1*)	69.4	7.3	1.72	0.62	101.8	24.5
DGWG (*sd-1*)	64.7	7.2	1.59	0.55	92.9	—

NR = Nitrate reductase activity; FW = Seedling fresh weight.

three productive semidwarfs, NZD_{13} (SD), $TCAP_2$-5 (SD) and T 141 (SD), the level of NR activity was almost similar to that of IR 8. Hence, NR activity may be used as an additional parameter in identifying superior genotypes. The tall semidwarf, NZD_{13} (SD), with high chlorophyll content, high beta-amylase and NR activity, appears promising as a donor-source for high physiological efficiency.

An overview of the results indicates the possibility of inducing alternative SD mutants endowed with superior agronomic features and high physiological efficiency.

Summary

The present report deals with the performance of diverse SD mutants at four N levels, allelism of certain SD mutants and their physiological characterization. Data recorded on grain yield and yield components, lodging index, total dry matter and harvest index indicate that SD mutants surpass

tall parents in their response to increased levels of N applied. Especially three SD mutants, $TCAP_2$-5 (SD), T 141 (SD) and NZD_{13} (SD), exhibited N-response patterns, for various characters, similar to that of IR 8. Observations on internode length indicate that superior SD mutants tend to exhibit base-shortening type of internode pattern.

Four SD mutants, viz., Basmati 370 (SD_1) and (SD_3), TCA_2 (SD), TCA_3 (SD), and an early maturing dwarf (EMD) mutant induced in IR 8, proved to be nonallelic to *sd-1* gene. Hence, these mutants may be utilized as alternative gene sources to guard against genetic vulnerability.

Most of the SD mutants with superior grain-yield potential exceeded tall parents in their chlorophyll content, beta-amylase and nitrate reductase (NR) activity besides seedling fresh and dry weights. In three productive SD mutants, NZD_{13} (SD), $TCAP_2$-5 (SD) and T 141 (SD), the level of NR activity was almost similar to that of IR 8. Thus, NR and beta-amylase activity may be used as additional criteria while screening for superior semidwarfs.

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