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DEVELOPMENT OF HIGH-YIELDING DWARF COMPOSITES OF PEARL MILLET*

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ABSTRACT

Dwarf versions of morphologically diverse seven tall pearl millet (*Pennisetum glaucum* (L.) R. Br.] composites (recurrent parents) were developed by a limited sidecar backcrossing of a d_2 dwarfing gene from an elite dwarf population GAM 73. Yield trials of the seven pairs of tall and dwarf composites, and GAM 73 were conducted for two years at two locations in southern India. Culm length of dwarf composite was 35-43% less than their tall versions and 5-25% more than GAM 73. All the dwarf composites outyielded GAM 73 by 10-33%. In five composites, dwarf versions yielded as much grain as their tall counterparts. In the two tallest composites (203-212 cm culm length), the dwarf versions yielded 12-19% more grain than their tall counterparts. These results indicate that d_2 gene can be effectively utilized to breed dwarf pearl millet populations without a significant reduction in grain yield, and that breeding of tall-dwarfs may prove to be best strategy to develop high-yielding dwarf pearl millets.

INDEX WORDS : *Pennisetum glaucum*, sidecar backcrossing tall and dwarf composites.

Several major dwarfing genes have been reported in pearl millet (Burton and Fortson, 1966; Gupta, Premachandran and Chaubey, 1985; Appa Rao, Mengesha and Rajagopal Reddy, 1986). The d_2 dwarfing gene, however, has so far been more widely utilized than others because it was among the first ones to be discovered, and has been found to have no adverse effect on general combining ability for grain yield and several of the developmental traits (Thakare and Murty, 1972). The d_2 dwarfing gene has also been shown to generate a much wider range of useful variability for plant height in crosses (Murty and Tiwari, 1967). Eight diverse d_2 dwarf populations, developed by West African breeding programmes were introduced and evaluated at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India, for grain yield and adaptation. GAM 73, bred in Senegal, was the highest yielding among those with appropriate maturity (<55 d to 50% flower). Several medium to tall composites of diverse origin and varying morphological characteristics had been taken up for recurrent selection at ICRISAT center. A programme of limited sidecar backcrossing, using the d_2 gene

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TABLE 1. Origin and composition of seven tall and seven dwarf composites

Composite	Origin	Parentage: Tall version	Parentage: Dwarf version
Early Composite (EC)	ICRISAT India	194 geographically diverse lines which flowered in less than 45 days at ICRISAT center during the 1973 rainy season.	32 BC_3F_3 dwarf progen.es from EC.
Medium Composite (MC)	ICRISAT India	197 geographically diverse lines which flowered in 45-55 days at ICRISAT center during the 1>73 rainy season.	50 BC_3F_3 dwarf progenies from MC.
World Composite (WC)	Samaru Nigeria	144 S_4 progenies from world collection germplasm stocks.	55 BC_3F_3 dwarf progenies from WC.
Inter Varietal Composite (IVC)	ICRISAT India	73 superior, visually selected, intervarietal crosses of mostly Indian × African origin.	51 BC_3F_3 dwarf progenies from IVC.
Super Serere Composite (SSC)	ICRISAT India	Random-mated bulk of SC_1 (S_4)†, SC_2 (M)†, SC_3 (M), SC_4 (M), all initially developed at Serere Research Station in Uganda	50 BC_3F_3 dwarf progenies from SSC
Nigerian Composite (NC)	Samasu Nige:ia	200 S_4 progenies from Nigerian and other West African germplasm	41 BC_3F_3 dwarf progenies from NC.
E × Bornu (E × B)	Samaru Nigeria	A landrace variety from the Gashva region of Bornu province in Northern Nigeria.	38 BC_3F_3 dwarf progenies from E × B.

† SC—Serere Composite; S_4—S_4 progeny; M—Mass selected.

from GAM 73, was initiated in 1975 to develop dwarf versions of seven of these diverse composites. The objective of this paper is to describe the development of dwarf composites and report on their yielding ability and other morphological characteristics in comparison to their tall counterparts and the d_2 gene donor population GAM 73.

A sidecar method of backcrossing was adopted to transfer the d_2 dwarfing gene. This metod differs from the conventional backcrossing in only one important respect: the recurrent parents used in the backcross series were genetically changing composite bulks derived from the latest recurrent selection cycles which were available at a given backcross stage, rather than the composite bulks used in making

Seven medium to tall composites (Table 1) were used as recurrent parents. GAM 73, a synthetic developed in Senegal, was used as a donor parent of the d_2 dwarfing gene.

The initial crosses were made on GAM 73 as the female parent with the bulk pollen from more than 100 plants of recurrent composite in the 1975 dry season. First

TABLE 2. Composite cycle bulks used as recurrent parent at various stages of backorcssing in dwarf sidecar programme

Composite	Cycle bulks of composite used to produce			
	F_1	BC_1	BC_2	BC_3
EC	C_0	C_1	C_1	C_1
MC, WC	C_0	C_1	C_2	C_2
IVC, SSC, NC	C_0	C_1	C_2	C_2
E×B	C_0	C_0	C_0	C_1

backcross was made by using the bulk pollen from the dwarf F_2 plants on its parental (recurrent) tall composite. BC_1F_1's were advanced to BC_1F_2's which were grown head-to-row along with the composite bulks. Based on the visual evaluation for the typical maturity and head length characteristics of the respective composites, selected dwarf plants from selected rows were selfed to produce BC_1F_3 progenies and backcrossed with the bulk pollen from more than 100 plants of the respective composites. BC_1F_3 progeny rows were planted 2 weeks earlier than the corresponding BC_2F_1's and the composite bulks. The difference of 2 weeks between the two plantings permitted the evaluation of the BC_1F_3 progenies for d_2 height before the start of flowering in BC_2F_1 rows. The third backcross, using the bulk pollen from a composite, was made on only those BC_2F_1 rows whose corresponding BC_1F_3 progenies had been selected. BC_3F_1's were planted head-to-row to produce BC_3F_2's which were again planted head-to-row. The dwarf plants were selfed in the segregating rows. Selection of selfed dwarf plants was made between and within the rows I on the visual selection for high-yielding ability and the typical head length and maturity of the respective composites. BC_3F_3 progeny rows were grown in the unreplicated observation nurseries at ICRISAT center, Patancheru (18°N) and at Bhavanisagar (11°N) in southern India for visual assessment of plant height, maturity, seed set and yielding ability. BC_3F_3 progenies were advanced to BC_3F_5 by the bulk pedigree method. The Syn 0 dwarf version of a tall composite was constituted by recombining generally 40-50 dwarf BC_3F_5 progenies derived from a composite (Table 1). About .000 plants of Syn_0 bulks of each composite were grown in the 1983 dry season to develop Syn_1 bulks by sibbing.

Trial entries consisted of those cycle bulks of the seven tall composites that were involved in the final (third) backross, the dwarf versions of these tall composites, and GAM 73. Thus, fifteen entries were evaluated for two years (1982, 1984) in the rainy season at two locations (ICISAT center, Bhavanisagar). Each yield trial was planted in a randomized complete block design with four replications. Plots consisted of eight rows (four rows at Bhavanisagrr in 1984) of 4 m length, spaced 60 cm apart at ICRISAT center and 50 cm at Bhavanisagar with 10 cm spacing within the rows. All trials received 40 kg N and 4, P (plus also 20 kg K at Bhavanisagar only) /ha as a basal dose, followed by a topdressing of 40 kg N/ha, 15-20 days after planting. Field data on five characters (Table 3) were recorded from the central six rows (all four rows at Bhavanisagar in 1984) of each plot. The mean of three samples, 100 seeds each, ite 100

TABLE 3. Mean squares for various characters of tall and dwarf composites

Source of variation	df	Culm length	Time to 50% flower	Grain yield	Head length	Effective tillers	Seed mass
Environment (E)	3(2)+	30531**	752.0**	9177720**	304.4**	1.7*	83. 4**
Replication/E *	12(9)	141	1.7	632683	6.3	0.4	0.75
Partition 1							
Tall composites (TC)	6	5380**	223.8**	151941	169.6**	0.35**	1.05**
Dwarf composites (DC)	7	1202**	118.0**	844237**	168.7**	0.18**	1.36**
– Dwarf test composites (DTC)	6	915**	118.8**	43447**	181.9*	0.20**	1 31**
– Dwarf test vs Dwarf check	1	2922**	112.8**	3302979**	90.0**	0.03	1.65**
E×TC	18(12)	172**	5.1**	156494	3.6	0.10	0.37
E×DTC	18(12)	77	3.2**	184974	3.3	0.04	0.64*
Partition 2							
Between Composite pairs (BCP)	6	5260**	327.6**	330751*	350.9**	0.48**	1.81**
Within Composite pair (WCP)	7	40800**	31.3**	345478**	45.6**	0.08*	0.72**
Height (H)	1	[illegible]	129.0**	884526**	315.9**	0.17**	1.80**
H×BCP	6	1035**	15.0**	255637*	315.9*	0.17**	1.80**
E×BCP	18(12)	148*	4.5**	193314	3.7	0.06	0.54
E×WCP	21(14)	498**	5.2**	191461*	3.6	0.09*	0.64
E×H	3(2)	2879**	13.6**	45108*	5.8	0.20**	1.13*
E×(H×BCP)	18(12)	101**	3.9**	148154	3.3	0.07*	0.56
Error	168(126)	73	1.3	117187	2.5	0.04	0.33

*$P<0.05$; **$P<0.01$

+Degrees of freedom in parentheses for seed mass which was recorded in 3 environments only.

The locations and two years provided four environment. A fixed effects model was used for the analysis of variance. The sum of squares due to composites and due to their interaction with the environments was partitioned in two ways. Partiton 1 examined the differences among tall composites, among dwarf composites, and their interaction with the environments. Partition 2 examined the effect of height and its interaction with the genetic background of composites (composite pairs) and with the environm—

RESULTS AND DISCUSSION

The differences among composites, both within tall and dwarf groups were highly signifiant ($P<0.01$) for all the characters except for grain yield in the tall group (Partition 1, Table 3). Dwarf composites also differed signifiantly from the d_2 gene donor composite for all the characters except effective tillers per plant. In general, neither tall composites nor their dwarf versions showed significant interaction with the environments except

TABLE 4. Mean values of various characters of tall and dwarf composites over four environments

Composite	Character						
	Height group	Culm length (cm)	Time to 50% flower (d)	Grain yield (kg/ha)	Head length (cm)	No. of effective tillers per plant	1000 Seed mass† (g)
BC	Tall	159	41	2380	22	1.6	7.4
	Dwarf	104	44	2360	25	1.4	7.1
MC	Tall	172	43	2480	25	1.4	7.5
	Dwarf	111	46	2590	27	1.5	7.4
WC	Tall	174	46	2590	24	1.4	7.3
	Dwarf	107	48	2610	26	1.4	7.2
IVC	Tall	182	46	2570	25	1.4	7.3
	Dwarf	111	47	2560	28	1.2	7.5
SSC	Tall	186	48	2640	25	1.4	8.1
	Dwarf	113	48	2730	27	1.3	8.0
NC	Tall	203	49	2410	31	1.3	7.8
	Dwarf	124	51	2860	34	1.2	7.3
BXB	Tall	212	52	2450	30	1.1	7.8
	Dwarf	122	52	2750	32	1.2	7.0
GAM 73	Dwarf	99	45	2140	31	1.3	7.0
LSD (0.05)		6	0.8	238	1.1	0.2	0.5
Mean of composites	Tall	184	46	2500	26	1.4	7.6
	Dwarf‡	113	48	2630	29	1.3	7.4
LSD (0.05)		2	0.3	90	0.4	0.1	0.2

† Mean of only three environments

‡ Does not include GAM 73

composites, culm length in the tall group and seed mass in the dwarf group of composites. Partition 2 showed that the differences between tall and dwarf versions of the pairs were highly significant for all the characters. A larger part of these differences for all the characters, except grain yield, was accounted for by the height effect than by the height x genetic background interaction. Height x environment interaction was significant for all the characters except head length. The interaction of height x genetic background effect with environment, however, was significant for culm length, time to 50% flower, and number of tillers per plant.

Among the composites used as recurrent parents, BC was the shortest with an average culm length of 159 cm (Table 4). NC and E x B were on the other height extreme with average culm length of 203 and 212 cm, respectively. Among the dwarf versions derived from the dwarf sidecar programme, the shortest composite with a culm length of 104 cm was a derivative of BC whereas the tallest dwarf composites with a culm length of about 124 cm were from NC and E x B. This amounts to a culm length reduction of 35% in EC and 43% in E x B. The correlation between the plant height of tall and dwarf versions of the composties was positive and highly significant (r=0.92**), indicating that a polygenic system of varying genetic constitution controlling plant height in different composites is superimposed over the effect of the d_2 dwarfing gene, and that the interaction of d_2 gene with the genetic background, though significant, is not of a major consequence. Thus, the taller the composite, the taller the dwarf version from it that can be expected. The tallest dwarf composite produced from the dwarf sidecar programme had a culm length of 124 cm (NC dwarf) which was about 22% shorter than the shortest non-d_2 composite (EC).

The tall composites had a narrow range for grain yield : 2380 kg/ha for EC to 2640 kg/ha for Super Serere Composite (SSC). The dwarf composites, on the other hand, had a wider range for grain yield : 2360 kg/ha for EC to 2860 kg/ha for NC. All the dwarf composites derived from this programme outyielded GAM 73 by 10-33%. The dwarf version outyielded its tall version by 19% in NC and by 12% in E x B. In the other five composites, the grain yield of dwarf versions was 99-103% of their tall counterparts. The highest yielding population in the trial was the dwarf version of NC with a yield level of 2860 kg/ha which was 8% more than the highest yielding tall composite (SSC). The lowest yielding tall and dwarf populations were both from EC which gave grain yield of 2380 kg and 2360 kg/ha, respectively. This shows that the opportunities for producing higher yielding dwarf composites may vary with the genetic background of tall materials, and that the highest yielding tall populations may not necessarily result in the highest yielding dwarf populations. Similar observations have been made in barley (Ali, Okiror and Rasmusson, 1978) and wheat (Joppa, 1973).

Plant height and grain yield were not correlated in tall composites. In dwarf composites, however, the correlation between these traits was positive and highly significant (r=0.88**). A closer look at the relationship between these two traits (Table 4) revealed that the pattern of relationship in both height groups was quite similar when NC and E x B (with plant heights of over 2 m in tall group) were not considered. The inclusion of NC and E x B strengthened the positive relationship between plant height and grain yield in dwarf group but weakened it in the tall group. Thus, it implies that for the level of management conditions used in this experiment, the plant heights of NC and E x B were excessive, resulting in the decline of productivity whereas a culm height of 122-124 cm with d_2 dwarfing gene led to improved productivity. Selection of tall-dwarfs, therefore, might be an efficient method of grain yield improvement in dwarf populations. Higher yielding ability of tall-dwarfs has been observed in wheat (Mcneal *et al.*, 1972; Allan, 1980), sorghum (Graham and Lessman, 1966) and pearl millet (F.R. Bidinger, personal communication).

Reduction in plant height of the dwarf versions of tall composites did not cause any reduction in head length. On the contrary, the head length of the dwarf composites increased by 2-3 cm over their tall versions. This could have occurred as a result of heterosis associated with heterozygosity at about 6% of those loci for which the recurrent and donor parents differed. But more likely, this could have resulted due to correlated response to improved yield potential which was one of the selection criterion during the backcross programme. The delays in flowering of dwarf composites by 1-3 days over their tall counterparts could have also occurred due to selection for improved yield potential.

Most of the tall composites did not differ greatly from one another for tillering ability and seed mass. Not many large differences were observed among dwarf composites for these two traits either. In most of the tall-dwarf comparisons, dwarf versions had slightly fewer tillers and slightly smaller seed size. Dwarfs have been shown to have smaller seeds than tall cultivars in wheat (Joppa, 1973), barley (Ali, *et al.*, 1978) and sorghum (Casady, 1965). But in these crops, dwarfs had plant heights of 60-80 cm. In this study, the higher yielding dwarfs were in the culm lenght range of 112-124 cm. Thus, the question is whether this plant height is too dwarf to have the adverse seed size consequences reported to be associated with dwarfism in other cereals.

All the yield trials of our study were conducted under non-lodging conditions. Under high management conditions, leading to vigorous growth, non-d_2 tall composites may suffer serious yield losses due to lodging whereas the dwarfs will likely avert that risk and have a higher yield advantage than that observed in our study. Although not based on isogenic lines, dwarf wheats have been reported to yield less than the tall ones under nutrient and moisture stress (Allan, 1980). Thus, it would be desirable to evaluate the relative yielding ability of these tall and dwarf composites under varying agronomic situations.

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