ISSN : 0974 - 7532 Volume 8 Issue 9

Research & Reviews in

BioSciences

Regular Paper

RRBS, 8(9), 2014 [337-342]

Pollination and yield dynamics of cocoa tree

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ABSTRACT

This study was conducted to evaluate pollination and yield along the vertical plane of cocoa trees. Assessment of fruit-set, survival of set fruits to maturity, pod size, and number of seeds in pods at the canopy, mid- and basal-trunk sections of cocoa tree was conducted. Contrasting pattern in fruit-set, number of pods and number of seeds per pod along the vertical sections were recorded. While the least fruit-set occurred at the canopy level, mid trunk recorded the least and highest pod survival and beans per pod respectively. This inconsistency appears not to follow any known phenomenon in cocoa reproduction, and behaviour and efficiency of pollinators are implicated. Pod sizes were similar despite significant variation in the number of seeds per pod and correlations between pod size, number of pods and number of beans per pod were not statistically significant. Pod production dynamics relative to pollinators and pollination needs intensive assessment.

KEYWORDS

Pollination;
Ceratopogonid midge;
Fruit-set;
Cocoa;
Beans;
Pod.

INTRODUCTION

Cocoa is one of the tropical crops whose low proportion of flowers that are pollinated naturally has generated interest among researchers[1-3]. This is mainly due to its high economic value in the international commodity market. It is the main stay of many rural folks in West Africa which produces about 70% of world's total production[4,5]. Optimizing yield is therefore important for sustained production of the crop and one key area is enhancing natural pollination.

Cocoa exhibits unique characteristics from pollination through pod development. The flower is non-scented and has no nectar[6], which are key attractants and reward for pollinators of flowers[7]. Floral parts are intricately arranged such that most generalist pollinators are barred from effectively transferring pollen to stigma of the flower. Pollination can thus be effected by pollinators that have co-evolved or adapted to this intricate arrangement of the floral parts[8]. Among the guild of insects found on the cocoa flower, only ceratopogonid midges have been confirmed to effectively pollinate it through dexterous manoeuvres on the floral parts[8-10]. The population density, spatial distribution and behaviour of midges directly influence fruit-set hence yield of the crop[3,11].

Although intensive studies relating to cocoa pollination have been sporadic over decades[12], important strides resulting in increasing the overall yield of the crop has been achieved[13]. Shade cover[14], availability and spatial distribution of breeding substrates[15]as well as light intensity and relative humidity[16] have been found to affect midge population and their activities. Other studies on pollen flow, pollen threshold for fertilization,

Regular Paper

flower and fruit development have offered researchers insight into ways of increasing yield production[17,18]. Cocoa is cauliflorous and pollinator access to flowers may be different at the dense canopy compared to the trunk, and this has the potential to influence pollination and fruit survival at different sections of the tree. Hand breeding is widely used by breeders and for production of hybrid seeds for planting hence understanding this dynamics will help determine if pollination intensity should be staggered along the cocoa tree or not. However, dynamics of pollination and pod production along vertical plane of the cocoa tree relative to pollinator services still appears to be in obscurity. A study aimed at opening up this aspect for more intensive research was carried out by investigating the dynamics of fruit-set and pod production along the vertical plane of the cocoa tree.

METHODOLOGY

The study was conducted in two cocoa farms (N05^{0}19.410' W001^{0}24.211' and N05^{0}19.516' W001^{0}24.107') at Abrafo in the Central Region of Ghana, between October 2009 and May 2010, as part of investigation to identify factors that affect fruit set and pod yield in cocoa. Cocoa flowers produce pods throughout the year but the peak and lean periods are influenced by seasons. The study period was therefore designed to cover the dry season and part of rainy season. Both farms had mixtures of hybrid and Upper Amazon varieties of 15 – 25 years old trees, with the latter variety being relatively older.

Each farm was divided into 4 plots, each measuring 1.2 ± 0.2SD acres. Eight cocoa trees were randomly selected from each plot and their measured heights ranged between 3.7m and 5.5m. Three vertical sections of each trunk at heights 0.30 – 1.30m (basal trunk), 1.31 – 2.30m (mid trunk) and 2.31 – 3.30m (canopy) were measured and marked with permanent marker. Due to the many branches at the canopy section (2.31 – 3.30m), the trunk and two branches were selected and their means used.

Fruit-set along vertical plane of cocoa tree

Flower buds due to dehisce within 24 hours at the selected trunk sections were marked on the flower stalk with black indelible ink before 10:00h. Buds about to open are identified by the prominence of grooves along the lines of dehiscing of sepals. Buds were checked the next morning, within the same time period that they were marked, and those that had open remarked with red indelible ink and the numbers were recorded. A total of 23,928 open flowers were marked and the numbers for canopy, mid trunk and basal trunk were 7,884, 8,856 and 7,188 respectively. Open flowers were inspected again, approximately after 72 hours, and those that had set fruit were counted. Flowers that are not pollinated usually drop after 48 hours hence intact flowers still on the trees were considered pollinated[19]. Pollinated flowers are also visible through the enlargement of the ovary and drying up of the tips of the sepals. Another set of flowers were marked after the 72 hours and pollinated ones checked as before. Results of the two set of experiments were pooled together as a single replicate. This was replicated monthly (last week of the month) from October through May.

Fruit yield along vertical plane of cocoa tree

Pods within each vertical section were harvested as and when they ripe and labelled according to the categories between October and May. The number of matured pods measured for canopy, mid trunk and basal trunk were 124, 67 and 115 respectively. The following parameters were determined:

1 *Number of pods*: The number of pods harvested for each category on each sampling day was recorded. Pod survival was also calculated from percent of set fruits that reached maturity.
2 *Pod Size*: Pod sizes were determined by measuring length and girth of the pods using tape measure. Pod length was determined by measuring the distance between the point of attachment to pod stock and the apex of pod. The girth was also measured by winding the tape measure along widest section of the pod.
3 *Number of beans per pod*: Labelled pods were slit open with the blunt edge of cutlass and the number of beans inthem counted.

Data analysis

Fruit set, number of pods at maturity and number of beans per pod at the different tree heights were analysed through one-way ANOVA at 95% confidence interval, using Minitab release 13.3. Data were square root $(X + 0.5)^{1/2}$ transformed before analysis and back transformed before interpretation. Correlation between

pod length, pod girth, number of pods and number of beans per pod were analysed by calculating their Pearson correlation coefficients.

RESULTS

The results showed that the mean number of open flowers produced at the canopy, mid- and basal-trunk were statistically uniform (p>0.339) (TABLE 1). There were significant differencesin mean number (p<0.016) and percent fruit-set(p<0.021)at the three sections of the cocoa tree. While the numbers of fruit-set at the basal- and mid-trunk sections were similar, both were significantly higher than that at the canopy level. The mean number of pollinated flowers that set fruit over the experimental period ranged from 18.24 to 26.67 with the canopy section recording the least. This correspondsto 18.51% to 26.67% of total flowers within these sections of the tree setting fruit.

Although the number of fruit-set at the mid- and basal-trunk sections were not significantly different, their percent fruit-sets were significantly different.

The number of mature cocoa pods also varied among the various sections of the tree butthe trend was different from that observed infruit-set. The number of pods at the mid trunk was significantly lower (p<0.008) than those at the basal-trunk and canopy sections (TABLE 1). Least proportion of fruit-set at mid-trunk survived to maturity and though the pattern was similar to the number of matured pods, significant differences exist among the three sections. It was only at the canopy level that over 50% of set fruits reached maturity. Againthe trend of variation in number of mature pods was exactly opposite that of number of beans per pod relative to the three sections. The number of beans per pod at mid-trunk was significantly higher than both canopy and basaltrunk sections. Both the number of pods and beans per pod were similar at the canopy and basal-trunks.

The lengths (p>0.433) and girths (p>0.845) of pods,as measure of fruit size, were not significantly different within the three sections (Figure 1). The girths of pods, however,exceeded the length of pods by over 7cm. There were weak positive correlation between pod girth and length, as well as pod girth and number of pods (TABLE 2). Similarly, the positive correlation between pod length and number of pods was not significant. The pod length and girth were negatively correlated but they were also not statistically significant.

DISCUSSION

The observation that both the number of fruit-set and proportion of flowers that set fruit at the canopy level was the lowest and also differences in number of beans in pods at different sections of cocoa, may be linked to the behaviour of pollinating midges and abundance of flowers. Ceratopogonid midges are the prime pollinators of cocoa in all growing areas although suit of insects contribute, as incidental pollinators and their limitation critically affect fruit-set[1,3,14]. These midges breed in decaying organic substrates such as moist rotting

TABLE 1 : Pollination and yield variables along the vertical plane of cocoa tree

Vertical section of cocoa tree	Mean number of open flowers	Fruit-set		Matured pods		Mean number of beans/pod
		Mean number	%	Mean number	%survival	
Canopy (2.31 – 3.30m)	98.55±29.72a	18.24±1.01a	18.51±0.97a	15.50±4.73a	57.81±7.44	43.73±1.35a
Mid trunk (1.31 – 2.30m)	110.70±23.28a	23.56±1.81b	21.28±1.32b	8.37±2.06b	23.80±5.77	46.05±0.29b
Basal trunk (0.30 – 1.30m)	89.85±33.63a	23.96±2.66b	26.67±2.60c	14.37±2.96a	40.19±3.78	43.39±0.47a

Number of cocoa trees (N) = 64.Means followed by same letter in a column are not significant at α=0.05.

TABLE 2 : Correlation between pod size, number of pods and number of beans per pod.

Variable	Pearson Correlation Coefficient (r)	p-value
Girth – Length	+0.236	0.460
Girth – Number of pods	+0.208	0.516
Girth – Number of beans per pod	-0.374	0.231
Length – Number of pods	+0.304	0.337
Length - Number of beans per pod	-0.309	0.328

Regular Paper

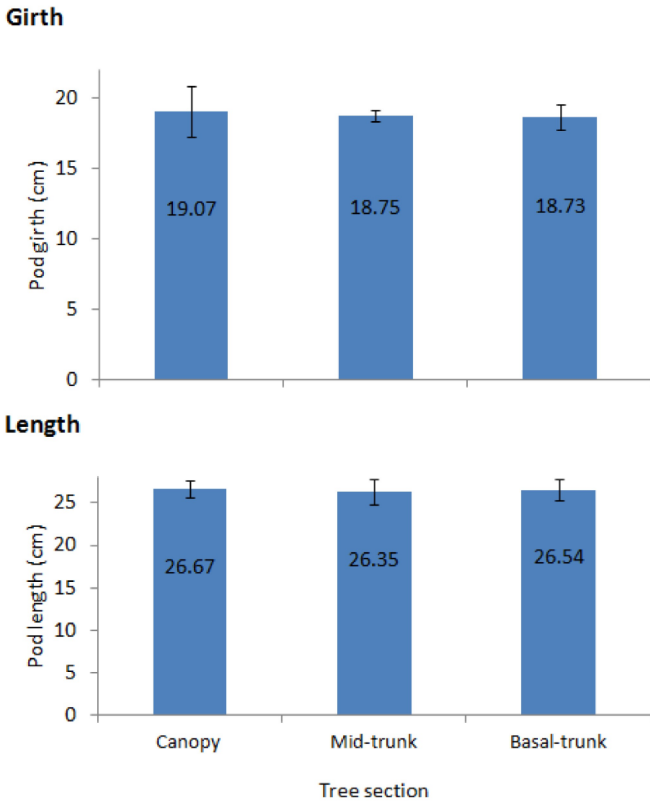

Figure 1 : Pod length and width at different sections of cocoa tree.

cocoa pod husks and leaves, plantain and banana stems, and decaying tree stumps on the ground. They are also found to be more abundant among cocoa trees close to their breeding microhabitat resulting in higher fruit-set among these trees[10,15,20]. Winder[21] also observed that pollinating midges are scarcely available beyond 2m above the ground level.

There are so many branches at the canopy and therefore a lot of flowers are available at this section. Consequently, more floral resources will be available for the relatively fewer pollinating midges in the canopy compared to lower parts of the tree. Thus, relatively less proportion of flowers in the canopy will be visited by pollinating midges. This is supported by the result that the numbers of fruit-set for basal-trunk and mid-trunk were similar but proportion of flowers that was pollinated within the basal-trunk was higher. Based on this argument, the number of beans per pod was expected to be least at canopy section since the lesser the frequency of visitation, the lesser the pollen balls deposited[10,18]. Conversely,number of beansat the canopy was similar to the basal section, which supposedly had higher visitation resulting in significantly high rate of fruit-set.

The high unexpected number of beans at the canopy level therefore shows that though low proportion of flowers was pollinated at that section, they were efficiently pollinated. Falque et. al.[18] demonstrated that there is a positive correlation between the number of pollen grains deposited and the number of beans per pod and that intensively pollinated flowers result in increased number of beans in pods. This suggests the quantity of deposited pollen grains was high at the canopy level, pointing to possible involvement of another pollinating agent since varieties sampled were self-incompatible. Kaufmann[22] observed in Ghana that *Lasioglossum* sp. was more efficient (but not as common as midges) cocoa pollinator which normally forage in the canopy, and might be the candidate responsible for the high pollination efficiency on the canopy flowers in this study. Cocoa pollinator survey in three different cocoa growing areas, including farms used in this experiment, by Frimpong et al.[23] identified *Hypotrigona* (*Liotrigona parvula* Darchen) (rather than *Lasioglossum* sp.) foraging in the cocoa canopy even though their pollination efficiency status for cocoa is yet to be determined. Thus observeddiscordance between fruit-set and number of beans is probably due to the complementary pollination effort by these stingless bees.

It is also worth noting that the mid-trunk recorded the highest number of seeds per pod though the number of fruit-set at this section and basal-trunk were similar but differed in percent fruit-set. This also suggests the possibility of variation in pollinationintensity at different tree sections. The question as to whether different pollinator species, even among the ceratopogonid midges, prefer foraging at different heights and that pollination efficiency is influenced by them appears more complex and needs to be investigated.

Flower-drop and cherelle wilt which occurs few days and from third week after fertilization respectively are phenomena in cocoa that tend to be higher in flowers that receive lower number of pollen grains[19,24]. Thus heavily pollinated flowershave higher chance of surviving to maturity barring diseases and nutrient deficiency[18]. On the contrary, the high fruit-set and number of beans per pod observed on mid-and basal-trunksdid not result in highpod survival. For instance, mid-trunk section recorded relatively high fruit-set and number of seeds per pod but extremely low pod survival. Since this pattern does not appear to follow any

known phenomenon, it is likely that some external pressures such as pests and mechanical removal by wind, man or others may be responsible for these observations.

It can also be inferred from the results that there is a negative correlation, though not statistically significant, between pod size and number of beans in the pod. Moreover, pod sizes along the different sections of cocoa treeswere comparable and therefore significant variation in the number of beans in pods suggest sizes of beansalso vary. Observations indicate that bigger pods do not necessarily contain higher number of beans. There were instances where smaller pods contained more beans than bigger pods and these bigger pods were found to have thicker and woody pod husks. It is suggested that a research into the relation between pod size, weight and number of beans be conducted.

The number of beans did not affect pod size because the correlation between the two was positive though not statistically significant. This means there may be no trade off between increased number of pollinated flowers (fruit-set) and pod sizes but rather a possibe one betweeen increased pollination and bean sizes. Further assessment of these relationships is also recommended.

CONCLUSION

Pollination is highest at the basal section of cocoa tree and this may be attributed to the abundance of pollinating midges at the lower level and the high number of flowers resulting from branches at the canopy level. Natural pollination and yield dynamics of cocoa seem more complex and further study in this area is required for practical application.

ACKNOWLEDGMENT

We are very greatful to the farmers who allowed their farms to be used and also for their cooperation through out the experiment. The logistical and technical services provided by the Global Pollinator Project partners in Ghana is also appreciated.

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Regular Paper

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