Adaptation of Pigeonpea (*Cajanus cajan* Millsp.) to a Loamy Sand Site in Minnesota

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Abstract. Pigeonpea, a subtropical legume, was successfully grown in a high-latitude ($\approx 45^\circ\text{N}$) environment. Four short-season pigeonpea accessions from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) were subjected to three cycles of pedigree selection. Performance trials (175,000 plants/ha) were conducted on loamy sand with dryland and irrigated sites in 1991 and 1992. Thirty-eight S_3 -derived lines from ICRISAT ICPL 83004 were used in both years and seven S_3 -derived lines from ICRISAT P 2125 and ICRISAT ICPL 85010 were added the second year. Differences ($P \leq 0.05$) in seed yield ($\text{kg}\cdot\text{ha}^{-1}$) were observed among the S_3 lines, with a maximum yield of $1468 \text{ kg}\cdot\text{ha}^{-1}$. The lines also differed ($P \leq 0.05$) for harvest index (HI), calculated as the ratio of seed yield to shoot total dry matter (TDM) with a maximum of 0.48 (line MF-26). Dryland seed yield was strongly correlated with TDM ($r^2 = 0.98$), HI ($r^2 = 0.92$), and early bloom ($r^2 = 0.76$). In a time-of-planting comparison of seven lines in 1992, seed yield was highest ($754 \text{ kg}\cdot\text{ha}^{-1}$) at the earliest (29 Apr.) planting date and declined progressively to $178 \text{ kg}\cdot\text{ha}^{-1}$ at the latest (2 June) planting date, while HI decreased from 0.42 to 0.12. Plants were shorter at maturity in the earliest planting date.

The pigeonpea is a subtropical legume cultivated in tropical and subtropical Australia, India, Africa, the Caribbean, and other warm regions of the world. The crop ranks sixth in world production of dry legumes (Nene and Sheila, 1990). The pigeonpea is used in many ways across the geographic range in which it is grown: immature seeds are used as a fresh or processed vegetable; dry seed is used as a source of flour; the foliage is used for fuel and fodder; and crop stands are used for control of soil erosion from wind and water (Morton, 1976). In the United States, there is current interest in pigeonpea for use as a pulse, forage legume, cover crop, and specialty vegetable. Interest has increased as this crop has been extremely productive under low soil moisture and fertility (Nene and Sheila, 1990).

Landraces in India, the probable center of origin, are usually late maturing (180 to 210 days) and typically are intercropped with a wide variety of earlier maturing legumes, cereals, and oilseeds (Ali, 1990). Short-season, photoperiodically insensitive cultivars recently have been developed at the International Crops Research Institute for the Semi-Arid Tropics

(ICRISAT) ($\approx 30^\circ\text{N}$) for use in a monoculture cropping system (Nene and Sheila, 1990). Gupta et al. (1991) indicated the possibility of successfully cultivating short-duration pigeonpea cultivars at latitudes of 46°N to 46°S .

Our objective was to select within ICRISAT breeding lines that vary for maturity and plant type and to evaluate the resulting selections for productivity. Our long-range goal was to determine if maturity might be hastened such that pigeonpea could be grown in our high-latitude ($\approx 45^\circ\text{N}$) environment, where the frost-free cultivation season is ≈ 120 days. Adaptation of the pigeonpea to this environment could increase opportunity for agricultural diversity and, in particular, might provide a crop species adapted to droughty, infertile soils.

Materials and Methods

Germplasm source, description, and selection procedure. Three pigeonpea accessions (ICPL 83004, ICPL 85010, and ICPL 85024) were obtained in 1988 from John Kraft, U.S. Dept. of Agriculture/Agricultural Research Service, Prosser, Wash. Kraft obtained these accessions in 1986 from Laxman Singh, pigeonpea breeder at ICRISAT, and grew them for observation. We obtained an additional 33 accessions directly from ICRISAT in 1989. The three original accessions were grown at the Univ. of Minnesota Sand Plain Experiment Station, Becker, Minn., on a loamy sand Hubbard Series soil (sandy, mixed udorthentic haploborolls) in 1988 and were variable for maturity and plant habit. Only a few plants in most accessions matured seed, although all plants reached the flowering stage by frost. ICPL 83004, however, was earlier than the

other accessions but also was variable. Earlier maturing plants were shorter and possessed shorter branches, thus appearing more compact in habit. Selection pressure was applied for early maturity in each of three successive years, with selection intensity varying by year. Lines were advanced by pedigree selection in nonreplicated plots each year using the cultural practices described below for a replicated performance trial conducted in 1991 and 1992. The 33 accessions obtained from ICRISAT in 1989 were grown in the field for observation in that year. Individual plant selections were made from two of these accessions (ICPL 87093 and P 2125) and advanced via pedigree selection as described above.

Performance trial. Thirty-eight of the earliest maturing ICPL 83004-derived S_3 lines were chosen for a 2-year performance trial for earliness and yield. In 1991, the 38 lines were compared to each other. Seed of each line was harvested and bulked for trials in 1992. The original ICPL 83004 population was included as a control in 1992. In addition, three S_3 bulked lines from ICPL 85010 and four S_3 bulked lines from P 2125 were added.

Fungicide-treated seed was hand-spaced ≈ 7 cm apart in single-row, 4.5-m plots on 0.9-m centers on 21 May in both years. Single rows were planted as borders along the sides of each experiment, and 4.5-m border plots were planted at the ends of the rows. A randomized complete-block design with two replications was used each year in both a dryland site and an irrigated site separated by several hundred meters. Preplant broadcast incorporation of 42 kg N/ha was practiced both years, and additional N was incorporated during the growing season at $143 \text{ kg}\cdot\text{ha}^{-1}$ in 1991 for the irrigated and dryland areas, respectively. Both test areas received an additional 57 kg N/ha in 1992.

Weed control was achieved via applications of 0.56 kg α,α,α -trifluoro-2,6-dinitro-*N,N*-diphenyl-*p*-toluidine (trifluralin)/ha and 1.68 kg 3-amino-2,5-dichlorobenzoic acid (chloramben)/ha in 1991. In 1992, 0.28 kg trifluralin/ha was the sole herbicide used. The irrigated area received supplemental water as needed to ensure that all plots received at least 25 mm of water per week.

Flowering data (percentage of plants to have reached anthesis) were collected on 6 Aug. 1992 [77 days after planting (DAP)], but were not collected in 1991. Stand counts were made on 26 Aug. 1992 (97 DAP) as number of plants per plot. Plant height also was recorded at 97 DAP for each plot by measuring the distance from the soil surface to the tallest portion of the canopy. At harvest, after killing frosts on 19 Sept. (121 DAP) both years, plants from the middle 2.5 m of each plot were excised at ground level and forced-air-dried at 38°C . Total dry matter (TDM) was recorded, plants were threshed, and harvest index (HI) was calculated, on a plot basis.

Time-of-planting experiment. Seven early maturing S_3 bulked lines were planted on 30 Apr., 14 May, 21 May, and 2 June 1992 at Becker, Minn. There were two lines each from ICPL 83004 (MF-44 and MF-45), ICPL 85010 (MF-47 and MF-48), and P 2125 (MF-51 and

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MF-52), and one (MF-50) from ICPL 87093. A randomized complete-block design with two replications was used at each date. Fungicide-treated seed was hand-spaced ≈ 5 cm apart in single-row, 1.2-m plots on 0.9-m centers. Herbicide and N rates used were identical to those of the 1992 performance trial. Up to 25 mm water per week was applied to supplement rainfall until irrigation was discontinued 21 July (83, 68, 61, and 49 DAP).

The experimental site was visited on numerous occasions to estimate the date of 50% flowering for each plot. Growing degree days (10C base temperature) were calculated for the period of planting until 50% flowering. Plot stand counts were made on 26 Aug. (119, 104, 97, and 85 DAP). Plant heights were measured on the same date as the distance between the soil surface and the highest point of every plant. On 19 Sept. (143, 128, 121, and 109 DAP), entire plots were harvested and data were obtained as in the performance trial.

Data analyses. Analysis of variance (ANOVA) was used to evaluate data from the performance trial. Rank correlation was performed across years to compare performance between dryland and irrigated growing regimes. Due to significantly lower yields under irrigation, dryland data were used for all subsequent analyses. Because the two years differed greatly for growing season temperatures, with drastic reduction in yield in year 2, mean comparisons of breeding lines were performed within year. Following the ANOVA for the time-of-planting experiment, differences among planting dates and among breeding lines were determined via the least significant difference test. Phenotypic correlation analysis testing trait relationships was performed for both experiments, using plot means, with means from both years used in the performance trial.

Results

Performance trial. Yields were 3 to 6 times higher in 1991 than in 1992 (Table 1). Mean daily temperatures for June, July, and August averaged 3.3C lower in 1992 than in 1991. The uncharacteristically cool season in 1992 delayed maturity relative to 1991.

In both years, yield and HI in dryland plots were higher than in irrigated plots (Table 1). Dryland and irrigated plots did not differ for stand ($P \leq 0.05$). The rank correlations for seed yield ($r^2 = 0.55$) and HI ($r^2 = 0.52$) between the dryland and irrigated sites were low, suggesting that performance at one site was not indicative of performance at the other. More dryland plots had plants in bloom 77 DAP than irrigated plots ($P \leq 0.05$) (data not presented), suggesting that irrigation delayed first bloom, with consequent delay in maturity.

Mean dryland seed yields of all ICPL 83004-derived lines in 1991 and 1992 were 1239 and 466 kg-ha⁻¹, ranging from 1026 to 1468 and 376 to 612 kg-ha⁻¹, respectively (lowest yielding lines not shown). The original ICPL 83004 line yielded 565 kg-ha⁻¹ in 1992 (Table 1). The four lines from P 2125 averaged 484 kg-ha⁻¹ and the three from ICPL

Table 1. Mean seed yield and harvest index (HI) of Minnesota pigeonpea S₃ breeding lines selected from ICRISAT ICPL 83004 and grown under dryland and irrigated regimes in 1991 and 1992 at Becker, Minn.

Soil moisture regime ^z	Highest yielding lines ^y	1991		1992	
		Yield (kg-ha ⁻¹)	HI	Yield (kg-ha ⁻¹)	HI
Dryland		1239	0.46	466	0.32
Irrigated		1159	0.41	186	0.15
LSD _{0.05}		19	0.01	20	0.01
	MF-32	1451	0.47	548	0.34
	MF-26	1436	0.48	543	0.34
	MF-27	1404	0.47	548	0.33
	MF-14	1420	0.47	521	0.33
	MF-24	1468	0.47	460	0.34
	MF-11	1416	0.47	504	0.34
	MF-10	1299	0.47	612	0.34
	MF-5	1362	0.47	491	0.34
	ICPL 83004	---	---	565	0.30
	LSD _(0.05) ^x	251	0.05	164	0.05

^zMeans across 38 lines.

^yLines having the highest total yield across both years under dryland culture.

^xLSD based on all entries.

85010 averaged 592 kg-ha⁻¹, but did not differ significantly from the parents (496 and 502 kg-ha⁻¹, respectively).

Dryland seed yield was associated with high HI ($r^2 = 0.92$) and greater TDM ($r^2 = 0.98$) (Table 2). A high correlation was detected between seed yield in 1992 and percentage of plants flowering at 77 DAP ($r^2 = 0.76$). Selection for earliness was effective, as several lines, such as MF-10 and MF-26, were at 60% and 75% bloom, respectively, compared to 40% bloom for ICPL 83004.

HI was improved ($P \leq 0.05$) for lines derived from ICPL 83004 (0.32 vs. 0.30) and ICPL 85010 (0.33 vs. 0.25). Selected lines from ICPL 83004 ranged from 0.33 to 0.34 for HI in 1992 (Table 1). No improvement in HI occurred with selection in P 2125 (0.29 vs. 0.28, $P > 0.05$).

Time-of-planting experiment. Lines derived from ICPL 83004 and ICPL 85010 outyielded lines from P 2125 and ICPL 87093 (Table 3). Lines from ICPL 83004, P 2125, and ICPL 85010 developed a higher HI than the line from ICPL 87093. Plants from the earliest planting dates were shorter than those in later plantings. Final plant stand improved with later planting dates, reaching 92% for the 2 June planting date compared to 76% for the 30 Apr. planting date (Table 3). Seed yield and HI decreased from the earliest to latest planting date. All lines reached at least 50% flowering in all dates of planting. Planting date had no significant effect on the number of growing degree days to 50% flowering.

Seed yield was correlated with HI ($r^2 = 0.88$, $P \leq 0.05$). Seed yield was negatively correlated with plant height ($r^2 = -0.28$, $P \leq 0.05$), suggesting that greater yield was achieved from shorter plants. TDM and plant height were moderately correlated ($r^2 = 0.44$, $P \leq 0.05$).

Discussion

The strong relationships among seed yield, HI, TDM, and flowering suggest various breeding goals, depending on the intended commer-

Table 2. Phenotypic correlations between seed yield, total shoot dry matter (TDM), and harvest index (HI) for 38 Minnesota pigeonpea breeding lines grown under dryland culture at Becker, Minn. (combined data, 1991 and 1992).

	TDM	HI	Bloom ^z
Yield	0.98*	0.92*	0.76*
TDM		0.82*	0.38*
HI			0.74*

^zCorrelations involving days to bloom were based on 1992 data only.

*Pearson correlation coefficients significant at $P \leq 0.05$.

cial use of pigeonpea. Remanandan (1990) reported a negative correlation between seed yield and earliness to flower in tropical cropping systems for pigeonpea, but with the short season in Minnesota, only the earliest genotypes matured. The high positive correlation between yield and flowering date indicates that gains in seed yield and HI may be made by selecting the earliest flowering plants. The extremely early Minnesota-selected genotypes might be expected to produce a high HI as these lines produce a minimum of vegetative material before maturing. Hence, while selection progress for yield can be made by selecting for early flowering in the Minnesota environment, the selected plants will be small. In a tropical environment, higher individual plant yields should be possible, while in a short-season location, high yields probably would more likely be accomplished by increasing the plant density of small-stature plants.

Breeders should strive for later-maturing genotypes if the goal is to increase forage production. Later-maturing ICRISAT accessions have reached heights of 1.5 m in observational plots under Minnesota conditions (data not presented). These genotypes branched heavily and produced large amounts of plant material per hectare, but failed to yield mature seed.

In spite of its subtropical origin and sensitivity to frost, pigeonpea has shown a high degree of cold tolerance at various stages of development during the 6 years we have grown

Table 3. Mean stand, seed yield, plant height, and harvest index (HI) of seven S₃ pigeonpea breeding lines in a time-of-planting trial at Becker, Minn., in 1992.

Minnesota selection designation	Source	Planting date	Stand ^a (%)	Seed yield (kg·ha ⁻¹)	Plant ht (cm)	HI
<i>Lines across planting dates</i>						
MF-45	ICPL 83004		86.4	381	37.9	0.31
MF-44	ICPL 83004		90.8	364	35.9	0.32
MF-47	ICPL 85010		86.0	357	35.9	0.32
MF-48	ICPL 85010		84.4	354	36.8	0.31
MF-50	ICPL 87093		83.2	279	43.4	0.19
MF-51	P 2125		73.2	274	34.0	0.28
MF-52	P 2125		78.0	270	31.2	0.31
LSD _{0.05}			6.5	46	1.1	0.03
<i>Planting dates across lines</i>						
		30 Apr.	76.0	754	34.0	0.42
		14 May	78.8	732	35.2	0.36
		21 May	86.0	506	38.1	0.25
		2 June	91.6	178	38.4	0.12
		LSD _{0.05}	4.9	59	0.9	0.02

^aMeans of four replications, with 25 seeds planted per plot.

it. For example, in the time-of-planting experiment, emerged plants of the earliest two plantings (30 Apr. and 14 May) were subjected to 2C (recorded at standard shelterhouse height) ambient air during the early morning hours of 25 and 27 May. The 21 May planting had not yet emerged, but the low temperatures did not result in decreased plant stand at this time of planting. Some leaf bronzing occurred in the earliest two plantings, but plants quickly resumed growth upon return to normal late-May temperatures.

Future research avenues. The higher yields of pigeonpea grown on dryland loamy sand in 1991 and 1992, as compared to those under irrigated culture, are consistent with the known ability of this crop to withstand environmental stresses (Nene and Sheila, 1990). Based on the small-plot performance in 1991, grain yields of 1200 to 1500 kg·ha⁻¹ are possible at populations of 175,000 plants/ha. In a tropical envi-

ronment, Wallis et al. (1983) reported short duration pigeonpea yields of up to 4570 kg·ha⁻¹ at 400,000 plants/ha. More research is required to determine the plant densities, and other cultural practices, that would maximize the potential of early maturing pigeonpea germplasm in Minnesota. The selections evaluated in our experiments did not fill the 0.9-m interrow space, possibly failing to efficiently use available canopy space.

Additional research regarding time of planting may provide more insight into possible photoperiod effects on early maturing pigeonpea, but under field conditions in Minnesota, photoperiod and temperature effects might be confounded. Chauhan et al. (1987) found that shorter photoperiod hastened flowering in short-duration pigeonpea, while McPherson et al. (1985) found that moderate temperatures (20 to 24°C) hastened flowering.

Our attempts to grow pigeonpea on our

abundant fine-textured soils in Minnesota have been unsuccessful due to failure of the crop to mature. Compared to the droughty loamy sand at the Becker site, these soils are higher in organic matter, warm more slowly in the spring, and retain moisture longer.

The pigeonpea should be investigated further as a possible new crop for low-input culture on sandy soil sites in the upper mid-western United States.

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