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**Fruit and seed production in a natural population of a dioecious plant:
Piliostigma reticulatum HOSCHT (Caesalpinioideae)**

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ABSTRACT

Plant fruit/seed production is a central subject of many questions in plant evolutionary and conservation biology. In the Sudano-Sahelian forest of Burkina Faso, fruit and seed production of a common dioecious shrub, *Piliostigma reticulatum*, were assessed by considering plant size, fruiting success and distance between male and female individuals. The results showed that *P. reticulatum* has a low production of fruits and seeds (17.63 g \pm 3.33 SE of fruit per plant and 0.1045 g \pm 0.0018 SE per seed). A large percentage of the seeds aborted (40%) and were damaged by herbivory (10%). The fruiting success ranged from 0.1 to 0.4. The percentage of seeds attacked by insects was negatively correlated with the mean diameter of the canopy and the height of trees. When the female of *P. reticulatum* was more than 10 meters from the male, fruit and seed productions were greater. The conclusion was that losses of flowers and fruits were important and suggested further information on pollination limitation or genetic studies to identify the cause of the insufficient quality and quantity of fruit and seed productions of *P. reticulatum*.

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Keywords: *Piliostigma reticulatum*, dioecious, fruiting success, soudanian forest, Burkina Faso.

INTRODUCTION

Piliostigma reticulatum (Caesalpinioideae) is a dioecious forage species widely recognized in the soudanian and sahelian areas of West Africa. Its pods are collected almost entirely from natural populations and the processing is done locally. During the last 10 years, however, large scale collection has frequently occurred in northern soudanian zone of Burkina Faso where commercial

harvest and marketing represent a major income source for rural and suburban collectors and processors (CIFOR and CNRST, 2006). Therefore the household income shortfall across this entire supply chain was frequently attributed to insufficient pod production. The socio-economic link between pod production and income can also have clear consequences for sustainable management of the natural population of *P.*

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reticulatum. A comprehensive synthesis of factors explaining fruit production of *D. reticulatum* is lacking. Indeed, there is a paucity of quantitative information on fruit production of most tropical non-timber forest product (fruits, nuts, and seeds) of commercial interest. This is surprising given that non-timber forest products are considered as important component of the economy in developing countries as well as tropical forest conservation strategies (Lescuyer, 2010). Moreover, the status of dioecy confers additional vulnerability in the sahelian area. Since dioecious plant species are largely pollinated by insects rather than through wind pollination (Bawa, 1990), fruiting success in such species largely depends on the sex ratio of the population (Carlsson- Graner et al., 1998; Osunkoya, 1999), and behaviour of pollinators (House, 1992; Stacy et al., 1996). In addition to this, human practises in the open dry tropical forest such as excessive cutting of branches and trees to feed goats, sheep and cattle (personal observations) may also limit the fruit and seed production. The potential effect of the spatial distribution of the sexes within the population of the dioecious species is of particular importance for the fruiting. Fruit set can be limited also by the size of the plant and by fruit and seed predation. Plant size had a consistent positive effect on flowering amplitude in both sexes in a dioecious plant but its effects on other factors, including the extent of fruit set, varied (Torimaru and Tomaru, 2006). Fruit and seed are often eaten by larvae of predators in the soudanian zone (Dao et al., 2006). Many studies have been done in tropical rain forest on the sex ratio, reproductive success and spatial patterns of dioecious plants (Mack, 1997; Ollerton and Lack, 1998; Torimaru and Tomaru, 2006) but it has not received much attention in the dry tropical regions. Therefore, the main objective of this study was to estimate fruit and seed production of trees and to investigate the consequences of

the distance between male and female trees on fruit and seed production of *P. reticulatum* in tropical dry forests, a dioecious plant with different types of plant visitors (Dao et al., submitted). The main focus was to address the following questions: (1) what is the average fruit and seed productivity of *Piliostigma* tree? (2) Do fruit and seed production vary in response to distance between the male and female individuals? (3) What factors explain production, focusing on the tree size (diameter of the canopy and height)? (4) What is the effect of predation on fruit and seed production? (5) Is loss of fruits and seeds to predators related to the plant size?

MATERIALS AND METHODS

Study species

P. reticulatum is a perennial dioecious tree or shrub about 8-10 m of height, growing from the northern part of the soudanian zone to the sahelian zone of Burkina Faso (Arbonnier, 2009). Both females and males produce flowers which are white with pink stripes. Inflorescences are axillaries or terminal panicles and range from 5-15 cm long. Flowering begins in July and the fruiting in late September which corresponds with the rainy season (Dao et al., 2010). Flowers attract many insect visitors and Apidae (Hymenoptera) has been identified as the most abundant and frequent potential pollinators (Dao et al., submitted). Flower buds and flowers are often eaten by larvae of predators. Fruits pods develop during the growing season, ripen in December-January and remain on the plant even after the next year's flowering. Relatively few pods are produced because they are damaged by predators and have few viable seeds.

Study site

The study was conducted at Budtenga village located 40 km east of Ouagadougou, Burkina Faso (Figure 1). Budtenga is located in the north soudanian zone, and the

vegetation is a shrub savannah. Soils are ferruginous tropical loamy soils (Guinko and Fontès, 1995). Rainfall is unimodal: the rainy season lasts from May to September and the average monthly rainfall during the last three years shows an increase in rainfall (in 2007 particularly in August and September).

Vegetal material

The study was conducted in a natural population of *P. reticulatum* at Budtenga where we expected to sample a large number of male and female plants with flowers. All the plants with flowers were marked and Sex expression was determined on the abscised flowers. The study population was characterized by female individuals that produced fruits (female trees) and by fruitless male individuals.

Plants sampling and data collection

Distance between male and female individuals and fruit production

To determine the favourable distance for successful fruit production all the female plants have been selected and the distance between each female and the nearby male measured. A total of 19 circles with 20 m radius were sampled. Twenty meters are used based on the main pollinator's behaviour of *P. reticulatum* (*Apis mellifera*) (Diallo, 2001). The circle was centered around a female plant. During the period of fruit maturity (December 2008) fruit and seed were collected from all female plant in each circle and then the dry mass was estimated.

Fruiting success

Twenty one female plants, 10 racemes per plant and 10 flower buds per raceme were selected at random at the beginning of flowering period (July 2007). During the period of fruit maturity, the number of racemes with mature fruits was counted. Fruits were determined to be ripe from their colour had changed from green to brown. The proportion of flowers that developed into

mature fruits was used as an estimate of fruiting success after open pollination in the population.

Impact of the plant size on fruit and seed production

To evaluate fruit and seed production, 25 female plants were selected at random in the population at the beginning of flowering time (July 2007). We measured the following growth parameters of the plants: height (m) and diameter of the canopy (m). During the period of fruit maturity, all mature fruits from each plant were collected. The damaged (pods that were perforated by parasites or aborted) and undamaged pods were collected separately for each plant. Fruit length and dry mass were recorded. Fruits were oven-dried at 70 °C for one day. The average weight of fruit coat and seeds were estimated and the percentage of damaged fruits and seeds calculated.

Data analysis

Fruiting success was calculated as the ratio the number of mature fruits in a raceme to the number of flower bud in the raceme [mature fruits/flower buds per raceme]. Minitab 13 was used to perform a simple regression analysis to examine the relationship between the responses variables (fruit and seed dry mass, seed attacked and seed abortion) and the predictor variables (distance to nearest male, plant height and canopy diameter).

RESULTS

Impact of distance between female and male plants on fruit and seed production

The Figure 2 shows that the percentage of undamaged seed was positively related to the distance to the nearest male (Pearson's correlation coefficient $r = 0.55$, $P < 0.05$; $n = 19$ females). Keeping in mind that the radius of the circles was 20 m, the nearest flowering male was within a distance of 5 m in 52 percent of flowering females (Figure 3a) and

the maximum distance to the nearest flowering male was 15 m from any flowering female. Fruit and seed production differed according to distant between male and female plants (Figure 3b). For distances less than 5 m, females produced less fruit (2 631 g) and seed (6 446 g) than the others. For distances greater than 10 m, females produced more seed (8 286 g).

Fruiting success

Fruiting success ranged from 0 to 40% (Figure 4). The greatest success was recorded among a small percentage of trees (10%) and 38% of sampled trees completely lost their fruit before maturity.

Fruit and seed production

P. reticulatum produced $17.63 \text{ g} \pm 3.33$ SE of fruit coat per plant and $0.1045 \text{ g} \pm 0.0018$ SE per seed in the study population. Fruit length was estimated at $16.35 \text{ cm} \pm 0.45$ SE. Figure 5 shows the percentage of seed attacked (10.49%), seed aborted (39.98%) and undamaged seed (49.57%) per plant. There was an effect of height on fruit and seed production (Table 1). The production of fruit per class ranged from 16.91 to 18.26 g. The lowest height class (2-3 m) produced the lowest average weight of mature fruit (16.91 g) and the highest height class (4-5 m) produced the highest average weight of mature fruit (18.26 g). The production of seed per height class was also different and ranged from 45.29 g to 41.59 g. But the lowest height class produced more seed (45.29 g) than the

other classes. A decrease in percent of seed attacked was observed from the smallest to the highest height class (Table 1). This means that 13.57% of seeds produced by individuals in the 2-3 m height class were attacked, but only 8.48% were attacked in the highest height class. The same tendency was observed when we considered the average number of holes made by the predator on fruit. The percentage of abortion of seeds varied according to the height of the plants. The middle height class of height (3-4 m) aborted 42.61% of their seeds whereas the lowest class aborted only 33.62%. Figures 6a and 6b show that fruit production was unrelated to the size of the female trees (Pearson's correlation coefficient $r = 0.39$; $P > 0.05$ for canopy diameter and Pearson's correlation coefficient $r = 0.09$; $P > 0.05$ for the height). But there was a significant positive relationship between fruit production and the mean number of holes on the fruit (Figure 6c) (Pearson's correlation coefficient $r = 0.47$; $P < 0.05$). The regression analysis showed that the strongest relationship was with the variable "seed attacked" (Figure 7). The variable "seed attacked" was negatively correlated with the mean diameter of the canopy (Figure 7a) and the height of the female trees (Figure 7b). Their Pearson's correlation coefficients were respectively $r = 0.45$ and 0.52 and their P-values were less than 0.05. Whereas in the Figure 7c, seed abortion was unrelated to the height of the female trees (Pearson's correlation coefficient $r = 0.09$; $P > 0.05$).

Table 1: Fruit and seed production according to the size of trees.

height (m)	Number of individuals	Average weight of fruit coat (g)	Average number of holes/fruit	Average weight of seed (g)	Seeds aborted (%)	Seeds attacked by parasites (%)
2-3	5	16,91	2,98	45,29	33,62	13,57
3-4	18	17,76	2,59	37,55	42,61	9,71
4-5	2	18,26	2,24	41,59	36,01	8,48

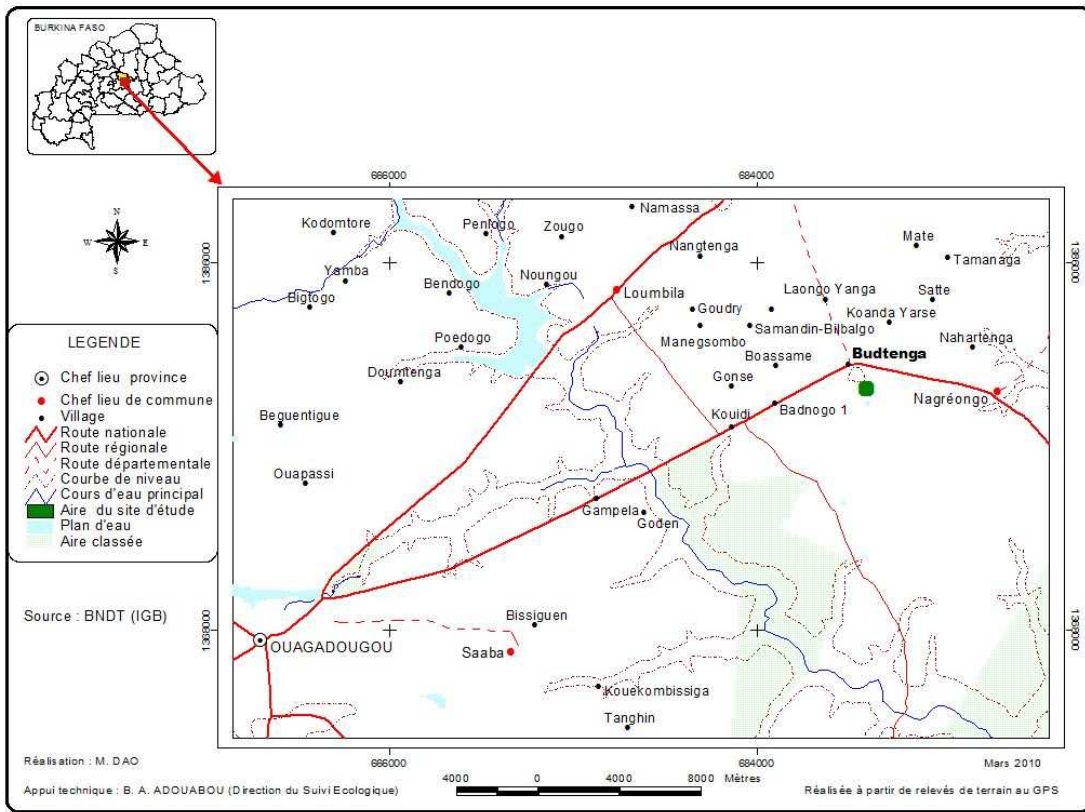


Figure 1: Location of the study area.

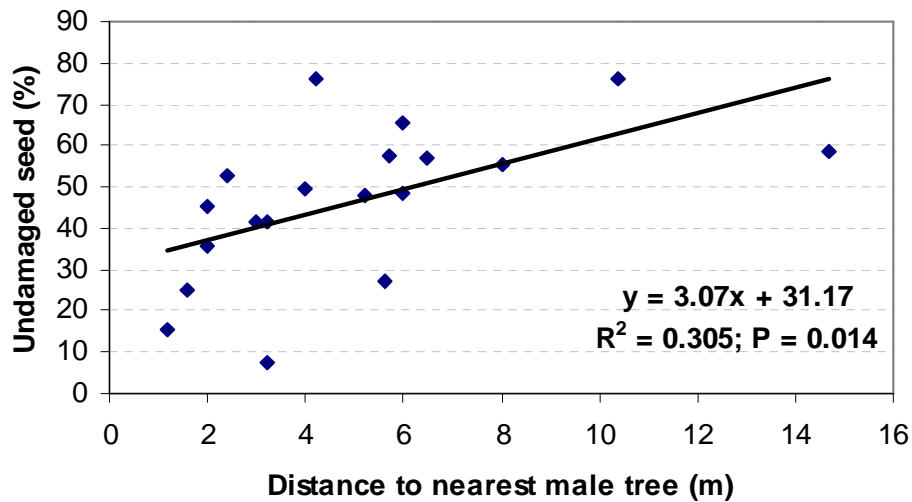


Figure 2: The relationship between the percentages of seed undamaged produced by female trees and the distance to the nearest male trees in *P. Reticulatum*.

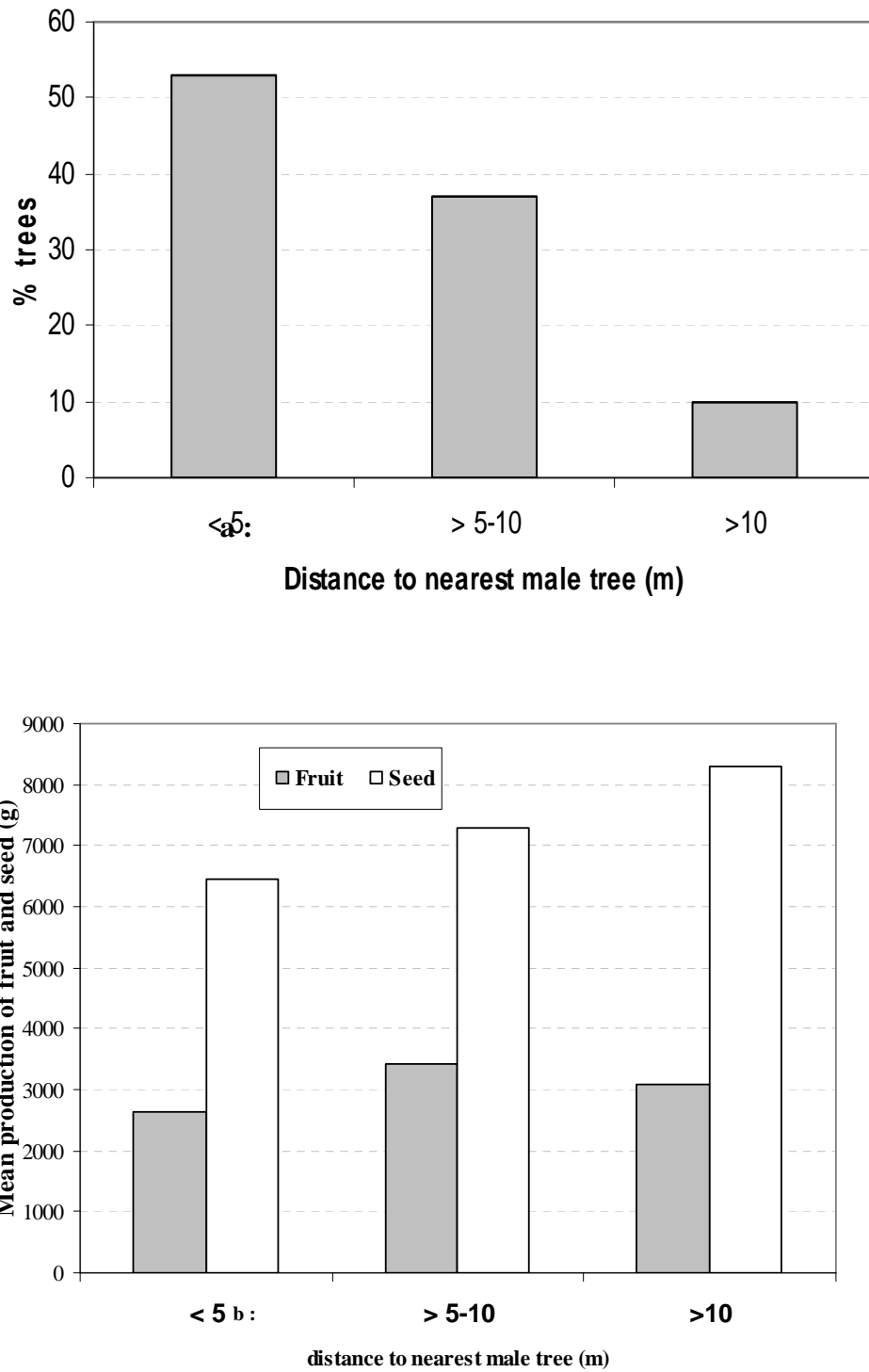


Figure 3: Frequency distribution of the distance from female trees to the nearest male trees (a) and fruit and seed production in *P. reticulatum* (b).

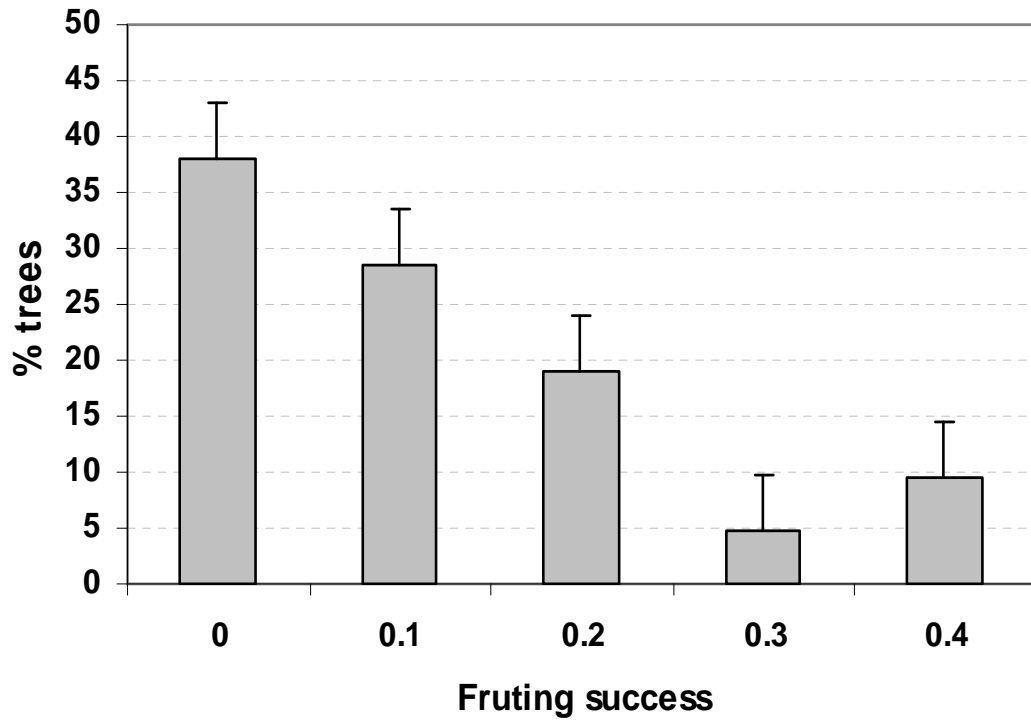


Figure 4: Different fruting successes and their percentages of trees.

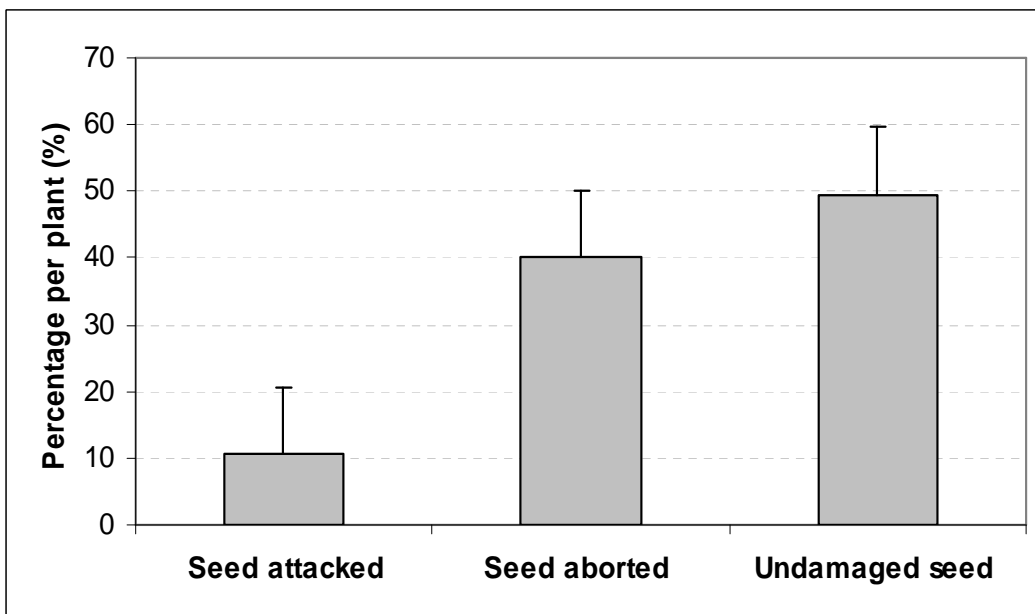
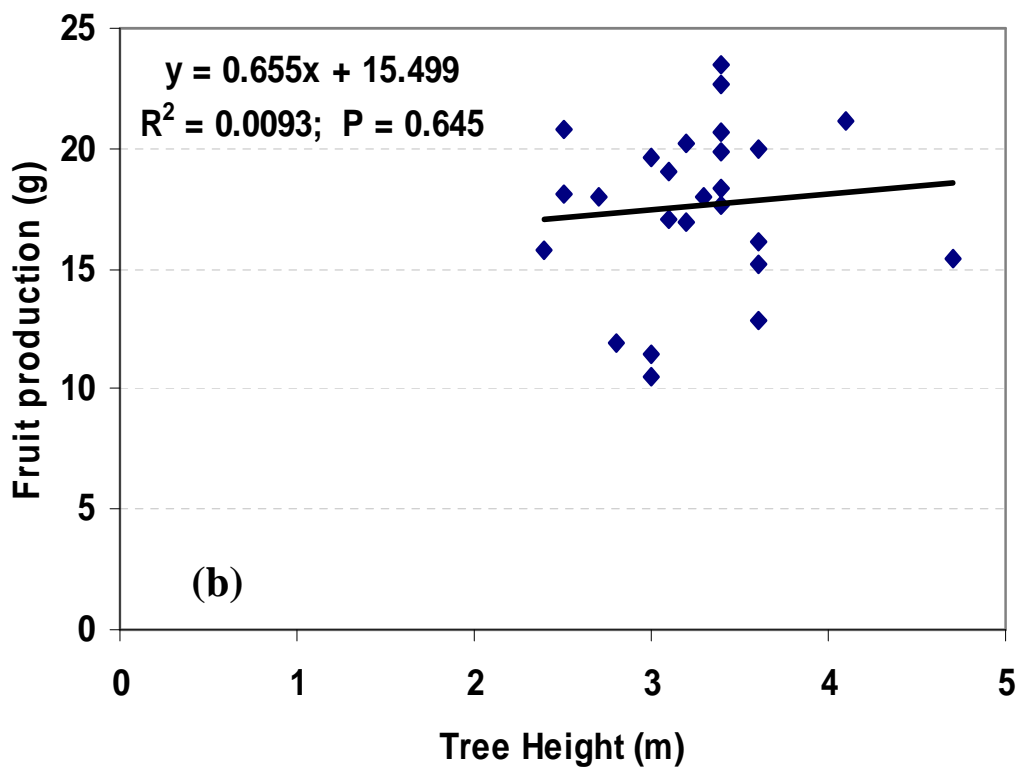
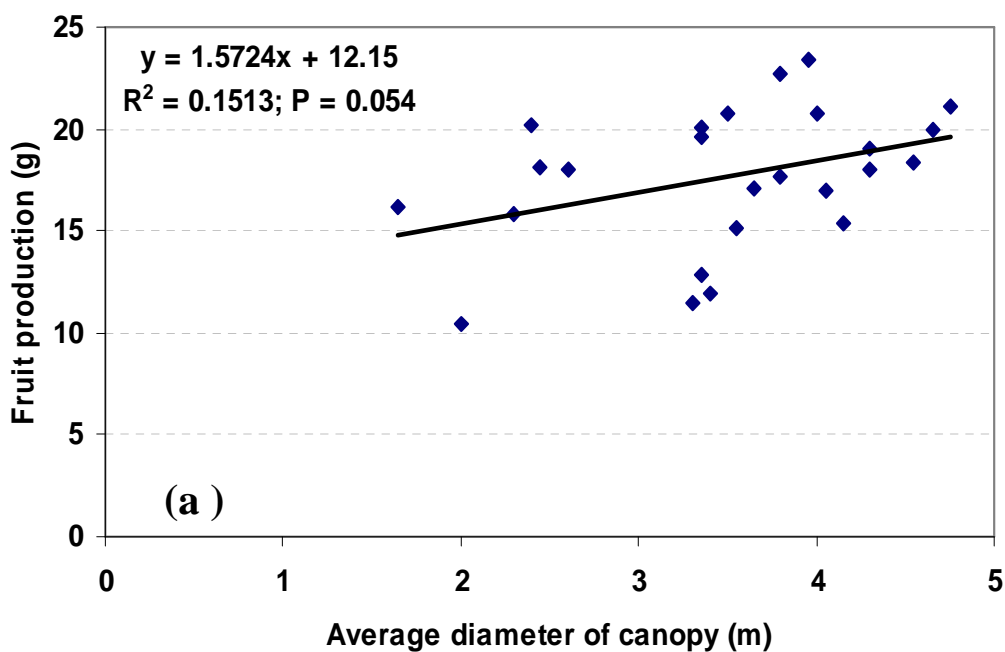


Figure 5: Percentage of seeds attacked, aborted and undamaged per plant.



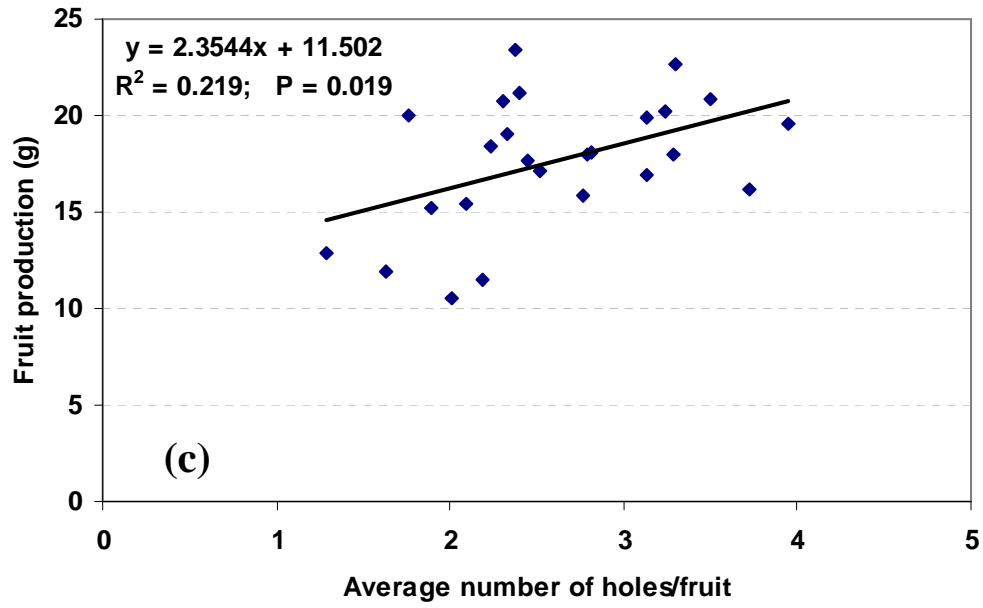
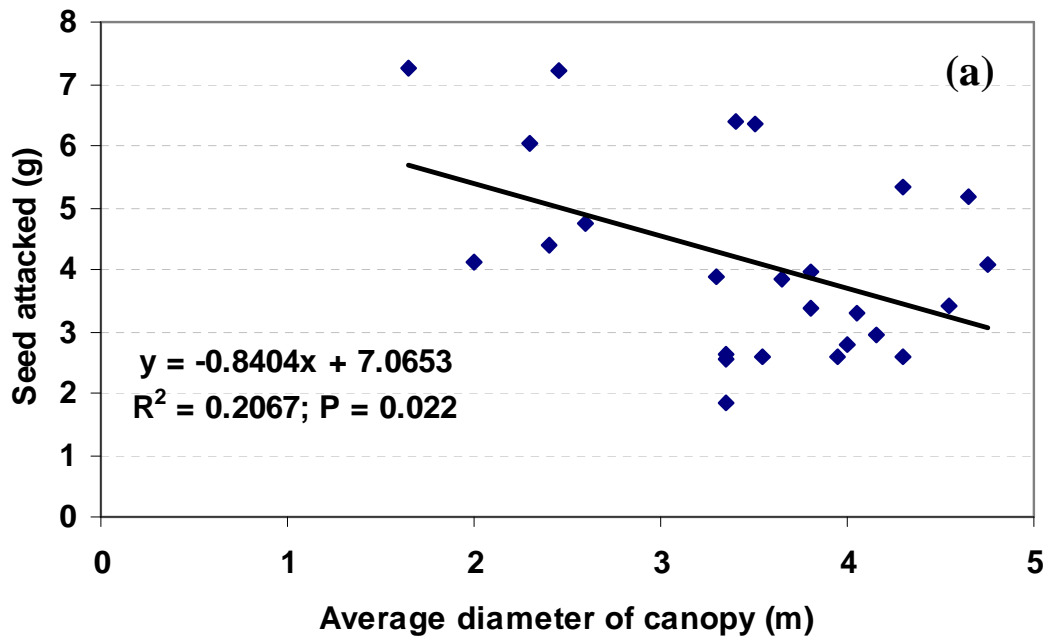


Figure 6: The relationship between the weight of fruit produced and (a) the average diameter of canopy of the female trees; (b) the height of tree (c) the average number of holes per fruit (n = 25).



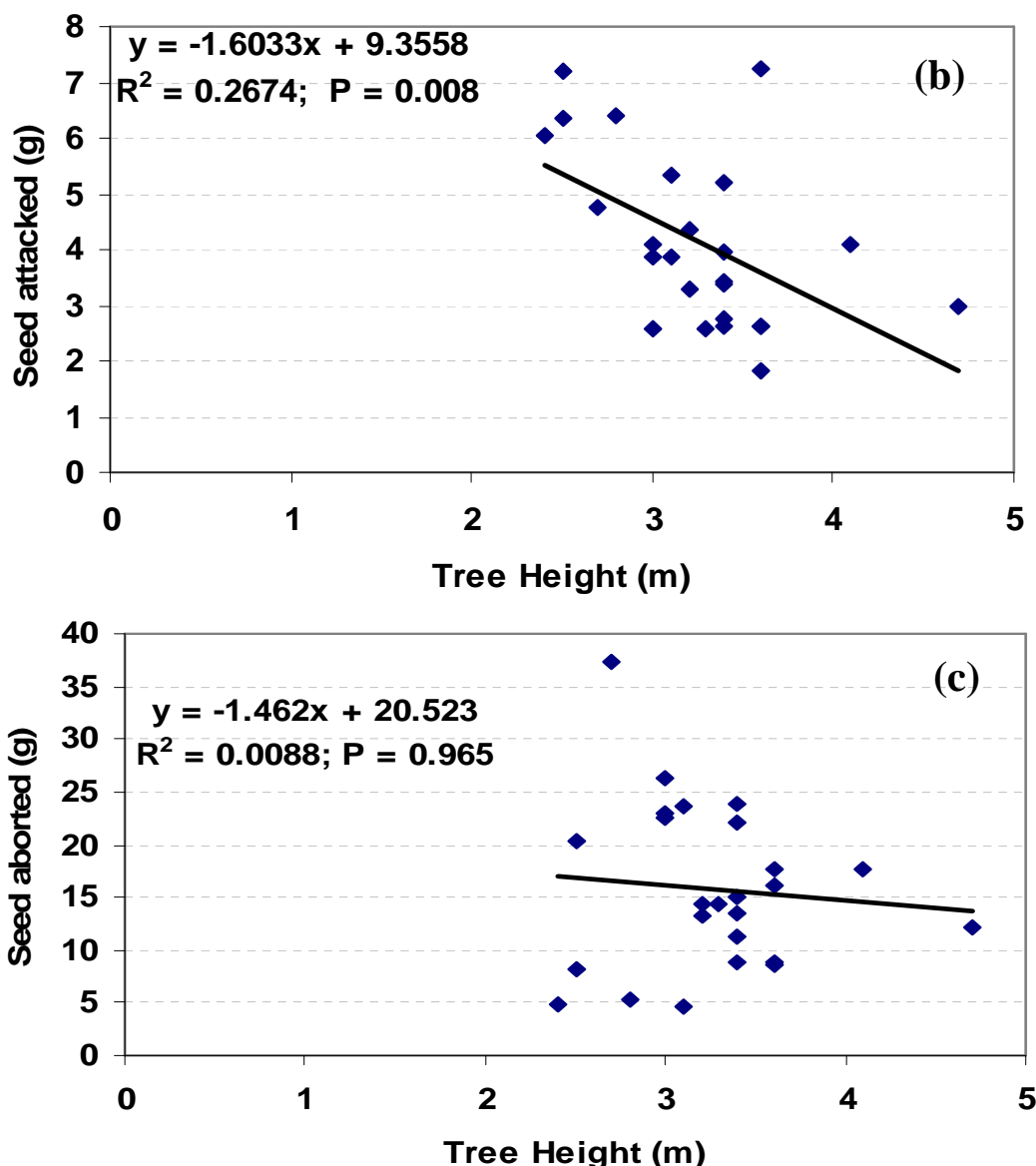


Figure 7: The relationship between the weight of seed attacked in *P. reticulatum* and (a) the diameter of canopy of the female trees; (b) the height of tree; (c) the relationship between the weight of seeds aborted and the height of tree (n = 25).

DISCUSSION

We found that fruit and seed production differed according to distant between male and female individuals. Below 5 m, the average production of female plants were 2 631 g of fruits and 6 446 g of seeds. Above 10 m, the female individuals produced greater mass of seed (8 286 g). When male and female were less distant, this produced

an aggregate of abundant flowers which were expected to display an important number of flowers and to enhance the attractiveness to a variety of insects where predators were commonly observed at any time during the flowering season and regardless of weather conditions (Dao et al., submitted). Predator species often aggregate to areas of high resource abundance (Ushimaru et al., 2007).

When the insect predators were abundant on the tree, they caused severe limitation of fruit and seed set or their total failure (Rathcke, 2001). The results showed that the fruiting success in *P. reticulatum* was low. Plants fruits/flowers was low. Only a few racemes bore a few mature fruits. During the reproductive period, losses of flowers and fruits were quite high as also reported in other leguminous trees (Diallo et al., 2008). In dioecious species, many factors can explain why not all flowers develop into mature fruits. For example, predation due to herbivory may have caused reduction in fruit and seed production or alternatively, quality of pollen transfer in a dioecious species has caused low fruit production (Sutherland and Delph, 1984).

The estimated yield per tree was an average of $17.63 \text{ g} \pm 3.33 \text{ SE}$ of fruit coat per plant and $0.1045 \text{ g} \pm 0.0018 \text{ SE}$ per seed. The low yield of *Piliostigma* confirms what is known in most of the Sudanian and Sahelian legume tree species such as *Tamarindus indica* (Diallo et al., 2008). This may be due to climatic conditions. Moreover, we recorded per plant 40% of aborted seeds and 10% of parasitized seeds. This finding is in line with previous studies on the major African insect pests *Caryedon serratus* which feed on the seeds of some native host plants like *Bauhinia rufescens*, *Piliostigma reticulatum*, *Piliostigma thonningii*, *Tamarindus indica*, which all belong to the Leguminous subfamily Caesalpinioideae (Delobel et al., 2003). The high percentage of aborted seeds may reflect self-incompatibility which is important in the breeding systems of many tropical species (Sage et al., 1994). Self-incompatibility is related to the quality of pollen transferred on the stigma. Honeybees (*Apis mellifera*) have been identified as the dominant floral visitors to flowers of *P. reticulatum* and potential pollinators of the species. They frequently groom pollen from their body, storing it in the corbiculae making it inaccessible for transfer onto the stigmatic surface (Bernhardt

and Weston, 1996; Paton, 1997; Wallace et al., 2002). Combined with the high proportion of movements within plants (Gross, 2001; Dupont et al., 2004) and restricted movements between plants (Michaelson-Yeates et al., 1997), this would encourage selfing and biparental inbreeding, respectively. Therefore, honeybees may be inefficient as pollinators of *P. reticulatum*, which is an outcrossing species. Honeybees co-visited *P. reticulatum*'s flowers with a range of other insect families including Ichneumonidae, Vespidae, Muscidae, Syrphidae, Lycidae, Meloidea Scarabaeidae Acraeidae and Nymphalidae, Acrididae and Coreidae (Dao et al., submitted). This composition of floral visitors has been shown to have a direct negative effect on reproductive success (Spira, 2001), to alter the genetic structure of populations (England et al., 2001) and to encourage (bi-parental) inbreeding depression (Spira, 2001). Other causes of flower, fruit, and seed abortion have been described by Bawa and Webb (1984) for several tropical trees. In that study, the position of the fruits within the inflorescence and seed within the ovary affected abortion. Their results indicated that some fruits abort because of competition for resources, and flowers that open first have a higher probability of retention than those set by flowers that open later. Older fruits may interfere with resource allocation to younger fruits. Therefore, all these factors, as well as self-incompatibility, may contribute to fruit and seed loss in *P. reticulatum*.

A relationship between tree size and fruit and seed production was observed. Plants with low percentage of seed attacks tended to be taller and larger. Although plant height and canopy diameter were significantly and negatively correlated with attacked seed, they were not significantly correlated with other parameters of fruit and seed production. Thus, even if they are simple non-destructive measures, they could not be considered as good predictors of plant production after one year estimation.

Conclusion

The present study revealed that *P. reticulatum* bloom profusely but fruit and seed production are low. There are many flower and fruit losses during the reproductive period. It appears that distance between male and female individuals in the population influences tree productivity. The quality of fruit and seed produced are severely reduced by predation. These results emphasize that a consideration of plant–animal interactions, including pollinators and predators and their unique responses, may be necessary to understand the insufficient production of fruit and seed of *P. reticulatum*

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