Use of the Kenya Transect for Selecting and Targeting Adapted Cultivars to Appropriate Production Systems

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Introduction

Pigeonpea product ion systems in eastern and southern Africa are based on intercropping or mixed cropping of indeterminate, unimproved long- and medium-durat ion landraces wi t h cereals, short-duration legumes, or wi t h such other long-duration annuals as cot ton, cassava, and castor (Laxman Singh 1991). More recently, longdurat ion pigeonpea varieties have been used in agroforestry (Silim et al. 1991). In these traditional cropping systems, pigeonpea often suffers f rom abiotic (intermi t tent and terminal drought) and biotic (pests and diseases) stresses.

The crop is grown mainly for its grain, which contains between 17 and 28% protein and is an impor tant diet supplement for subsistence farmers, who eat mainly lowprotein cereals and root crops (Jambunathan and Singh 1981). Pigeonpea helps improve soil fer t i l i ty, thus contributing to sustainability, through atmospheric N-fixat ion, nut r ient cycling, and leaf fall (Sheldrake and Narayanan 1979).

The traditional landraces in eastern and southern Africa are grown at altitudes varying f rom sea level to about 2000 m. However, pigeonpea is extremely sensitive to temperature and photoper iod, wi t h plant height, vegetative biomass, phenology, and grain yield being the most affected (Byth et al. 1981, Whi teman et al. 1985). This sensitivity is a major constraint to the development of stable and predictable management practices, product ion systems, and varieties (Whi teman et al. 1985). Instability in height and vegetative biomass make management practices (e.g., insecticide spraying, determining plant density) and harvesting difficult. Sensitivity in phenology, if it leads to a delay in matur i ty, may interfere wi t h a wel l developed cropping sequence when the succeeding crop is sown soon after pigeonpea is harvested. A delay in phenology may also reduce yield in areas where rainfall duration is short and where the crop depends on residual moisture. In areas wi t h bimodal rainfall, such as Kenya, acceleration in phenology may result in reproductive growth occurring between the two rainfall periods; the crop woul d thus suffer f rom drought stress. Similarly, where there is accelerated phenology, reproductive growth may coincide wi t h a per iod of high pest incidence (Wallis et al. 1981).

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Concer ted research effort by ICRISAT has resulted in the development of extra short and short-duration varieties that escape drought and are relatively insensitive to photoper iod, thus increasing the flexibility of pigeonpea cultivation and facilitating its use in di f ferent cropping systems (Nene 1991). However, these extra short and shortdurat ion varieties are still sensitive to temperature. For example, our attempts to introduce the crop in the highlands of Kenya in rotation wi t h wheat have not been successful because at low temperature, there was delayed phenology and stunted growth.

Al though pigeonpea is an impor tant source of protein in the dry areas of eastern and southern Af r ica and has a high potential as a commercial crop, there has been no continuous, concerted research effort. We need, therefore, to intensify pigeonpea research in Af r ica because there are still major problems to be solved. Adaptation of the crop in the region is different f rom that in the Indian subcontinent. Medium- and long-duration breeding lines developed at ICRISAT Asia Center, India, have shown high potential there, but have often per formed poorly and are not wel l adapted in eastern and southern Africa. Most of the lines developed in India have small, brown seeds, whereas large, cream or speckled seeds are preferred in Af r ica.

In eastern and southern Af r ica, pigeonpea is grown at altitudes varying f rom sea level to about 1800 m in three major production systems, all of which are found in Kenya:

- Semi-arid, intermediate season (100-125 days) sorghum/maize/rangeland
- Intermediate season (125-150 days) sorghum/maize/finger millet/legumes
- Sub-humid lowland wi t h mixed rice/maize/groundnut/pigeonpea/sorghum.

In stressful environments such as those in which pigeonpea is often grown, if phenology can be predicted, then it would be possible to target and fit genotypes wel l into di f ferent product ion and farming systems. This would enable appropriate genotypes to be grown, exploiting environmental resources to the best benefit of the crop and minimizing the effects of seasonal constraints (Byth et al. 1981).

The Kenya transect, which is near the equator (1°15' to 4°25' S) and which we refer to as a *field laboratory,* varies f rom 0 to over 1800 m in altitude. This offers a unique oppor tuni ty for screening genotypes for adaptation to temperature (which is lower at high altitude) wi t h l i t t le variation in daylength. Variation in photoperiod for screening medium- and long-duration cultivars is achieved by extending daylength using artificial lighting. Four locations that vary in temperature are being used for the study (Table 1).

Objectives

For extra short and short-duration pigeonpea the objectives are to:

- Understand the influence of temperature on phenology, height, biomass, and grain yield
- Determine whether there is variability among cultivars for adaptation to temperature, particularly at sub-optimal levels, so that lines adapted to low temperatures

Table 1. Long-term mean annual maximum and minimum temperatures at locations used in the study, Kenya.

Altitude (m)
Mean temp (°C)
Location Max Min Mean Remarks
Mombasa
Kiboko
Kiboko (Apr-Jul)1
Katumani
Kabete
50
980

1560
1825
30.4
30.4
28.7
24.7
22.3
27.4
16.3
15.3
13.9
12.9
28.9
23.3
22.0
19.3
17.6
High max, high min
High max, moderate nights
High max, low nights
Intermediate max, low min
Low max, low min
1. Data for 1994 only.

are targeted at high-altitude areas where cereals are currently continuously cropped, e.g., wheat-growing areas in Kenya

• Determine whether the Kenya transect is a useful tool for screening pigeonpea cultivars and defining thei r adaptation to temperature, to permi t targeting at appropriate product ion systems in the region. This woul d economize on the number of genotypes required to be tested by the NARS.

For medium- and long-duration pigeonpea the objectives are to:

• Understand the influence of temperature and photoper iod on phenology, height, biomass, and grain yield

• Determine whether genetic variability exists among cultivars f rom different environments in adaptation to temperature and photoper iod

• Determine whether the Kenya transect is a useful tool for screening pigeonpea cultivars for thei r adaptation to temperature and photoperiod so as to best target them to the most suitable environments.

For all matur i ty durat ion groups, major selection criteria (in addition to phenological response) are high grain yield, large seed size, and cream seed color.

Short- and extra short duration pigeonpea

A nursery consisting of 121 lines of determinate (DT) and non-determinate (NDT) extra short and short-duration pigeonpea f rom ICRISAT Asia Center and the Kenyan national program were sown between late Oct and early Nov 1992 at Kiboko, Katumani , and Kabete; and in Apr 1993 at Mombasa. In Oct 1993 and Apr 1994 another set of 64 lines was tested at Kiboko, Katumani, and Kabete. Each treatment plot consisted of two rows 5 m long. Records were kept for daily maximum and minimum temperatures, plant height at flowering, days to flowering and matur i ty, grain yield, and 100-seed mass.

Phenology. Days to flowering and matur i ty were fewest for the Nov sowing at Kiboko. At Mombasa, where mean temperature was high during the growing season,

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phenology was delayed. Similarly, phenology was delayed at Katumani and Kabete, where mean temperatures were low (Tables 1-3). The cultivars developed by the Kenyan national program were of later phenology than those developed by ICRISAT. The results show that the delay in phenology associated wi t h low temperatures may interfere wi t h the cropping sequence in areas wi t h bimodal rainfall, e.g., high-elevat ion (>1600 m) areas of Kenya.

Table 2. Effect of temperature on phenology, height, 100-seed mass, and grain yield in 121 extra short and short-duration pigeonpea genotypes, Kenya, 1992/93.

Days; to
Plant height 100-seed Grain yield
Location Flowering Maturity (cm) mass (g) (t ha-1)
Mombasa1
Range 66-117 110-167 50-217 1.00-3.10
Mean 80 122 91 1.77
Kiboko2
Range 52-110 95-158 36-249 6.9-13.3 0.83-4.33
Mean 60 106 77 10.0 2.18
Katumani3
Range 66-137 119-179 34-153 8.8-15.8
Mean 76 128 58 11.2
Kabete4
Range 83-116 136-178 30-124 9.1-15.1 0.91-4.93
Mean 90 152 57 11.2 2.14

Temperature: 1 = high mean, 2 = high max, moderate min, 3 = intermediate max, low min, 4 = low max, low min

Table 3. Effect of temperature on phenology, height, 100-seed mass, and grain yield in 64 short-duration pigeonpea genotypes sown in Nov 1993 and Apr 1994, Kenya.

Days to
Plant height
(cm)
100-seed Grain yield
Location Flowering Maturity
mass (g) (t ha1)
Kiboko1, Apr 1993 sowing
Range 55-73
Mean 61
82-141
95
46-134
74
6.3-11.6 1.07-2.20

7.7 1.50
Kiboko1, Apr 1994 sowing
Range 60-71
Mean 63
105-158
110
44-94
63
8.2-12.9 1.36-3.56
9.7 2.41
Katumani2, Nov 1993 sowing
Range 79-99
Mean 85
127-163
137
33-69
52
7.3-14.1 0.19-1.97
9.8 1.08
Kabete3, Nov 1993 sowing
Range 76-94
Mean 80
116-138
122
40-91
62
7.4-12.9 1.22-3.15
9.4 2.16
Temperatures: 1 = high max, intermediate min, 2 = intermediate max, low min, 3 = low max, low min

To determine the response of individual genotypes to temperature, we used the general model of flowering responses to photothermal conditions in annual crops in terms of rate of progress towards flowering ($1/f$) (Summerfield et al. 1991), using only the thermal component because short-duration cultivars are relatively insensitive to photoper iod:

$1/f = a + bT$, where f is the number of days to first flower, T is mean preflowering temperature (°C) , and a and b are cultivar-specific constants. The results show that among the lines tested, opt imum temperature (for most rapid flowering) ranged f rom 19.0 to 23.9°C. Since our study focused on pigeonpea suitable for rotation wi th wheat at high elevations, we selected cultivars that showed stability in phenology at sub-optimal temperatures. These cultivars were: KO 71/3, KO 91, KO 109, KZ 63, KZ 69/2, Kat 50/3, Kat 60/8, and ICPLs 87 W, 83016, 86005, 86023, 87091, 87109, 89030, 90013, 90037, and 91009 (Table 4) . The first seven lines were developed in Kenya at high elevation, hence their stability. They are, however, late in phenology and woul d not fit into the cropping sequence in rotation wi t h wheat in Kenya.

Plant height. Reduction in temperature through increase in altitude reduced crop height—plants were shorter at low temperatures (Table 2) . ICPLs 87091, 87109, 90001, and 95004 showed relative stability in height in all environments, whi le cul t i vars f rom the Kenyan national program showed the least stability, growing to 2.5 m at high temperatures.

Grain yield. Grain yields were not adversely affected by variation in mean temperatures (Tables 2 and 3) . Location mean yields were 1.77 t ha-1 for Mombasa, 2.18 t ha-1 for Kiboko, and 2.14 t ha-1 for Kabete (Table 2). Cultivars adapted to various al t i tude/ temperature conditions are listed in Table 5. The criteria used whi le selecting a cultivar for release include acceptable height, phenology that would permi t fitting into a cropping sequence, high grain yield, and acceptable grain color and size. ICRISAT has been supplying nurseries to collaborators in the region for testing. The Kenyan national program has identified Kat 60/8, ICPL 87091, and ICPL 87109 for on- farm trials. Except for Kat 60/ 8 (identified specifically for medium to high elevations), the other cultivars were selected for cultivation at a wide range of altitudes, f rom low to high. Selections made by the national program through multilocational testing agree wi t h ours, which were done using the transect. The major constraint at high altitude is delayed phenology. In Tanzania, ICPL 86005 has consistently performed wel l at low to intermediate elevations and is now being tested on- farm. The same cultivar was also ident i f ied, using the Kenya transect, as adapted to low to intermediate elevations. In multilocational trials conducted in Uganda at about 1000 m al t i tude, Kat 60/8 and ICPLs 86005, 87091, 87101, 87109, and 90029 were ident i fied as the best yielders. A study using the Kenya transect identified the same cul t i vars as among the best adapted and highest-yielding at intermediate elevations. These results conf i rm that the Kenya transect is an effective tool for screening cultivars and ident i fying areas in eastern Af r ica where they are best adapted. We wi l l therefore continue using the transect to test introductions and new breeding lines to target cultivars to appropriate product ion systems.

Table 4. Extra short and short-duration cultivars suitable for different environments in Kenya.

High-yielding,
High to medium altitude, medium altitude, Medium to low
High-yielding, low to intermediate intermediate altitude, high
widely adapted mean temperature temperature mean temperature
ICPL 84031 Kat 60/8 ICPL 83016 ICPL 86005
ICPL 86020 KZ 69/2 ICPL 85045 ICPL 87101
ICPL 86023 KZ63 ICPL 86023 ICPL 89016
ICPL 87091 KO109 ICPL 90009 ICPL 89031
ICPL 87109 Upas 120 ICPL 90043 ICPL 90029
ICPL 87114 ICPL 83024 ICPL 90053 ICPL 90031
ICPL 88018 ICPL 86029 ICPL 91004
ICPL 89008 ICPL 87115
ICPL 89015 ICPL 88034
ICPL 89017 ICPL 89001
ICPL 89031 ICPL 89004

ICPL 90013 ICPL 89014
ICPL 90036 ICPL 89015
ICPL 90043 ICPL 89018
ICPL 90044 ICPL 89019
ICPL 90050 ICPL 89030
ICPL 91036 ICPL 89037
ICPL 90032
ICPL 90033
ICPL 90034
ICPL 90045

Medium- and long-duration pigeonpea

Medium- and long-duration pigeonpea cultivars of diverse origin were grown along the Kenya transect at Mombasa under natural daylength (12 h ± 15 min) and under natural and extended (=14 h ± 30 min) daylengths at Kiboko, Katumani, and Kabete. Mean temperatures vary f rom high at Mombasa to low at Kabete, wi th increase in altitude (Table 1).

Height and biomass. Plant height and biomass production were highest at Mombasa, where mean temperature is high. There was a gradual reduction in height and biomass wi t h a reduction in temperature, such that the shortest plants and lowest biomass were recorded in Kabete, which had the lowest mean temperature.

Medium- and long-duration cultivars under natural daylength

Phenology. Of the 48 lines tested under natural daylength, 29 flowered at Mombasa, 40 at Kiboko, 47 at Katumani, and 48 at Kabete (Table 6) . Al l the test entries

Table 5. Days to flower and percentage change in days to flower due to reduction in growing temperature for extra short and short-duration genotypes, Kenya, 1992/93.

Genotype	Days to flower at Kiboko	Percentage change in days to flower from Kiboko at Katumani	Kiboko
KO 91	110	21	2
KO 71/3	103	-8	12
KZ 69/2	94	47	14
Kat 50/3	85	12	15
KO109	88	16	15
ICPL 83016	79	-4	16
KZ63	91	17	18
Kat 60/8	84	17	22
ICPL 87108	62	16	38
ICPL 87109	63	20	40
ICPL 86005	62	23	40
ICPL 89030	62	16	40
ICPL 91009	59	17	41
ICPL 87091	65	16	41
ICPL 86023	63	16	44

ICPL 87 W *60* 20 45
ICPL 90037 59 22 46
ICPL 90013 62 17 46

Table 6. Influence of temperature and photoperiod on height, phenology, 100-seed mass, and grain yield in medium- and long-duration pigeonpea, Kenya, 1992/93.

Mombasa3 Kiboko4 Katumani5 Kabete6
Attribute Range Mean Range Mean Range Mean Range Mean
Plant height (cm)1 99-310 220 67-285 210 44-173 114
Plant height (cm)2 173-388 285 40-169 116
Days to flower1 78-155 126a 67-269 148b 88-235 124d 97-138 118f
Days to flower2 94-279 190c 83-282 176e 102-192 132g
Days to maturity1 134-184 162 124-268 182 132-268 178 158-209 180
Days to maturity2 147-325 251 155-303 219 172-230 201
100-seed mass (g)1 9.8-17.1 13.1 8.3-18.1 12.0 9.6-20.9 14.5
100-seed mass (g)2 7.6-19.0 12.9 9.2-21.3 13.9
Grain yield1 (t ha-1) 0.73-2.67 1.75 0.66-3.63 1.75 0.53-2.93 1.86
Grain yield2 (t ha-1) 0.94-4.92 2.72 0.42-3.11 1.33

Daylength: 1 = normal, 2 = extended.
Number of lines that flowered: a = 29, b = 40, c = 37, d = 47, e = 48, f = 48, g = 48
Temperature at various locations: 3 = high mean, 4 = high mean with moderate night temperatures, 5 = intermediate,
6 = cool.

flowered and produced grain at Kabete (low mean temperatures), and most flowered and produced grain at Katumani (intermediate maximum, low minimum temperatures). The cultivars that originated f rom high altitude or latitude and were longduration types, failed to flower at Mombasa (high temperatures); at Kiboko they were either late in phenology or failed to flower. The inhibition in flowering was greatest at Mombasa. When the whole transect is considered, results show that most of the lines that flowered at Mombasa flowered earliest at Kiboko and progressively later at Katumani, Kabete, and Mombasa (Table 6) . The cultivars that failed to flower at Mombasa experienced a progressive acceleration in phenology wi t h decrease in temperature (increase in elevation), such that flowering and matur i ty were earliest at Kabete.

We used the component of the photothermal model $1/f = a + bT$ to determine response to flowering.

Results show that crop responses to variation in temperature were basically two: medium-durat ion cultivars that flowered at Mombasa (high mean temperature) and long-duration cultivars that did not flower at Mombasa. The opt imum temperature at which flowering is most rapid in medium-duration cultivars was 2 2 - 2 4 °C, which is similar to that for short-duration cultivars. Temperatures below or above the optimal led to delayed flowering. At high elevation (sub-optimal temperature) ICPs 9191, 10816, 11984, 12113, 12130, and 13510, Tanz 9, and Tanz 23 were stable, as shown by minimum delay in flowering. At supra-optimal temperatures Gujarat Local and ICPs 9191, 11984, and 13582 were stable, as shown by minimum delay in flowering. The results thus show that among the medium-duration cultivars tested, ICP 9191 is stable across a wide range of environments. Across the whole transect, the phenology of long-duration cultivars was accelerated by decrease in temperature, suggesting that long-duration pigeonpeas flower earliest at lower temperatures than the ones tested. We are presently testing at even lower temperatures to determine the point at which flowering is most rapid. In addition, the study has indicated differences among longduration cultivars: those originating f rom high elevations (where temperatures are low) or high latitudes (where days are long during vegetative growth and temperatures are low during reproductive growth) experience greater delay in phenology than do cultivars f rom intermediate altitudes/latitudes, when grown in areas warmer than thei r areas of adaptation (Table 7).

Grain yield. Results show that medium-duration cultivars were generally better adapted and gave high yields in areas wi t h high to intermediate temperature, i.e., areas of low to intermediate elevation (<1500 m) . We have constituted a nursery consisting of the most promising medium-duration lines, which is now being tested in Kenya. The nursery could also be sent, on request, to Uganda and Tanzania for testing.

Long-duration cultivars are better suited to areas wi t h intermediate to low temperatures. We have selected seven cultivars specifically for high elevation: Kat 840, ICP 12783, Farmer 20, Farmer 28, Farmer 31, Farmer 33, and Kenya 5. In the 1994/95 season these wi l l be tested in the Babati area in northern Tanzania. Subse-

Table 7. Effect of temperature under natural daylength (12 h ± 20 min) on number of days to flower in selected pigeonpea cultivars of different origin at four locations in Kenya, 1992/93.

Genotype	Origin Location	Origin Altitude (m)	Days to flower at Mombasa	Kiboko	Katumani	Kabete
ICP 7035	India: Madhya Pradesh	<500	122	86	95	110
ICP 8800	India: Haryana	<500	103	78	103	108
Kat 777	Kenya: Katumani	=1560	*	211	119	123
ICP 9191	Kenya: Kisumu	=1000	117	93	113	115
T 7 * *	India: Uttar Pradesh	<600	*	163	152	132
Kenya 10	Kenya: Machakos	1070	*	234	143	135
ICP 13470	Malawi		155	134	135	127
ICP 6927	Trinidad	<100	119	80	102	120
ICP 13510	Malawi		*	192	122	122
Gujarat Local	India: Gujarat	<300	117	91	110	118
ICP 13252	Kenya: Malindi	<100	112	89	120	117
ICP 9150	Kenya: Makueni	-1100	*	178	131	128
ICP 12783	Tanzania: Mbeya	>1400	*	219	128	123
ICP 13562	Ethiopia: Diban		*	127	138	125
Tanz 23	Tanzania: Nachingwa	470	*	140	110	115
ICP 11984	Philippines: Pingad	<300	149	108	109	114
ICP 10816	India: Assam	<300	93	75	97	98
Kat 81/3/3	Kenya: Katumani	1560	137	133	111	121
ICP 13089	Kenya: Meru	=600	149	143	127	119

Kenya 6 Kenya: Sultan Hamud 1200 * 255 149 130
ICP 12085 Tanzania: Kondoa -1100 * 198 146 132
Babati 1 Tanzania: Babati 1200 * 154 151 128
Tanz 9 Tanzania: Masasi 410 127 96 112 117
ICP 9161 Kenya: Kilifi <100 139 79 104 117
ICP 12134 Tanzania: Kilosa <700 * 206 150 127
* did not flower
** from high latitude

quently, we wi l l also constitute and distribute nurseries of long-duration cultivars for intermediate elevations and high latitudes.

Medium- and long-duration cultivars under extended photoperiod

Extending photoperiod delayed flowering and matur i ty. The effect was greatest at Kiboko, where mean maximum temperatures are high. Cultivars that showed less inhibi t ion of flowering under extended photoperiod were those that originated f rom high elevations, e.g., Kenya 10, Babati 10, and ICP 12782.

Conclusions

The study indicated that medium- and long-duration pigeonpeas have specific adaptat ion. Cultivars f rom low elevation are mostly medium duration, and have high opt i mu m temperature for rapid flowering, similar to the short-duration cultivars. Longdurat ion cultivars have low opt imum temperature (<18°C) for rapid flowering, and are therefore able to flower and produce grain at intermediate to high elevations or latitudes, where temperatures are intermediate to low. The study has further indi cated that there are differences among the long-duration cultivars, wi t h lines originating f rom high-elevation (low-temperature) areas experiencing delayed flowering when grown at intermediate elevations.

Al though we have used the prediction of phenology to target cultivars to specific areas, high grain yield and acceptable grain size are still major considerations during selection.

References

Byth, D.E. , Wallis, E.S., and Saxena, K.B. 1981. Adaptation and breeding strategies for pigeonpea. Pages 450-465 *in* Proceedings of the International Workshop on Pigeonpea, 15-19 Dec 1980, 1CRISAT Center, India (Nene, Y.L., ed.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Jambunathan, R., and Singh, U. 1981. Grain quality of pigeonpea. Pages 351-356 *in* Proceedings of the International Workshop on Pigeonpea, 15-19 Dec 1980, ICRISAT Center, India (Nene, Y.L. , ed.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Laxman Singh. 1991. Overview of pigeonpea improvement research: objectives, achievements, and looking ahead in the African context. Pages 5-16 *in* Proceedings of the First Eastern and Southern Africa Regional Legumes (Pigeonpea) Workshop, 2 5 - 27 Jun 1990, Nai robi , Kenya (Laxman Singh, Silim, S.N., Ariyanayagam, A.P., and Reddy, M.V. , eds.). Nai robi , Kenya: Eastern Africa Regional Cereals and Legumes (EARCAL) Program, International Crops Research Institute for the Semi-Arid Tropics.

Nene, Y.L. 1991. Pigeonpea research: future strategies in Africa. Pages 1-4 *in* Proceedings of the First Eastern and Southern Africa Regional Legumes (Pigeonpea) Workshop, 25-27 Jun 1990, Nai robi , Kenya (Laxman Singh, Silim, S.N., Ar iyanayagam, A.P. , and Reddy, M.V. , eds.). Nairobi, Kenya: Eastern Africa Regional Cereals and Legumes (EARCAL) Program, International Crops Research Institute for the Semi -Ar id Tropics.

Sheldrake, A.R. , and Narayanan, A. 1979. Growth, development and nut r ient uptake in pigeonpea. Journal of Agricultural Science, Cambridge 92:513-526.

Silim, S.N. , Johansen, C, and Chauhan, Y.S. 1991. Agronomy of traditional and new cropping systems of pigeonpea and potential for Eastern Africa. Pages 17-30 *in* Proceedings of the First Eastern and Southern Af r ica Regional Legumes (Pigeonpea) Workshop, 2 5-27 Jun 1990, Nai robi , Kenya (Laxman Singh, Si l im, S.N., Ar -iyanayagam, A.P. , and Reddy, M.V. , eds.). Nai robi , Kenya: Eastern Af r ica Regional Cereals and Legumes (EARCAL) Program, International Crops Research Institute for the Semi -Ar id Tropics.

Summerfield, R.J., Lawn, R.J., Roberts, E.H. , and Ellis, R.H. 1991. Towards the reliable prediction of t ime to flowering in six annual crops. I I . Soyabean *(Glycine max)*. Experimental Agr icul ture 27:11-31.

Wallis, E.S., Byth, D.E. , and Whiteman, P.C. 1981. Mechanized dry seed production of pigeonpea. Pages 51-60 *in* Proceedings of the International Workshop on Pigeonpea, 15-19 Dec 1980, ICRISAT Center, India (Nene, Y.L., ed.). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Whi teman, P .C, Byth, D.E. , and Wallis, E.S. 1985. Pigeonpea *[Cajanus cajan* (L.) Millsp.]. Pages 658-698 *in* Grain legume crops (Summerfield, R.J., and Ellis, E.H., eds.). London, UK: Collins Professional and Technical Books.