

Full Length Research Paper

Genetic enhancement of pigeonpea for high latitude areas in southern Africa

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Pigeonpea [*Cajanus cajan* (L.) Millsp.] is becoming increasingly important in small-holder farming systems in southern Africa. Abiotic factors such as sensitivity to photoperiod and terminal drought frequently reduce yields in the region. Sensitivity to photoperiod results in delayed flowering and maturity which in turn leads to increased susceptibility to terminal drought stress, low winter temperatures, frost as well as interference from free-ranging domestic livestock. The objective of this study was to develop enhanced early maturing pigeonpea types that are suitable for production in the cropping systems prevalent in southern Africa. Segregating populations (through F₉) were developed from crossing combinations between five parental genotypes possessing marked differences in the genetic control of period to flowering and maturity as well as good agronomic and end-use characters. Using morphological markers and agronomic performance indicators, six elite cultivars with enhanced duration to flowering (97 d), maturity (161 d) and high yield potential (3.0 t/ha) were identified following field evaluation for two consecutive seasons at a representative testing location in the prospective production region. The seed of this elite germplasm was disseminated to growers in order to facilitate adoption and to increase the flexibility of pigeonpea production in the region.

Key words: Elite germplasm, genetic enhancement, high latitude, pigeonpea.

INTRODUCTION

Pigeonpea [*Cajanus cajan* (L.) Millsp.] is becoming increasingly important in small-holder farming systems in Eastern and southern Africa partly due to its ability to produce food grain under harsh conditions that are imposed by moisture stress, high temperatures and infertile soils. Typically, the legume is intercropped with cereals such as corn (*Zea mays*), sorghum (*Sorghum bicolor*) and millets (*Pennisetum* spp.). The cereals benefit from the enhanced soil fertility through nitrogen (N₂) fixation and crop residue which improves the levels of organic matter content in the soil. Pigeonpea is also compatible with indigenous soil bacteria (rhizobia), ubiquitous in African soils and requires no artificial seed inoculation with commercial inoculants in order to form effective nodules that can fix N₂.

Although biotic factors cause considerable yield reductions in the region (Gwata et al., 2006; Minja et al., 1999

and 1996; Silim et al., 2005), abiotic factors such as sensitivity to photoperiod and terminal drought are also important. When grown in high latitude areas (> 10° away from the equator), traditional types of pigeonpea are sensitive to photoperiod and temperature (Silim et al., 2006) with plant height, vegetative biomass, phenology and grain yield being affected most (Whiteman et al., 1985). Consequently, the delayed flowering and maturity lead to increased susceptibility to terminal drought that frequently occurs in the region. In addition, the winter season (starting in June in the region) is associated with low temperatures and frost, to which pigeonpea is susceptible. Furthermore, after harvesting the main crops (during May), the small-holder farmers traditionally release their domestic livestock to graze freely (or unattended) in the fields. Such livestock interfere with late maturing crops that may still be growing in the fields. In addition, the delay in crop maturity may interfere with the timing of the succeeding crop thus making it difficult for farmers to develop consistent crop management practices as well as predictable cropping systems. From a marketing view-

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point, the pigeonpea grain from the region is exported particularly to markets in Asia where the prices are attractive before the glut in November. Therefore, the pigeonpea growers in southern Africa require pigeonpea types that can flower and mature early in order to have ample time for processing the grain for export to these markets when demand is at a peak.

This study focussed on the genetic enhancement of early maturing pigeonpea types that are suitable for production in the cropping systems prevalent in high latitude areas in southern Africa. The implications of the newly developed pigeonpea germplasm are discussed.

MATERIALS AND METHODS

Genetic material

Five parental genotypes (originating from the International Crops Research Institute for the Semi-Arid Tropics) possessing marked differences in the genetic control of period to flowering and maturity as well as good agronomic and end-use characters were selected for this study. A short-duration cultivar (ICPL 87091), which is insensitive to photoperiod and matures within 90 d (from emergence) in the southern Africa region (Silim and Omanga 2001), and a medium-duration genotype (ICEAP 00068) that has large grains (100-grain weight = 17 g), formed part of the genetic material. The latter matures within 160 ± 5 d after emergence but is susceptible to fusarium wilt (Gwata et al., 2007). The remainder of the genetic material consisted of three long-duration genotypes (maturing in ≥ 165 d after emergence) that were either resistant (ICEAP 00040; ICEAP 00020) or moderately resistant (ICP 13076) to fusarium wilt. The grain of each of the parental genotypes was white since it is the preferred color by end users in the region.

Hybridization and trait combination

In 1994, crosses (and their reciprocals) were made between the medium-duration cultivar (ICEAP 00068) x short-duration cultivar (ICPL 87091) types at Kiboko Research Station (KRS) ($2^{\circ}20'$ S, Kenya). Similarly, in 1995, crosses (and their reciprocals) were made between long-duration cultivars (ICEAP 00020, ICEAP 00040 and ICP 13076) x short-duration cultivar (ICPL 87091) at KRS. In 1996, seed harvested from F_1 plants of each of the crosses was raised at the same location and advanced to F_6 using a modified single-pod descent method. The later generations through F_9 were raised at Chitedze Research Station (CRS) ($13^{\circ}59'$ S, Malawi) which represented the prospective production region requiring pigeonpea types that flower and mature early in southern Africa.

Selection of elite germplasm

In 2003/2004, single plant selections (SPS) were made at CRS and subsequently planted in unreplicated progeny rows (or observation plots) at the same location during 2004/2005. A high selection intensity ($< 5\%$) was used in order to identify only superior experimental cultivars (exhibiting desired agronomic traits and grain characters) that were subsequently advanced to the next field trial stage. Selection was based primarily on four key indicators for agronomic performance namely the number of days to 50% flowering (50%DF), the number of days to 75% physiological maturity (75%M), grain size as measured by 100-grain weight (100-GW) and grain yield (GY). The underlying assumption was that the values of

the genotypes must be inferred from their developmental impact on the phenotypes. The breeding procedure was adopted in order to optimize the efficiency with which superior combinations of genes could be identified within the shortest possible time with the available resources.

Field evaluation and data analysis

The selected germplasm was evaluated for agronomic performance under rain fed conditions at CRS in 2004/2005 and 2005/2006. At the beginning of the cropping season (in early December), seed of each genotype was sown manually in field plots, each measuring 5.0 m in length and containing five rows spaced 120 cm apart with 50 cm between plants in the row. Standard agronomic management recommendations for pigeonpea were followed throughout the season. During the season, 50%DF, 75%M, 100-GW and GY were measured. Data sets were analyzed using SAS (Statistical Analysis System) procedures (SAS Institute, 1989). Tukey's method was applied to separate the means.

RESULTS AND DISCUSSION

Initially, a total of 1353 SPS were identified at physiological maturity during the 2003/2004 cropping season and subsequently planted in unreplicated observation plots in the following season. During the second half of the 2004/2005 season, there was an abrupt decline in rainfall coupled with a long period of high diurnal temperatures ($\geq 26^{\circ}\text{C}$) at the location (Figure 1). Under these conditions, soil moisture receded rapidly. Consequently, widespread leaf shedding, flower abortion and poor pod development occurred (Figure 2). Similarly, normal seed development was impeded with most genotypes producing shrivelled seed (Figure 3). Under these conditions, the optimum grain yield attained did not exceed 1.0 t/ha (data not shown). On the other hand, the drought provided a realistic form of water limitation condition during the period of cultivar selection. Poor agronomic performance by some of the experimental genotypes under this moisture stress period suggested that they were susceptible to drought. Therefore, the progenies that failed to produce good quality grain were excluded from the next phase of evaluation. In contrast, 30 superior genotypes that were capable of withstanding the severe drought and produced normal grain were evaluated further. Inadvertently, these elite genotypes were selected for at least partial tolerance to drought. Because of the recent increase in the frequency and severity of droughts in the region, the ability of the genotypes to produce yield under moisture deficit conditions is critical to successful crop production in these rain fed cropping systems.

The newly developed germplasm showed considerable improvement in terms of duration to flowering (Figure 4), maturity and yield potential (Figure 5). For instance, in order to attain 50% flowering, cultivar ICEAP 01144/13 and the unimproved local landrace Mtawajuni required 86 d and 119 d respectively (Table 1). Cultivar ICEAP 01514/15 matured significantly ($P < 0.01$) earlier (153 d)

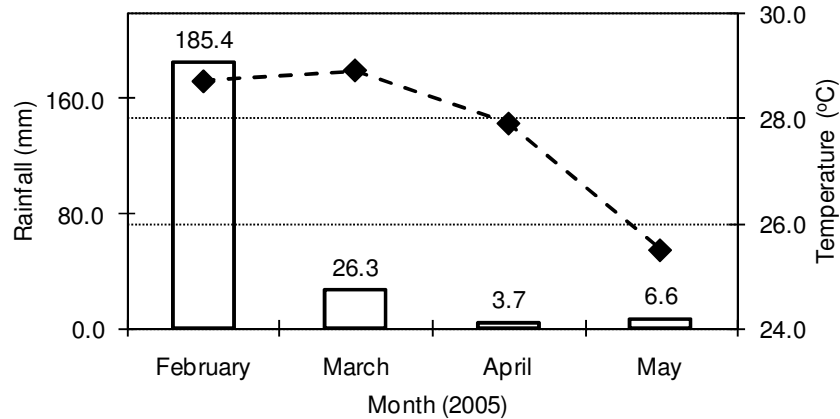


Figure 1. Amount of rainfall (vertical bars) and mean daily temperature (dashed line) during the second half of the 2004/2005 season at Chitedze (Malawi).



Figure 2. Flower abortion and poor pod development in pigeonpea.



Figure 3. Normal, plumb (left) versus abnormal, shrivelled (right) pigeonpea seed.

than both the commercial cultivar Royes (173 d) and the landrace Mtawajuni (172 d). On average, the time to flowering and maturity among the new germplasm was reduced by 10 d in comparison with that for the unimproved landrace. However, there was a weak correlation ($R^2=0.45$) between 50%DF and 75%DM suggesting that early flowering genotypes may still require a relative-

ly long pod fill period. Variation in pod fill period has been reported in other legumes including cowpea (Hall and Grantz, 1981) and peanut (Duncan et al., 1978).

In contrast to the small grain size (100-GW = 13.1 g) associated with the commercial cultivar Royes, the average grain size among the enhanced elite cultivars ranged between 13.6 - 15.5 g per 100 grains. The grain



Figure 4. Early flowering (left) in newly developed pigeonpea germplasm adapted to high latitude areas in southern Africa compared with late flowering in a traditional variety.

color of all the elite germplasm was white which is preferred in the market. The highest grain yield (3.0 t/ha) was observed for the cultivar ICEAP 01480/32 compared with 1.0 t/ha attained by Royes (Table 1). Similarly, cultivar ICEAP 01514/15 obtained 2.9 t/ha. Although higher grain yields (>4.0 t/ha) of hybrid pigeonpea have been reported elsewhere (Saxena and Kumar, 2006), it remains unclear whether such technologies can outperform this newly developed germplasm in the high latitude areas in southern Africa. Probably, this enhanced germplasm could be useful in future genetic improvement activities aimed at development of hybrid pigeonpea technologies for southern Africa.

Because of the high yield potential, appropriate time to maturity and good grain attributes of commercial value, the cultivars are expected to be adopted easily by growers in the region. The seed of this elite germplasm was disseminated to growers in order to facilitate adoption and to increase the flexibility of pigeonpea production in the region. Efforts to introduce this germplasm to non-traditional areas for pigeonpea such as the north-eastern region of South Africa were initiated recently partly because of the high local demand for pigeonpea and the lucrative domestic market that will benefit producers.

In this study, elite germplasm adapted to the high latitude areas was developed successfully. However, it is difficult to conclude unequivocally that the new germplasm is insensitive to photoperiod *per se*. Wallis et al. (1981) concluded that selection for early flowering at high latitudes (27° to 29°) did not necessarily identify material insensitive to day length. Since photoperiod is quantitatively inherited, a firm conclusion would also require a clear threshold which forms the basis for classifying insensitive versus sensitive material. Furthermore, the



Figure 5. High yield potential in newly developed elite pigeonpea germplasm adapted to high latitude areas in southern Africa.

combined effect of photoperiod length, temperature and photoperiod length x temperature interaction, frequently presents formidable limitations in the interpretation of results from several previous studies designed to elucidate photoperiod sensitivity in legumes. In pigeonpea, Lawn and Troedson (1990) observed that the magnitude of photoperiod and temperature effects could be similar over a range of photothermal values but Wallace and Yan (1998) reported modulation of photoperiod response for flowering by temperatures exceeding 24°C. In soybean, a series of E-genes (Bernard, 1971; Buzzell and Voldeng, 1980; McBlain and Bernard, 1987; Cober and Voldeng, 2001) was associated with its ability to adapt to a wide range of latitudes. Nevertheless, the early maturing pigeonpea types reported in this study were adapted to the high latitude areas in southern Africa. We are hopeful that firstly, the development of this germplasm will increase the flexibility of pigeonpea production in the cropping systems in southern Africa and beyond. Secondly, the specific details of these findings may not transfer to other leguminous species but the breeding principles should find useful parallels elsewhere. In future, it could be interesting to elucidate further the genetic basis of adaptation in pigeonpea.

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Table 1. Agronomic traits of improved pigeonpea cultivars insensitive to photoperiod in Eastern and southern Africa.

| Cultivar | 50% DF (d) | 75% DM (d) | Grain color | 100-Grain weight (g) | Grain yield (t/ha) |
|----------------|------------|------------|-------------|----------------------|--------------------|
| ICEAP 01144/13 | 86 b | 115 c | White | 13.7 a | 2.7 a |
| ICEAP 01160/15 | 112 a | 167 a | White | 14.4 a c | 2.4 a |
| ICEAP 01480/32 | 102 ab | 166 a | White | 13.8 a | 3.0 a |
| ICEAP 01162/21 | 102 ab | 163 ab | White | 14.9 a | 2.6 a |
| ICEAP 01167/11 | 96 ab | 166 a | White | 15.5 a | 2.2 a |
| ICEAP 01514/15 | 84 b | 153 bc | White | 14.4 a | 2.9 a |
| Mean | 97 | 161 | - | 14.4 | 2.7 |
| Royes* | 83 b | 173 a | White | 13.7 a | 1.0 b |
| MtawaJuni** | 119 a | 172 a | Brown | 16.8 a | 1.1 b |

Means in the same column followed by the same letter are not significantly different at the 0.05 probability level by Tukey's test.

*Commercial cultivar in Malawi; **Unimproved traditional landrace popular in Malawi.

inception in the early 1990's at ICRISAT-Nairobi. In particular, we thank the Rockefeller Foundation for the financial support which enabled us to conclude the latter stages of the project. We also sincerely acknowledge the contributions made by several national programs in the Eastern and southern Africa region and fellow scientists.

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