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The Phenological Characterization of *Calotropis procera* (Ait) and its Potential for Domestication for Wool Production in Drylands

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ABSTRACT

Nowadays, attention is being paid to exploration of possibilities of exploiting new and under-utilized plant resources with the aim of meeting the growing societal needs. *Calotropis procera* is one among the many under-utilized species despite its many economic and ecological uses. This study was done to characterize the phenology of the species and determine its potential for domestication for wool production. Phenological data was used to generate charts that depicted the flowering and fruiting phenophases for three provenances for four seasons. The data was subjected to Test of Homogeneity of Variances to isolate significant differences in study parameters. Spearman rank pair-wise correlations between wet seasons and flowering were done. Flowering intensity in different months of the year was significantly different (p<0.05) with clear-cut flowering phenophases. Flowering and fruiting durations and active phases were significantly longer and high (p<0.001) during the wet seasons and spearman rank correlations between wet seasons and flowering ranged from 0.89 to 0.96 and were highly significant (r_s, pair-wise correlations, p<0.0001). A very low flower to fruit ratio was recorded. The study concluded that *C. procera* can do well as a plantation crop and has a high potential for production of wool. The strongest impediment to flowering and fruiting was periodic attack by *Aphis nerii*. It is recommended that propagation seeds for *C. procera* should be sourced from the local provenances to reduce the effects of seed source transfer distance.

Keywords: *Calotropis procera*, flowering, fruiting, phenology provenances.

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I. Introduction

Increased population pressure coupled by fast depletion of natural resources has resulted in the exploration of possibilities of exploiting new plant resources in order to meet the increasing needs of human society [1], [2]. [3], [1] stressed on the importance of conservation and use of neglected and under-utilized plant species to meet human wants. Similarly, [4] and [5] advocated on the importance of use and conservation of underutilized plant species especially those whose genetic resources have the potential to address challenges of achieving sustainable agricultural development, food security and sovereignty, and climate change. *Calotropis procera* is one among the many under-utilized plant species with a wide range of economic and ecological uses. According to [6] and [7], *C. procera* has many uses such as medicinal, brewing, and curdling milk, production of silky wool, fodder from pods, production of charcoal, fiber, latex, dyestuff, poison for arrows and spears, soil fertility improvement, indicator of exhausted soils as well as monitoring of air pollution.

In temperate regions, flowering of *C. procera* begins in winter and is thought to start when the plant is at least two years [8], [9]. The plant bears clusters of flowers at the distal end of newly branching shoots. The fruit number varies from 1–3 per cluster. The maximum fruit length ranges from 7.5–9.5 cm depending on the season. The fruit attains maximum length in 20–25 days in early fruiting though this period can increase when fruiting occurs late. *C. procera* fruit takes 30–35 days to mature [10]. [11]–[13] recorded continuous flowering with annual peaks. Long flowering periods is an important attribute for invasive species [13]–[15]. According to [16], in Israel, flowering of *C. procera* occurs for six months, during the spring and summer, with likely slight variations caused by temperature fluctuations. In Israel, the distribution of *C. procera* has been shown to be drastically restricted by temperature conditions due to the plant's "thermophilic" nature [16]. Flowering of *C. procera* in Saudi Arabia starts early in the spring when temperatures are still moderate, last for four months, and finish two or three weeks before the highest temperatures of approximately 50ºC starts [17].

A study was done to characterize the phenology of *C. procera* and evaluate its potential for domestication for wool production in a typical farm setting in drylands. The experiment sought to document phonological events such as flowering and fruiting episodes.

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II. Materials and Methods

A. Research Site

1) Geographical location of the research site

The research work was done in Southeastern Kenya University (SEKU) which is situated in Kitui County, Southeastern Kenya. The study site is located 15km off Kwa Vonza Market, along the Kitui-Machakos road, Kwa Vonza/Yatta ward, Kitui Rural Sub-County, Kitui County. The experimental plot lies at GPS pickings of 01.31358^{0}S, 037.75546^0 E and 01.31422^{0}S, 037.75576^{0}E and at an altitude of 1173m above sea level (Fig. 1).

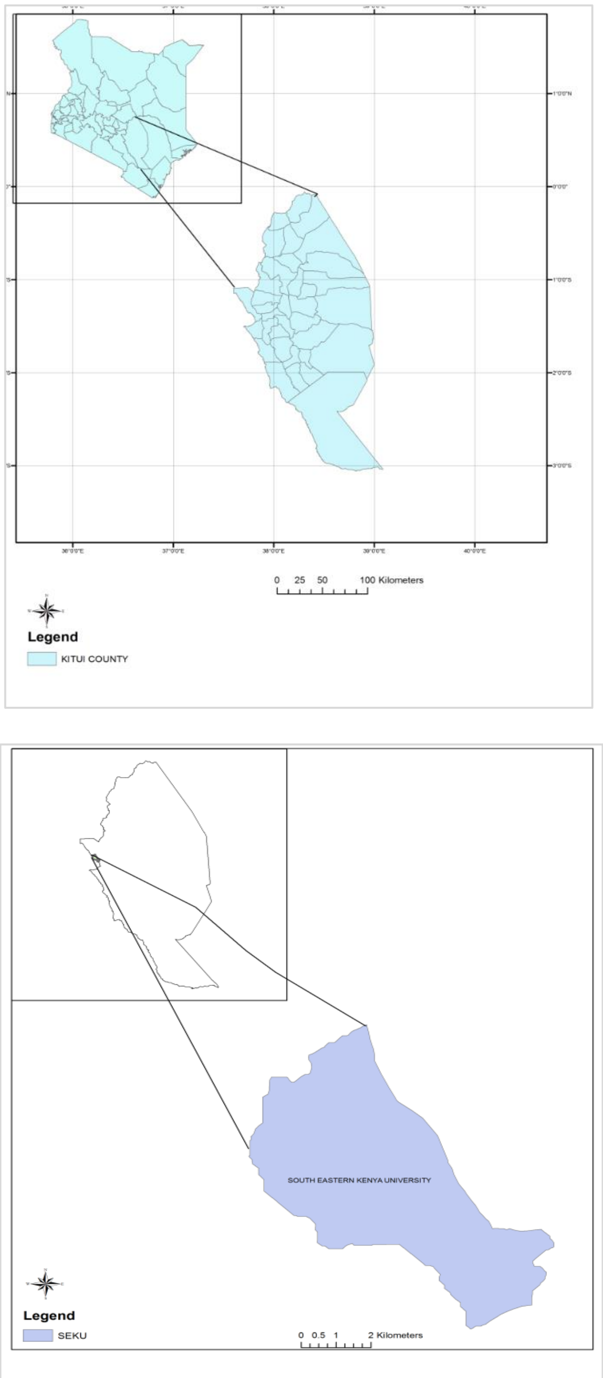

Fig. .1. Location of research site in SEKU, Kitui County, Kenya.

2) Climate

The study site falls in a semi-arid zone under agroecological zone IV whose rainfall regimes are erratic and unreliable. The site experiences a bimodal rainfall pattern with the short rains, which are more reliable, occurring between October-December while the long rains occurring between March-May [18]. The mean annual rainfall ranges between 500–1050 mm with 40% reliability. The study site experiences high temperatures throughout the year which averages between 16 ^{0}C–34 ^{0}C [18]. January-February and June-September are the hottest months with mean minimum and maximum temperatures of 28 ^{0}C and 32 ^{0}C respectively.

3) Soils and geology

The soils of the study site are mainly sandy to loam sand texture, prone to soil erosion and with limited water and nutrient retention capacity. The main soil type of study site is lixisols (red soils) with isolated pockets of alluvial deposits (fluvisols) along rivers and on hill slopes. The soil is poorly drained and readily eroded [19]. Pockets overlain by red well drained sandy loam soils which have quartz and feldspar grains, and felsic gravel rock fragments occur at the study site. Soil depths vary from between 1.2m at the study site to nearly 2.0m at the downslope side of Mwitasyano stream. The geology composed of the study site is characterized by high grade regional metamorphic granitoid granulites which are composed of quartz and feldspars (over 90%) and mafic hornblende and pyroxenes (about 10% or less).

B. Study Site Selection Criteria

The experimental site was selected subjectively since the site is semi-arid thus serving as representative of many drylands in Kenya. Additionally, the study required setting up of nursery and field experiments and the site has existing tree nursery with enough space and other requirements for establishing the two experiments.

C. Selection of C. Procera Provenances

To capture the dry land conditions in the country, seeds were collected from three areas in Kenya: Baringo, Kibwezi and Tharaka Nithi. Though the three areas are all drylands, they represent different geographical zones within the Country.

D. Field Experimental Design

The experiment was set up in a 60m by 80m plot. Within the main plot, 27 subplots were established. The experiment was laid out in a Randomized Complete Block Design (RCBD). In each subplot, 12 planting pits measuring 1ft by 1ft were established. The spacing between subplots was 4m. Three provenances of *C. procera* seedlings namely Tharaka, Kibwezi and Baringo were transplanted. For each provenance, three espacement namely 1.5m x 1.5m, 2m x 2m and 3m x 3m were used. The experiment was replicated three times to give a total of nine treatment combinations. Weeding was done two weeks after transplanting while subsequent weeding was based on the intensity of weeds until the plants were fully established.

E. Phenological Characterization

At the center of each subplot, four plants were randomly selected and tagged when the plants were one month after transplanting. Flowering and fruiting phonological events were monitored on the tagged plants monthly for two years. Data collected during monitoring included number of inflorescences, number of flowers per inflorescent, number of fruits per inflorescent and per plant. Measurement of fruit length and diameter at maturity was done.

F. Data Analysis

Flowering and fruiting data for two years was used to generate charts. Test of Homogeneity of Variances was used to identify statistically significant differences in the study parameters. Spearman correlation analysis between wet seasons and flowering episodes was done. Further, Spearman correlation analysis was done to establish the relationship between flowering and fruiting of the three provenances of *C. procera*. Flower to fruit ratio and mean fruit length and diameter were calculated.

III. Results

A. Flowering of the Three Provenances of C. Procera

Flowering started when the plants were four months old in the month of October (Plate 3.1). At this stage, the plants were still juvenile. However, some plants did not flower. Flowering intensity was very low with individual plants having 1–5 flower clusters (Fig. 2). Each cluster was characterized by 15–30 flowers (Fig. 2). At this age, all the three provenances showed similar trends in flowering with no statistically significant differences (P<0.05). However, when the plants were 1 year old, differences in flowering rates started manifesting with Tharaka provenance showing a slightly higher number of flower clusters followed by Kibwezi and then Baringo (Fig. 3).

Fig.2. Three flower clusters in a 4 month old *C. procera* plant.

Fig. 3. Twenty three flowers in one flower cluster of *C. procera* at the study site.

Flowering seemed to occur throughout the year with mean annual peaks of flower cluster per plant in the month of March (Tharaka–59, Kibwezi–50 and Baringo–49) and October (Tharaka–45, Kibwezi–43 and Baringo–42) every year for the three provenances (Fig. 4). On average, at peak flowering, a mature *C. procera* plant had at least 47 flower clusters translating to atleast 1000 flowers. Flowering was lowest in the month of February (Tharaka–3, Kibwezi–1 and Baringo–1) and June (Tharaka–2, Kibwezi–2 and Baringo–2) every year for all the three provenances (Figure 4).

Peak flowering seemed to be sychronized to concide with the onset of long rains in the month of March and short rains in the month of October (Fig. 4). Flowering durations and active phases seemed to be significantly longer and high ($p<0.001$) during the wet seasons. Further, spearman rank correlations between wet seasons and flowering ranged from 0.89 to 0.96 and were highly significant (r_s, pair-wise correlations, $p<0.0001$).

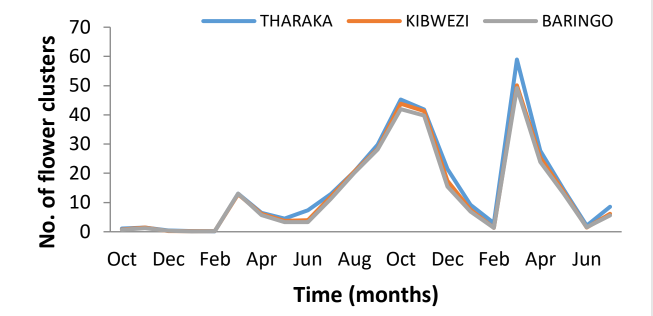

Fig. 4. Flower clusters and flowering phenophases of *C. procera* provenances.

In a typical year during the monitoring period, six flowering and fruiting phenophases were noted (Table I). Though flowering phenophases were clear-cut, flowering occurred throughout the year though off-season flowering was characterized by 1-2 flower clusters per plant.

TABLE I: Flowering and Fruiting Phenophases of *C. Procera*

No.	*Sequential phenophases*	
	Flowering	Fruiting
1	1-2 flower clusters and few flower buds	No fruits
2	1-2 flower clusters and many opening buds	No fruits
3	Opening flowers	Early fruits
4	Peak flowering	Green fruits
5	Few flowers and many withered flowers	Peak fruit maturation
6	1-2 flower clusters and many dried and withered flowers	Fruit dehiscence and seed dissemination

The three provenances did not show statistically significant differences in flowering though all of them portrayed very strong positive correlations (Pearson, $p<0.01$, 2-tailed, $n=189$) in flowering across the year where Baringo had $r_s=1$, Kibwezi ($r_s=0.853$) and Tharaka ($r_s=0.959$). However, flowering intensity in different months of the year was significantly different ($p<0.05$) for the three provenances with clear flowering phenophases (Figure 3.1). Peak flowering phenophases were characterized by massive flowering of the individual stems of *C. procera* (Plate 3.3).

Fig. 4. Mass flowering during peak flowering phenophases

Though the peak flowering phenophases were characterized by heavy flowering, massive flower abortion occurred all through with a limited number making it to the fruiting stage. Attack of flowers by oleander aphid (*Aphis nerii*) was common during flowering period. In extreme cases, all the flower in a cluster failed (Fig. 5) but typically 1–4 flowers made it to fruiting stage (Fig. 6).

Fig.5. Flower abortion in Fig.6. Two flowers transit to
whole cluster fruiting stage.

B. *Fruiting of the Three Provenances of C. Procera*

Fruiting phenophases were evident each year with peak fruiting occuring in the month of April during the long rains season and in the month of November during the short rains season (Fig. 7). A strong sychronization of fruiting and the rain seasons was evident. Fruiting durations and active phases seemed to be significantly longer and high ($p<0.001$) during the wet seasons. At the juvenile stages, fruiting levels in each provenance was almost negligible. Similarly, off season fruiting was negligible. A positive correlation was observed between fruiting and plant age, suggesting that the younger the plant, the lower the number of fruits. In the third and fourth seasons, Tharaka was the most significant in terms of fruit production with an average of 45 and 36 fruits respectively. In the same seasons (Fig. 7), Kibwezi had an average of 39 and 31 respectively while Baringo had the least (37 and 30 fruits respectively). Spearman correlation analysis showed a strong positive relationship ($p<0.05$) between flowering and fruiting in all the provenances.

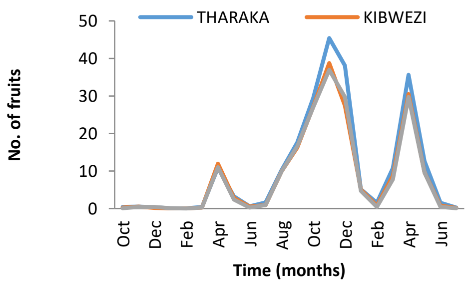

Fig. 7. Fruiting phenophases of the three provenances of *C. procera*.

Fig. 8 below shows the total number of fruits recorded and the number that was harvested for each provenance. In each season, the number of fruits that made to the harvesting stage was generally lower than the total recorded fruits. When the total recorded fruits and the harvested fruits were subjected to DMRT, significant differences were obtained for all the provenances in seasons two, three and four.

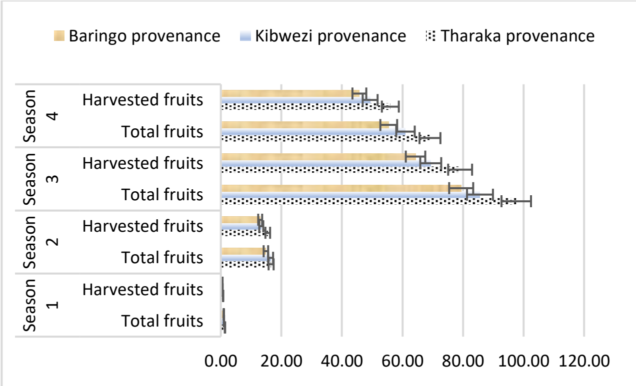

Fig. 8 Seasonal fruit production and number of harvested fruits of C. procera.

In some incidences, fruit abortion occurred at the initial stages of fruiting thereby reducing the total number of harvestable fruits. In other cases, fruits were heavily attacked by *Aphis nerii* (Fig. 9) leading to premature death of the fruits.

Fig. 9. Fruits heavily attacked by the oleander aphids (*Aphis nerii*) at the study site.

Despite the heavy flower and fruit losses, heavy fruiting was common in all the provenances with individual plants having 1-3 fruits per flower cluster (Fig. 10). The number of fruits per stems varied widely in the three provenances. Generally, in season 3 and 4, a minimum of 25 fruits and a maximum of 105 fruits was common in individual stems of the three provenances. Given that at peak flowering a single plant would bear at least 1000 flowers, the transition rate from flowers to fruits ranged between 2.5–10.5%. Generally, the flower to fruit ratio was very low. Concurrent flowering and fruiting was common in all provenances.

Fig. 10. Concurrent flowering and fruiting of *C. procera* plants at the study site.

Typically, fruits took an average of 30–40 days to ripen. Mature fruits had a diameter range of 8.4cm–11.3cm and a mean of 9.6cm. The fruit length at maturity ranged between 7.5cm–11.8cm with a mean of 9.7cm. Once ripe, the fruits split along the ventral suture releasing the wool and the seeds (Fig. 11). In many cases, fruits maintained their green colour at maturity (Fig. 11) making it difficult to differentiate mature and immature fruits. To avoid loss of wool, fruits were harvested shortly before they burst open or once the pericarp showed signs of dehiscence at the ventral suture. The harvested ripe fruits were stored in khaki bags in a laboratory and in 1-3 days, the fruits bursted open and the silky floss (wool) was seperated by hand from the seeds.

Fig. 11. Ripe fruits of *C. procera* at the study site

IV. Discussion

A. *Flowering of the three Provenances of C. procera*

The observed flowering at a tender age of 4 months is likely to have been triggered by the onset of the peak flowering season forcing the *C. procera* provenances to flower regardless of their age. The 4 months coincided with the month of October when flowering of *C. procera* peaked at the onset of short rains. Occurrence of flowering during the short and long rains is an indicator of bimodal phenological event. The observed syschronization of the peak flowering with the rain season is in consistent with [20], who in phenological studies documented that most of the native woody species flowered during the rainy season. [21] have reported similar synchronizing of flowering and rain season in a study on *Tamarindus indica* in Sahel and Sudan.

[22] reported that most of the desert species flower during or after rainy season. Further, [23], in a study using *Senegalia senegal* reported that the species had two peak flowering and fruiting phenophases which were synchronized to coincide with short and long rainy seasons. However, [24] reported a different scenario where flowering of *Sterculia setigera* in Ethiopia coincided with the dry seasons. According to [25] seasonal variation in rainfall and moisture availability are the main causes of flowering periodicity. Since *C. procera* is a dryland species, synchronization of the peak flowering with the onset of the rains is critical to the survival of the species since it ensures that the species flowers, fruits, and seeds at a time when critical resource such as water is not limiting. The 15-30 flowers per cluster obtained in this study is relatively higher than what has been documented. For instance, [26] noted that each flower cluster contains 3–15 flowers. The higher number of flowers per cluster in this study may be attributed to the fact that the *C. procera* were growing in a typical farm setting compared to those growing in the wild where competition for resources is usually high.

The significantly good performance in flower production by Tharaka provenance can largely be attributed to the influence of seed transfer distances. Tharaka being the nearest provenance to the study site in comparison to Kibwezi and Baringo made the provenance to enjoy near home-site advantages. The furthest moved provenance such as Baringo is usually disadvantaged due to changes in environmental and climatic conditions probably resulting to poor performance. Flowering of *C. procera* throughout the year with annual peaks seems to be a typical characteristic of the species. Previous studies, [11]–[13] have documented continuous flowering with annual peaks. [26] reported flowering of *C. procera* throughout the year. According to [13]–[15], long flowering periods is an important attribute invasive species. Elsewhere, [22] in a study on the wering and fruiting eco-physiology of *C. procera* served that the *C. procera* flowers nearly throughout the ar. [27] reported flowering of *C. procera* from March to tober. In temperate regions, flowering of *C. procera* gins in winter [8], [9]. In Israel, flowering of *C. procera* occurs for six months during spring and summer seasons [16] while in Saudi Arabia, flowering starts early during spring and continues for four months [17].

Typically, *C. procera* is characterized by mass flowering as noted during peak flowering seasons in this study. The average of about 1000 flowers per plant is very close to what was obtained by [22] who obtained an average of 959 flowers per plant at the end of the rain season. His study documented very low transition from flowers to fruits as noted in this current study. [22] attributed this low transition to probably lack of enough pollinators resulting in a similar massive failure in fertilization. Massive flowering is also a character typical of species of low fecundity since it ensures that out of the many flowers, a handful make to the fruiting stage thus ensuring continuity of the species.

In this study, mass flower loss was partly attributed to attack by *Aphis nerii*, which was controlled by application of pesticides. The *A. nerii* is a sap sucker which extracts sap from the flowers leading to premature death of flowers. Attack of *C. procera* by *Aphis nerii* (oleander aphids) has been documented by [28]–[30]. According to [31], many mass flowering trees are attacked by specialist flower and seed feeding insects that are satisfied in mast years. Since the *Aphis nerii* were found to attack leaves, flowers, and fruits of *C. procera* at the study site, it is likely that the pest is more of a generalist than a specialist.

The observed flower abortion was also attributed to poor pollination largely caused by the ant-pollinator conflicts. Flowers of *C. procera* had high visitations by ants not only to get nectar from flower but also sugarly dew produced by the *Aphis nerii*. It is most likely that the ants, in the process of protecting the aphids from natural enemies such as the ladybird beetle, kept potential pollinators away and this resulted in ant-pollinator conflict. This probably reduced the pollination and fertilization level and subsequently led to the observed massive flower abortion. The findings of this study agree with [32] who documented that similar protective services by ants which can in turn hinder pollination and keep away pollinators. In their study, they proposed the 'Distraction Hypothesis', whereby extrafloral nectaries located close to flowers can be used to attract the ants and, in the process, keep them away from the reproductive structures and consequently reduce ant-pollinator conflicts especially during pollination period. In a study using *Taramarindus indica*, [21] reported excessive flower abortion after massive flowering. [33] attributed abortion in *Tamarindus indica* to sterility, selfing and low floral visits by pollinators. According to [34], to deal with chronic pollen limitations some plant species have long-lived flowers with long periods of stigmatic receptivity.

The hermaphrodite flowers of *C. procera* might not only have contributed to the observed massive flowering but also a very low flower to fruit ratio. [22, 6, 20, 35] have all reported hermaphrodite flowers in *C. procera*. Most hermaphroditic species exhibit some degree of self-fertilization. Normally, hermaphroditic flowering plants are known to produce more flowers than fruits. According to [36], hermaphroditic plants usually produce many flowers but only a few fruits will reach maturity even in the absence of pollinator limitation and environmental changes.

B. Fruiting of the Three Provenances of C. procera

The occurrence of fruiting phenophases in the month of April and November is an indication that fruiting peaked shortly after peak flowering in the month of March and October when adequate moisture is available. Sychronization of fruiting phenological event with the rainy season is important to allow for fruit growth and maturation since this stage requires a lot of photosynthates. The synchronization of fruiting and rain seasons are in consistence with [21] who in a study in the Sahel and Sudan noted that synchronization of fruiting and rain seasons is an adaptation mechanism developed against water scarcity. [37] who reported that flowering and fruiting activities may be synchronized to coincide with favorable weather conditions for optimum performance further supports the findings of this study. Further, [23] reported synchronization of fruiting of *Senegalia senegal* to peak rain season. In a different study, [38] noted a positive relationship between phenology timing and atmospheric relative humidity.

Lack of fruits in the first season and during off seasons despite flowering taking place is an indication that it is only during mass flowering episodes that some flowers will make it to the fruiting stage. At tender age and off seasons, the number of flowers is small hence minimal chances of survival. As the *C. procera* plants matures and flowering seasons characterized by mass flowering, the chances of meaningful fruiting increases hence the observed positive correlation between *C. procera* age and the number of fruits. Similar relationship between tree size/age and number of fruits has been noted elsewhere. For instance, according to [39], fruit production is a function of tree size, nutrient availability and spacing and larger trees tend to produce more fruits.

The generally high number of fruits produced by Tharaka provenance can be attributed to the high number of flowers produced by the provenance as well as seed source transfer distance. Attack of fruits by *Aphis nerii* coupled with premature fall of juvinile fruits contributed greatly to the observed reduction in harvestable fruits in each of the fruiting seasons. Fruits that formed towards the end of rain seasons (end of April for long rains and end of December for short rains) mostly failed to reach harvestable stage probably due to reduced water availability. Such fruits, which are supposed to mature by May and January respectively fall prematurely due to hot conditions during the two months. The observed 1–3 fruits per flower cluster noted in this study has also been documented elsewhere. For example, [10] reported that the fruit number of *C. procera* varies from 1–3 per inflorescent.

The 25-105 fruits per plant obtained in this study was relatively high compared to [10] average of 23 fruits per plant. [22], in a study on flowering and fruiting eco-physiology of *C. procera*, reported an even lower number of ripened fruits that ranged between 4–18 fruits/plant. Probably, the high number of fruits obtained in this study is because the *C. procera* were grown in a typical farm setting where human agromanagement practices influence the overall productivity. When ripe fruits are not closely monitored, they can dehisce and release the wool. The 30–40 days required for *C. procera* fruits to mature as obtained in this study compares relatively well with the 30-35 days documented by [10]. The recorded fruit diameter and length at maturity in this current study is in consistency with what has been documented in previous studies. For instance, [6],[40] documented that the fruit of *C. procera* can be ≥10cm in diameter. Similarly, [41], [42] reported that the length of *C. procera* fruit varied from one to another averaging between 9–13.1 cm and a mean of 11.7±1.4.

The low number of fruits obtained in this study can also be attributed to the hermaphroditic nature of *C. procera*. In this study, a maximum of 10.5% of flowers per plant managed to transit to the fruiting stage. This percentage is relatively high compared to 1% obtained in other hermaphroditic species such as *Persia americana* where more than 99% of the flowers produced at anthesis are not able to form fruits [43]. It is important to note that hermaphroditic plants are characterized by selfing and some plants will give preference in resource allocation to fruits with a higher proportion of outcrossed seeds while the selfed seeds are aborted leading to selective fruit abortion linked to pollen origin.

V. Conclusion and Recommendations

A. Conclusion

C. procera can do well as a plantation crop in a typical farm setting and has a high potential for production of wool. Flowering occurred throughout the year with peak flowering and fruiting synchronized to coincide with rainy seasons. The plant showed clear cut flowering and fruiting phenophases. Tharaka provenance had the highest number of flowers and fruits compared to Kibwezi and Baringo provenances indicating that for maximum production, propagation seeds should be obtained from the nearest seed source possible. The economical number of fruits per plant can only be obtained from the third season when the plants are big and over one year old. The study can reliably conclude that the strongest impediment to flowering and fruiting was periodic attack by *Aphis nerii* which led to heavy flower and fruit abortions.

B. Recommendations

It is recommended that propagation seeds for *C. procera* should be sourced from the *local* provenances to reduce the effects of seed source transfer distance. Further, for maximum fruit production in a typical farm setting, there is need to control attack of flowers and fruits by *Aphis nerii*.

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Conflict of Interest

The authors declare that they do not have any conflict of interest.

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