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Effectiveness of juvenile traits as selection criteria for yield efficiency in kola

Abraham Akpertey*, Abu Mustapha Dadzie, Paul Kwasi Krah Adu-Gyamfi, Atta Ofori, Francis Kwame Padi

Cocoa Research Institute of Ghana, P.O. Box 8, New Tafo-Akim, ER, Ghana

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ABSTRACT

Variety development for a perennial fruit tree crop like kola (*Cola nitida* (Vent.) Schott and Endl.), requires huge resource investments over several years. Traits that are predictive of high yields and acceptable yield efficiency are therefore, needed to enhance the effectiveness of kola variety development. The objective of this study was to develop a selection criteria for yield in kola to facilitate the breeding of the crop. Thirty-six *C. nitida* progenies derived from bi-parental crosses were planted in a randomized complete block design with four replications in 1997 and analyzed for growth and yield characteristics over an 18-year period. Juvenile phase stem diameter increment and yield during the first 2 years of production were good predictors of nut yields. Progenies that combined slow juvenile growth rate and low yields in the first two yield-recording years had the lowest cumulative yields. Juvenile stem diameter growth and early yield were significantly associated with average yield. Early yield was significantly associated with yield efficiency. The combined selection for fast juvenile phase growth rate and high early yields have the potential of identifying the most productive progenies early in a kola breeding program.

1. Introduction

Kola (*Cola nitida* (Vent.) Schott and Endl.) is a perennial tropical cash crop which originated from the Liberia and Côte d'Ivoire forests (Bodard, 1960). The genus comprises about 140 species (Onomo et al., 2006) of which 50 have been described in West Africa (Bodard, 1962; Adebola, 2003). Kola, though native to Africa (Bodard, 1960), two species especially, *Cola acuminata* and *C. nitida* are commercially grown in various warm tropical regions around the world including West and Central Africa, Caribbean Islands, Mauritius, Sri Lanka and Malaysia (van Eijnatten, 1969; Oladokun, 1985). Kola is allogamous, and valued primarily for its seeds known as kola nuts. These nuts are traditionally used in Western and Central Africa during weddings, funerals and ritual sacrifices. They are also used to produce dyes for the textile industry for dyeing clothes and in the pharmaceutical and food industries to produce cardiac stimulants, laxatives, sedatives and sodas (Egbe and Oladokun, 1987). The nuts vary in colour from dark red to creamy white, each produced by the same species and often occurring in the same pod (Atanda et al., 2011). Pink and white nuts have the highest value because of their sweeter taste and higher caffeine content. In Ghana, the crop is cultivated mainly within latitudes 5 and 8° N where it serves as a source of livelihood of many farmers and traders.

Despite the social and economic importance of the crop, particularly in West Africa, its productivity is affected by many factors including self and cross incompatibility of trees, partial and total sterility, and inefficient natural pollination. The long gestation period in kola sometimes lasting over 10 years, and usually characterized by a long juvenile period, particularly in unselected planting materials limits its cultivation and hence production. Such long gestation periods can be a drawback to the improvement of the crop, as yields, pod and nut characteristics can only be effectively assessed after such long periods. This places a huge financial and human resource burden on kola improvement programmes. As the use of high yielding genotypes are essential for the improvement of kola farming systems, reliance on traits that would facilitate the development and identification of high yielding kola varieties early in the breeding process is paramount.

One primary goal of fruit tree crop breeding is to continuously develop and improve superior breeding progenies to enable genetic advancement through successive generations (Soh et al., 2003). Development of a selection criteria in this regard, is important to facilitate the crop improvement process. Also, to make this process

* Corresponding author.
E-mail addresses: aakpertey@yahoo.com, abraham.akpertey@crig.org.gh (A. Akpertey).

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more successful, selection is usually based on both phenotypic and genotypic differences among individuals and or progenies of crop plants for specific traits of interest (Milc et al., 2011). Yield is the best measure of integrated performance (Austin, 1993) and at the same time, potential yield sets the limit for profitability. Therefore, selection for high cumulative yields will integrate a range of physiological characters and plant response to a changing environment, and yield is thus a measure of overall adaptation and profitability provided that it is estimated over several years. Though kola plantations established from seed begin to bear fruits in the fourth year, peak production occurs between 15 and 20 years after planting (Asogwa et al., 2012). In breeding programmes therefore, yield in kola is typically estimated using average production of trees over at least 5 years of reproductive growth, typically discounting the first two years of production. It is, however, possible that improvement of yield in kola could be achieved efficiently by indirect selection for early yield in the first 2 or 3 years of reproductive growth after planting. Also, the success of indirect selection of best genotypes through the use of vegetative growth parameters determined at the juvenile stages of the plant could improve the efficiency of selection by shortening the breeding program.

Indirect selection for yield based on early stage growth traits has been proposed and effectively applied in other tree crops including rubber (Gonçalves et al., 2004), apples and pears (Visser and de Vries, 1970). Also, the use of morphological markers as an early selection technique for higher yielding varieties has been shown to be efficient in an apple breeding program (Hajnajari et al., 2012). Similarly, in olives, vegetative growth parameters at the seedling stage at transplanting has been shown to be effective as a pre-selection criterion for the early elimination of genotypes with long juvenile periods (Moreno-Alías et al., 2010). Apart from using early growth parameters as selection criteria for yield, the effectiveness of using early year yields as selection criteria for later year yields has been successfully shown in rubber (de Oliveira et al., 2015) and Arabica coffee (Cilas et al., 1998).

Kola progeny evaluation trials studied over several years as pertains in the Kola Improvement Programme of the Cocoa Research Institute of Ghana (CRIG) offers the advantage of studying traits that are predictive of cumulative yield over the productive life of the crop. The objective for this study, therefore, was to develop an effective selection criteria for yield in kola to facilitate the breeding of the crop for high yields in Ghana.

2. Materials and methods

2.1. Genetic materials and trial establishment

The study utilized 36 progenies of kola derived through manual pollinations among 25 female and 32 male parents using a bi-parental mating design. The female and male parents were elite clones in the kola germplasm collection of CRIG assembled from various locations in the Eastern Region of Ghana. The parental clones were selected because of their high yielding potential (>60 pods/tree/year; >200 nuts/tree/year) as well as good nut characteristics including high mean nut weight (>15 g) and high number of nuts per pod (>5).

The experimental site located at the Bunso sub-station (latitude 6°17′ N, longitude 0°28′ W) of the CRIG is characterized by Rhodilixic Ferralsols soil type (WRB, 1998; Ofori-Frimpong et al., 2010) with an annual precipitation of about 1500 mm. The 36 kola progenies were planted in a randomized complete block design with four replications in June, 1997. Five plants per progeny per replication were planted at a spacing of 8 m × 8 m. Plantain was planted 1.5 m away from each kola stand within rows to provide temporary shade whereas *Gliricidia sepium* was planted between rows at a spacing of 8 m × 8 m to provide longer-term shade to the kola plants.

2.2. Agronomic data collected

Juvenile stem diameter was measured 15 cm above the soil surface with electronic calipers at yearly intervals from December, 1997 to December, 1999. Adult tree trunk circumference was measured 30 cm above the soil surface at the commencement of reproduction in September, 2002 and in October, 2015 with a measuring tape. Total pods and nuts per progeny were recorded each year. Annual nut yield per plot (typically from September to March) were estimated from the weight of nuts per 50 pods as a function of the total number of pods collected throughout the season for each progeny. Nuts per pod was estimated as the total number of nuts obtained from the 50 pods divided by 50 for each season; nut weight was estimated as the weight of the total number of nuts collected divided by the total number of nuts obtained and shelling was estimated as the (weight of nuts divided by the weight of pods) × 100 for each progeny for each season. Yield data was collected from 2002 to 2015, except in 2010 and 2011. Trunk cross-sectional area (TCSA) was estimated from the tree trunk circumference measurements using the formula:

$$(\pi d^2)/4$$

where; d is the trunk diameter

The increase in TCSA during the reproductive growth phase for each progeny was taken as the difference between the final (2015) and initial (2002) TCSA estimates for the yield recording phase. Yield efficiency was calculated as the cumulative yield per progeny at the commencement of bearing (2002) to the conclusion of yield recording (2015) divided by the increase in TCSA over the same period.

2.3. Data analysis

All statistical analyses were performed using the GenStat statistical software, version 12 (VSN International Ltd., Hemel Hempstead, UK). Normality of each data was checked based on the plot of the residuals. An analysis of variance which considered all 36 progenies was carried out to test for significant differences among progenies for each trait using a mixed model (REML) repeated measures approach following the autoregressive model order 1 [((AR 1))] correlation structure. For this analysis, crosses and replications were considered random and fixed effects, respectively, and the individual years considered as the time points.

To assess the effects of retrospective selection for nut yield based on seedling growth rate, we used a *t*-test to assess differences in yield of two sets of progenies with contrasting stem diameter increment rates based on TCSA records from 1997 to 1999. For this analysis, the first set (fast growing) consisted of the progeny with the fastest stem diameter increment rate and those with stem diameter increments not significantly different ($P > 0.05$) from this progeny, and the second set (slow growing) consisted of the progeny with the slowest stem diameter increment rate and all other progenies with stem diameter increments not significantly different ($P > 0.05$) from this progeny. Also, we used a *t*-test to assess differences in yield of two sets of progenies (high and low yielding) with contrasting yield performance based on 2002/2003 average yields to assess the effects of possible retrospective selection for yield based on early production year yields. For this analysis the first set (high early yields) included the progeny with the highest 2002/2003 average yield and all the progenies that were not significantly different ($P > 0.05$) from this progeny whereas the second set (low early yields) consisted of the progeny with the least 2002/2003