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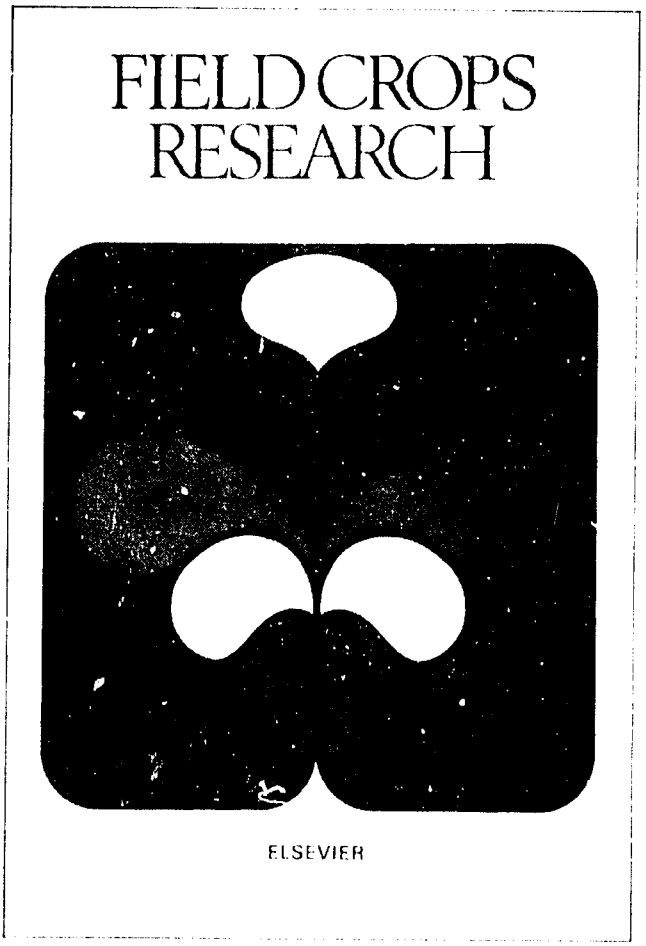

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Emergence and Stand Establishment of Pearl Millet as Affected by Mesocotyl Elongation and Other Seed and Seedling Traits

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ABSTRACT

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Pearl millet [*Pennisetum glaucum* (L.) R. Br.] often is grown in semiarid areas where deep planting could provide adequate moisture during early seedling growth. This study was undertaken to determine whether there are genotypic differences in mesocotyl, coleoptile, and/or primary root development of pearl millet and, if so, whether such differences are associated with variation in ability to emerge and establish from various field and greenhouse planting depths. Seeds of 25 genotypes (17 dwarf and 8 tall) were evaluated in the laboratory for germination and for radicle, mesocotyl, and coleoptile elongation. Seeds of the same genotypes were planted in the greenhouse at 40-, 80-, and 120-mm depths and various depths in the field in 1984 and 1985, then evaluated for emergence and establishment. Among-dwarf and among-tall genotypic differences ($P<0.05$) occurred in mesocotyl length, germination percent, and a germination index emphasizing early germination. Dwarf genotypes also differed in radicle and coleoptile length. Dwarf entries significantly exceeded tall in radicle length (25.8 vs. 21.9 mm). Tall genotypes exceeded dwarf in greenhouse emergence and establishment only at the 120-mm depth, even though dwarf and tall entries did not differ in mesocotyl length in the laboratory. Significant field effects occurred mainly in 1985, when dwarf genotypes exceeded tall in establishment at an 80-mm depth (32 vs. 25%, $P<0.05$) but not at 40 mm. This dwarf genotype advantage was due to superior post-emergence seedling survival rather than to superior emergence. Results indicate that radicle, mesocotyl, and coleoptile length are of limited value as criteria of field-establishment capability under conventional seeding conditions. Radicle and mesocotyl length appear to have potential as indicators of ability to emerge from greater-than-normal planting depth.

INTRODUCTION

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] is an important food crop in semiarid regions of Africa and Asia (Rachie and Majmudar, 1980). Millet often

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must be established under stressful environmental conditions, so that seed quality and seedling traits affecting establishment warrant high priority in any comprehensive program for improvement of the crop (Lawan et al., 1985). Seed germination, seedling emergence, and grain yield have been shown to be positively associated with seed size and seed density in pearl millet (Gardner, 1980; Lawan et al., 1985). Okonkwo and Vanderlip (1985) considered seed size and seed weight to be among the factors determining seed quality in the crop.

Adaptation to planting depth has special significance in crops like pearl millet, since, in areas of limited rainfall, depth of planting often must be adjusted to accommodate soil moisture availability. In several grasses, ability to emerge from various soil depths has been associated with potential for mesocotyl elongation (Hunt and Miller, 1965; Wilson and Loomis, 1967; Turner et al., 1982). Emergence also has been associated with coleoptile elongation (Burleigh et al., 1965; Turner et al., 1982). Tischler and Monk (1980) demonstrated a relationship between planting depth and primary root elongation in kleingrass (*Panicum coloratum* L.). Available literature, however, provides no reports of studies on mesocotyl, coleoptile, or radicle elongation in pearl millet. Objectives of this study were to: (1) characterize differences in mesocotyl, coleoptile, and radicle length among pearl millet genotypes; and (2) investigate relationships among the foregoing traits and seedling emergence and stand establishment.

MATERIALS AND METHODS

Twenty-five genotypes were obtained as seed from the breeding nursery at the Fort Hays Branch Experiment Station, Hays, Kansas. These varied widely in genetic constitution and breeding status, including inbred lines, F_1 hybrids, bulk populations, and open-pollination lines. Dwarf and tall genotypes were represented.

Preliminary examination of results indicated that dwarf and tall genotypes differed in several seed and seedling traits, and, on the basis of that observation, statistical analyses were adapted for comparison of the two groups. Seventeen genotypes were dwarf whereas eight were tall. Pedigrees of most dwarf genotypes included the large-seeded PI 185642 and reflected more breeding and selection for agronomic traits of importance in Kansas than those of tall genotypes.

Laboratory determinations

All laboratory determinations were replicated three times and analyzed as randomized complete blocks. Germination of each genotype was determined from randomly selected samples of 25 seeds. Samples were placed in 90-mm

petri dishes on filter paper moistened with an aqueous solution of sodium hypochlorite (2.6 g NaOCl/l of solution) and maintained in the dark in a germinator at 30°C for 5 days. Seeds were considered germinated when they had produced a plumule and a radicle. Germinated seeds were counted daily, beginning on the 2nd day, and discarded. Germination was the total number of seeds germinated after 5 days, expressed as a percentage of 25. Maguire's (1962) formula was applied to daily germination counts to provide a germination index weighted in favor of early germination.

Additional seeds were germinated to provide seedlings for mesocotyl, coleoptile, and radicle measurements. Twenty-five seeds randomly selected from each lot were arranged in a line across the middle of a double thickness of paper towel that had been soaked in an aqueous solution of sodium hypochlorite (2.6 g NaOCl/l of solution). Towels were rolled at right-angles to the lines of seeds, and rolls were placed upright in beakers. Beakers were placed in the dark in a germinator at 30°C for 5 days. Rolled towels then were removed from the germinator and soaked in tap water to facilitate removal of germinated seeds. Mesocotyl length was measured as the distance from the seed to the coleoptilar node. Coleoptile length was the distance from the coleoptilar node to the tip of the coleoptile. Radicle length was the distance from the seed to the tip of the primary root. Measurements for each sample of 25 seeds were averaged to give a single value for each of the three traits.

Greenhouse determinations

On 23 and 24 March 1985, 25 seeds of each lot were planted in plastic pots in the greenhouse. Pots were 200 mm in diameter and 200 mm deep. Seeds were placed on soil (clay loam texture) in the bottoms of the pots and covered with 40, 80, or 120 mm of sand to provide the desired planting depth. Soil and sand were autoclaved for 2 h before placement in the pots. The experiment was a split plot with planting depths as main plots and genotypes as subplots (individual pots). Main plots were arranged in a randomized complete block with two replications. Pots were watered with tap water at planting and as necessary thereafter. Greenhouse temperature was 29 and 21°C during day and night, respectively.

Emerged seedlings were counted daily for the first 6 days after planting. Total number of seedlings emerged on the 6th day, expressed as a percentage of 25, was recorded as emergence. Daily emergence counts were used to compute an index weighted in favor of early emergence, as indicated by Maguire (1962).

Time to emergence was recorded as the number of days from planting until seedlings had emerged from 20% of the seeds. The time was recorded as 10 when emergence on the 14th day was 1 through 19%, and as 14 when no seed-

lings had emerged by the 14th day. The number of emerged seedlings surviving on the 14th day, expressed as a percentage of 25, was recorded as establishment.

Field determinations

Field determinations were made at the Kansas Agricultural Experiment Station, Manhattan, in 1984 and 1985. The soil at the experimental site was a Haynie very fine sandy loam (coarse-silty, mixed, mesic, Mollic Udifluent). Rainfall for June and July, respectively, was 140 and 27 mm in 1984 and 113 and 51 mm in 1985. Mean temperatures for June and July, respectively, were 23 and 26°C in 1984 and 22 and 26°C in 1985.

Seed of each lot was planted at two depths: 30 and 50 mm in 1984 and 40 and 80 mm in 1985. Design was a split plot with genotypes as main plots and planting depths as subplots in 1984. In 1985, depths were made main plots and genotypes subplots to increase precision on genotype measurements. In both years, main plots were arranged in a randomized complete block with three replications.

Each subplot consisted of a single 5-m row. Row spacing was 0.75 m. Seeding was by a two-row vacuum planter, on 5 June 1984 and 28 June 1985. Ninety seeds were planted per subplot in 1984 and 50 in 1985.

Field emergence was determined, in 1985 only, as the number of emerged seedlings per subplot 5 days after planting. Field establishment in both years was the number of seedlings surviving 14 days after planting.

RESULTS

Laboratory determinations

Significant differences occurred among dwarf genotypes in all laboratory variables and among tall in all except radicle and coleoptile length; dwarf/tall differences are shown in Table 1. Dwarf genotypes exceeded tall in radicle

TABLE 1

Overall dwarf and tall genotype means for laboratory determinations

Determinations	Height		LSD ($P<0.05$)
	Dwarf	Tall	
Radicle length (mm)	25.8	21.9	3.2
Mesocotyl length (mm)	18.6	18.7	ns
Coleoptile length (mm)	12.2	11.6	ns
Germination (%)	90	87	ns
Germination index	9.3	9.9	0.5

length. Although the dwarf/tall difference in germination percent was non-significant, tall genotypes exceeded dwarf in germination index, indicating earlier germination for tall entries.

Greenhouse determinations

All variables were significantly affected by planting depth, the effect being modest as depth increased from 40 to 80 mm and more pronounced when it increased from 80 to 120 mm. In several subplots, emergence and establishment were 0 at 120 mm. Dwarf/tall differences were not significant at the 40- and 80-mm planting depths, but at 120 mm, tall genotypes reached 20% emergence sooner than dwarf and exceeded the latter in emergence, emergence index, and establishment (Table 2). The advantage of tall genotypes in time to 20% emergence and emergence index appeared to be largely accounted for by superiority in percent emergence rather than earlier emergence of tall entries. Significant among-dwarf and among-tall differences occurred in all variables except time to 20% emergence. Planting depth interacted significantly with tall genotypes in all variables and with dwarf genotypes in time to 20% emergence and establishment.

Field determinations

The 1984 field study yielded no significant effects except among-tall differences in establishment. In 1985, dwarf genotypes differed significantly in both emergence and establishment. Neither of the dwarf × planting-depth interactions was significant. Tall genotypes differed significantly in establishment and interacted significantly with planting depth in emergence. Although dwarf and tall genotypes did not differ significantly in emergence at either planting

TABLE 2

Overall dwarf and tall genotype means for greenhouse determinations at three planting depths

Determinations	Planting depths						
	40 mm		80 mm		120 mm		LSD[1] ($P<0.05$)
	Dwarf	Tall	Dwarf	Tall	Dwarf	Tall	
Time to 20% emergence (days)	4.5	4.5	5.3	5.7	9.6	7.8	0.8
Emergence (%)	70	71	56	55	5	22	9
Emergence index	3.8	3.8	2.7	2.7	0.2	1.0	0.5
Establishment (%)	76	79	70	68	24	40	8

[1]For comparing dwarf and tall genotype means at the same planting depth.

TABLE 3

Overall dwarf and tall genotype means for field determinations at two planting depths, 1985

Determinations	Planting depth				LSD[1] ($P>0.05$)
	40 mm		80 mm		
	Dwarf	Tall	Dwarf	Tall	
Emergence (%)	41	45	40	41	n.s.
Establishment (%)	32	32	32	25	5

[1]For comparing dwarf and tall genotype means at the same planting depth.

TABLE 4

Selected simple correlations between laboratory determinations and greenhouse and field determinations for dwarf genotypes[1]

Greenhouse and field determinations	Laboratory determinations			
	Radicle length	Mesocotyl length	Coleoptile length	Germination
Greenhouse establishment - 40 mm				0.59
Greenhouse establishment - 80 mm	0.54	0.65		0.76
Greenhouse establishment - 120 mm	0.52	0.57		
Field establishment - 1985 - 40 mm				0.70
Field establishment - 1985 - 80 mm				0.72

[1]All coefficients significant at $P<0.05$; those greater than $\pm$ 0.60 significant at $P<0.01$.

depth, or in establishment at 40 mm, dwarf genotypes exceeded tall in establishment at 80 mm (Table 3).

Correlations

Selected simple correlations between laboratory determinations and greenhouse and 1985 field-establishment are shown for dwarf genotypes in Table 4. The only significant correlations between laboratory and 1984 field variables, with dwarf genotypes, were germination with establishment at the 30- and 50-mm planting depths (r = 0.52 and 0.57, respectively, $P<0.05$). Correlations for tall genotypes have not been tabulated, because few of the coefficients were significant, and degrees of freedom were so low ($n-2=6$) that non-significance was ambiguous. Generally, correlations involving germination index were closely similar to those involving germination %. Similarly, relationships involving greenhouse emergence and greenhouse emergence index resembled

those involving greenhouse establishment, and relationships involving field emergence were similar to those for field establishment.

Radicle and mesocotyl lengths were positively associated with greenhouse establishment at the 80- and 120-mm planting depths but not at the 40-mm depth. Neither greenhouse variable was significantly associated with 1985 field establishment at either planting depth. Coleoptile length was unassociated with either greenhouse or 1985 field establishment at any depth, although it was positively associated with greenhouse emergence at 40 mm ($r = 0.49, P < 0.05$) and with 1985 field emergence at 80 mm ($r = 0.68, P < 0.01$). Germination % (and germination index) were positively associated with both greenhouse and field establishment at the 40- and 80-mm planting depths. They were not, however, correlated with greenhouse establishment at 120 mm.

DISCUSSION

Depths from which seedlings emerged in the greenhouse and field were not accounted for by combined mesocotyl and coleoptile lengths as measured in the laboratory (Table 1). Turner et al. (1982) observed differences in mesocotyl and coleoptile lengths of rice seedlings as measured in soil and on germination pads with and without air flow. They suggested that these discrepancies resulted from differences in CO_2 concentration. Coleoptile elongation in wheat (*Triticum aestivum* L.) has been shown to be affected by temperature (Burleigh et al., 1965). Recent findings (by Khaleeq, unpublished data, 1985) indicate that pearl millet shoot lengths greater than those reported here can be obtained in the laboratory and suggest that the procedure in this study allowed insufficient time for maximum mesocotyl and coleoptile elongation. The procedure followed here was based on results of preliminary trials in which some coleoptile rupturing, after which mesocotyl and coleoptile elongation normally ceases, was observed on the 5th day following initiation of germination. Seedlings were removed for measurement at that point to minimize difficulties caused by continued development and branching of the seedling root system. If seedlings were highly variable in time to coleoptile rupture, more time may have been required for rupture of all coleoptiles and termination of all shoot elongation. To the extent that the time provided was inadequate, mesocotyl and coleoptile lengths presented here would be more representative of rate of elongation than of maximum mesocotyl or coleoptile length, which would be a function of both rate of elongation and time to coleoptile rupture.

It is difficult to explain the superiority of tall genotypes in greenhouse emergence and establishment at the 120-mm planting depth (Table 2) in terms of traits evaluated in the laboratory. Except for a modest advantage in germination index, tall genotypes were inferior or equal to dwarf genotypes in all laboratory determinations (Table 1). Seedling emergence from deep planting

has been found to be more reduced with semidwarfs than with selection of normal height in rice (*Oryza sativa* L.; Turner et al., 1982) and wheat (Burleigh et al., 1965).

Since greenhouse establishment generally was greater than greenhouse emergence (Table 2), some seedlings obviously emerged later than 6 days after planting. That was especially apparent with dwarf genotypes at the 120-mm planting depth, among which a large proportion of established seedlings was unaccounted for at the 6-day emergence count. Greenhouse emergence and establishment counts are perhaps more meaningful as estimates of early and late emergence than as indicators of total emergence and subsequent seedling survival. However, the dwarf/tall differences in number of seedlings emerging from 120 mm, the only planting depth at which significant dwarf/tall differences occurred, were established at the 6-day count and did not change appreciably thereafter.

Superiority of dwarf genotypes at the 80-mm planting depth in 1985 field establishment obviously reflects a dwarf advantage in post-emergence seedling survival, since the dwarf/tall difference in emergence was not significant (Table 3). The advantage, which was not apparent at the 40-mm depth, may have been due to more rapid radicle elongation (Table 1) and superior, subsequent root development of dwarf seedlings. Such a relationship may indicate a partitioning effect, whereby dwarf seedlings devote a greater proportion of their resources to root development.

Correlations provide little support for the use of laboratory measurements of radicle, mesocotyl, and/or coleoptile length as criteria of field establishment capability under conventional seeding conditions. Although dwarf genotypes differed significantly in all laboratory determinations and in both 1985 field determinations, only germination (and germination index) of dwarf genotypes were convincingly associated with 1985 emergence and establishment in the field (Table 4). Greenhouse results, however, indicate that radicle length and mesocotyl length of dwarf genotypes are positively associated with ability to emerge and establish at greater-than-conventional planting depths (Table 4). Radicle and mesocotyl length may warrant attention by pearl millet breeders selecting lines for use in moisture-deficient areas, where deep planting is anticipated as a strategy for providing adequate moisture during germination and early seedling growth.

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