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RESEARCH ARTICLE

INFLUENCE OF PARKLAND LANDSCAPES ON SHEA TREE (*VITELLARIA PARADOXA*) POLLINATION IN NORTHERN REGION OF GHANA

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ABSTRACT

Pollinators provide essential services to Shea trees (*V. paradoxa*) in parklands. Parklands are modified into landscapes through human usage. Shea trees are found within landscapes in parklands of the Northern region of Ghana. However, influence of landscapes on pollinators is not known. This study therefore sought to find the influence of parkland landscapes on Shea tree (*Vitellaria paradoxa*) pollination in Northern Region of Ghana from November 2011 to March 2012. A bagging experiment with muslin was used to assess the type of pollination. Visual inspection and a long sweep-net were used to collect insect flower visitors or pollinators and assessed their abundance in the landscapes (farm land, settlement, undisturbed land and burnt land) within communities (Pagazaa, Kpalon and Zoonayili). ANOVA, t-test and regression analyses were used to analyze the results. It was found that *V. paradoxa* mostly undergoes cross pollination with little self-pollination. Fruiting due to cross-pollination on undisturbed land and settlement at Kpalon, Farm land and settlement at Pagazaa and Zoonayili were significantly ($P < 0.05$) higher than self-pollination. Three species of bees namely; *Apis mellifera, Meliponula ferruginea* and *Hypotrigona* sp. were the pollinators of *V. paradoxa* found with *Apis mellifera* as dominant. The study revealed that the number of insect visitors (abundance of pollinators (%) linearly and positively correlated with the number of fruits per Shea trees in the study area.

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INTRODUCTION

Shea tree is important both locally and internationally because of its multiple uses (Okullo *et al.,* 2010). A study conducted using fruit samples collected from Mali, Burkina Faso, Northern Cameroun and Uganda demonstrated that the Shea fruits are a rich source of sugars, protein, calcium, and potassium during the "hungry season", when food stores run low (Naughton, 2016). A study conducted in Nigeria found a strong correlation between fibre and protein in Shea fruits which present an attractive combination particularly, for children of the rural zones with restricted access to the more conventional and expensive food sources (Naughton, 2016). Food substances such as carbohydrate, protein and fat of the fruits ranged from 29.3 – 45.3 %, 2.6 – 7.0 % and 0.7 – 1.7 %, respectively (Aguirre-Dugua *et al.*, 2013). The mesocarp of the fruit was also found to have a high nutritional value and contains between 0.7 to 1.3 g of protein and 41.2 g of carbohydrate. The fruit pulp is a rich source of ascorbic acid and contains 196.1 mg/100 g in comparison with an orange which contains only 50 mg/100 g.

The iron and calcium content of the mesocarp of the Shea nut also compares favourably with that of raspberries. Shea nuts contain 1.93 mg/100g of iron as against 0.92 mg/100 g in raspberries. Shea nuts contain 36.4 mg/100 g of calcium as against 26 mg/100 g for raspberries. They also contain the B group of vitamins and a sugar level of about 3 to 6 % which is equally distributed among glucose, fructose and sucrose. Furthermore, Okullo *et al.* (2010) analyzing the contents of the Shea fruit in Uganda, found that the total ash, crude oil and crude fibre ranged from 3.6-5.9 %, 1.5-3.5 % and 10-15 % respectively. They also found that the crude protein, total carbohydrate, vitamin C and calorific value (on dry weight basis) ranged between 3.1 – 4.2 %, 12.4 – 19.4 %, 85.6 – 124.9 mg/100 g and 77.6 – 89.2 Kcal/100 g respectively. The trunk, bark cortex, the roots and leaves are all used for the preparation of many traditional medicinal remedies. The trunk of the tree also makes excellent charcoal and it is the favoured sources of fuel wood (Hatskevich et al., 2011).The Shea tree is also used for cooking at traditional ceremonies such as enskinment of chiefs and funerals; also for the making of coffins for the burial of chiefs (Courteau, 2012).

The Ghanaian Shea is exported to countries such as France, Great Britain, the Netherlands, Denmark, North America and Japan (Bijaou, 2017; Koloche *et al.,* 2016; Agene, 2015) The tree is also much sought after for placing hives in local beekeeping (ICRAF, 2013). Researchers have also found out that, the Shea tree is the second most important oil crop in Africa after the palm nut tree (Hatskevich *et al.,* 2011).The need to find substitutes for cocoa in the confectionery and cocoa butter industries in the early 1970s (Aguirre-Dugua *et al*., 2013), made the importance of Shea tree even more significant in Ghana. This has placed a high demand on the fruits from which the butter is obtained. This has led to it being rated as having the potential to do more than the nation's number one export earner-cocoa (Aboba, 2011). However, the shea tree is pollinator–dependent (Kwapong, 2011); and so without external agents' pollination, consequent fertilization and fruiting will not take place. There is very scanty and incoherent information in the area of Shea pollination, fruit-set and yield as influenced by landscapes. This current study therefore sought to assess the influence of the different parkland landscapes which arise as a result of land-use on the density/abundance of pollinators on shea tree pollination.

MATERIALS AND METHODS

The study area: A fieldwork was carried out in the Northern Region of Ghana. This was purposively chosen because more Shea trees occur in the Northern region (Guinea savannah) than the Upper east and Upper west (Sudan savannah) (Chimsah *et al.,* 2013). It is hoped to capture at least the variability in pollinators and flowering of Shea trees across the communities and landscapes in this region. The Northern Region occupies an area of about 70,383 square kilometers. It shares boundaries with the Upper East and the Upper West Regions to the north, the BrongAhafo and the Volta Regions to the south, and two neighboring countries, the Republic of Togo to the east, and La Cote d'Ivoire to the west.The land is mostly low lying except in the north-eastern corner with the Gambaga escarpment and along the western corridor. The region is drained by the Black and White Volta Rivers and their tributaries.

The climate of the region is relatively dry, with a single rainy season that begins in May and ends in October. The amount of rainfall recorded annually varies between 750 mm and 1050 mm. The dry season starts in November and ends in March/April with maximum temperatures occurring towards the end of the dry season (March-April) and minimum temperatures in December and January. The harmattan winds, which occur during the months of December to early February, have considerable effect on the temperatures in the region, which may vary between 14°C at night and 40°C during the day. Humidity, however, which is very low, mitigates the effect of the daytime heat. The main vegetation is classified as grassland, interspersed with the guinea savannah woodland, characterised by drought-resistant trees such as the acacia, baobab, shea nut, dawadawa, mango, and neem. The selected areas were Zoonayili (Tolon-Kumbungu District), Kpalon (Savelugu-Nanton Municipality) and Pagazaa (Yendi District) with the various parklands, namely; farm land, settlement land, burnt land and undisturbed land.

Testing for Self and Open pollination: Assessing Self and Open-pollination of Shea trees at communities and across landscapes. Five plants 30 meters apart were selected in a 30 x 450m area demarcated for this experiment in each landscape across the selected communities (i.e. Zoonayili, Kpalon, and Pagaaza). Four inflorescences at different locations in a circular fashion around the crown were selected and tagged. The buds initiating flowers of each were counted and recorded. Following (Stout *et al.,*2018: Aslan *et al.,* 2014) two of the inflorescences were randomly assigned to one of two pollination treatments: (i) open-pollination (natural pollination), i.e, unrestricted pollination of Shea flowers by insects and (ii) bagging of Shea flowers (self-pollination), that is, control treatment where no pollination by external agents was allowed, thereby testing for spontaneous self-pollination (autogamy), using a white nylon material, with fine mesh size [0.25 by 0.25mm] (muslin) impermeable to pollen. Three to four weeks after pollination, was determined by counting the number of fruits on each treatment branch (Stout *et al.,* 2018: Aslan *et al.,* 2014). The number of flowers aborted was also calculated. Self-incompatibility index was also calculated by using data on fruiting as a result of self and open-pollination (ISI) (Pandit, 2014). The values of self-incompatibility index (ISI) were used to estimate whether self-pollination or open-pollination took place.

Estimation of number of Shea fruits per tree: Number of fruits per tree was estimated using the total estimate of stalk of inflorescences (peduncles) per tree multiplied by the fruit-set due to open-pollination of that tree (Kwapong, 2012, personal communication).

Sampling and collection of pollinators: The survey for pollinators was conducted between January, 2012 and March, 2012. Field assistants and local farmers were engaged. The method that was used to sample the pollinators were similar to Hoehn, Steffan-Dewenter and Tscharntke (2010); Munyuli, (2010); Munyuli (2013). A quadrat measuring 30m by 450m was demarcated (Consejo *et al*., 2017; Woodall, 2016; Taran-Munteanu *et al.,* 2016) within each landscape and 10 plants, 30m apart were sampled and tagged. Observations of foraging and bee counts were done on inflorescence flowering patches found within different land – uses within the communities. Observations were made under conditions favourable for bee flights: sunny or cool weather and weak wind. Sweep-net sampling using long handled sweep-net was used to reach the pollinators in the canopy of the Shea trees. Sampling was done from 06:00 – 12:00h local time to collect bees visiting flowers of *V. paradoxa* blooming plants as recommended (Munyuli, 2011; Potts *et al.,* 2010). A visit was defined as occurring when an insect touched the anthers or stigmas (Campbell *et al.,* 2017). Five inflorescences of uniform sizes equally spaced on the crown of each was scanned for pollinators. Each inflorescence was observed (scanned) for 3 minutes, so 15 minutes was spent on a tree. The sampled insects were killed by drowning in soapy water, cleaned in clear water by shaking and preserved in 70% alcohol.

Data analysis: Testing for self and Open-pollination of Shea trees at communities and across landscapes and Pollination efficiency. The bagging experiment was used to test for self and cross-pollination in *V, paradoxa.* Data on weekly insect visitor abundance per tree for the various landscapes (farm land, burnt land, settlement and undisturbed land) within the communities (sites) (Kpalon, Pagazaa and Zoonayili) were coded using Microsoft Excel. The Kolmogorov-Smirnov test was used to check for normality of the distribution of the raw data. Mean weekly insect visitor abundance was square root +1 transformed and used in ANOVA using Genstat version 11 in order to test the main effects and the interaction of the factors; landscape and community (site). Means were separated using LSD at p<0.05. Estimation of Species dominance (D) [%] Species dominance (D) was calculated according to McKee *et al*., (2016) and Wilson *et al*. **(**2014): D = (abundance of a species/ total abundance recorded) x 100. If D > 5 %, the species is termed a dominant species.

Relationship between insect flower visitor abundance (%) and yield): The variables, insect visitor abundance (%), and yield of Shea tree (number of fruits per tree) were calculated. The relationship between insect's flower visitor abundance (%) and yield (fruits per tree) were established using simple regression in Minitab version 15.

RESULTS

Evaluation for Self and Cross-pollination in shea trees (*Vitellaria paradoxa*): An evaluation of self and cross-pollination in *V. paradoxa* using bagging experiment revealed that all the unbagged inflorescence fruited, (Table 1) indicating that *V. paradoxa* largely undergo cross-pollination. Whilst only few of bagged inflorescence fruited (Table 1) indicating that some self- pollination takes place in *V. paradoxa* thus *V. paradoxa* may be fruiting due to cross-pollination on undisturbed land and settlement at Kpalon, Farm land and settlement at Pagazaa and Zoonayili respectively were significantly ($P< 0.05$) higher than self-pollination (Table 1).

Variation in Self and Cross-Pollination (ISI) and Flower Abortion (%) across the communities (Kpalon, Pagazaa and Zoonayili) and Landscapes (farm land, settlement, burnt land and undisturbed land): An evaluation of self-incompatibility index (ISI) (Angoh *et al.,* 2017; Angoh, 2016) was also used to test for self and cross-pollination at the communities and landscapes level. The results show that Shea trees at Zoonayili recorded ISI of 0.0, 0.13, 0.0 and 0.0. Shea trees at Kpalon recorded ISI of 0.20,0 .17,0 .13 and 0.0; Shea trees at Pagazaa recorded ISI of 0.0, 0.0, 0.33 and 0.0 on the farm land, settlement, burnt land and undisturbed land respectively (Table 2). ISI of 0.0 means completely self – incompatible, < 0.2 means mostly self-incompatible and > 0.2 <1 means partially self-compatible (Angoh *et al.,* 2017; Angoh, 2016). This shows that shea trees at the communities and landscapes (study areas) could be completely self-incompatible, mostly self-incompatible and partially self-compatible. Flower abortion was very high at all the communities and landscapes. At Pagazaa flower abortion on the farm land was higher ($P< 0.05$) than the other landscapes (Table 2). However, using (Sinha *et al.,* 2015; Digby *et al.,* 2012) theory of dominance, Dominance (D) (abundance of species/total abundance recorded) x 100. If D> 5%, then the species is termed to be dominant. It was found that all the non-bees were not dominant, so they were not considered for further discussion. Of the remaining insects, *Apis mellifera, Meliponula ferruginea* and *Hypotrigona sp.* were the dominant flower visitors and comprised more than 90% of total flower visiting insects (Table 3). Their abundance was in the order: *A. mellifera*>*Meliponula ferruginea*>*Hypotrigona sp* (Figure 2). The other important insects frequenting *V. paradoxa* flowers were *Musca sp.* and some Hemipterans (Table 2).

The detailed investigations were, therefore carried out on "bees" (90.27%) which comprises: stinging bees – *Apis mellifera* (52.20%) and stingless bees – Meliponula *ferruginea* (21.43%) and *Hypotrigona* sp,(17.28 %) that frequented *V. paradoxa* flowers in relatively large numbers during the day and were anatomically suited for pollen collections. The non-bee species (Table 2) mostly collected nectar and therefore may not be considered beneficial pollinators. The relationship between abundance of pollinators and yield in the landscapes within the communities suggest that as the landscapes increase in the abundance of foraging pollinators due to the abundance of flowers in the landscapes which attracts a guild of pollinators to the Shea flowers, these results in enhanced fruiting of Shea trees. This explains the positive linear relationship observed for all the landscapes in the communities.

DISCUSSION

Evaluation for Self and Cross-pollination in shea trees: When insects were excluded from the inflorescence as a result of bagging, the trees mostly did not yield any fruit, but when pollination was allowed, all flowers yielded fruits, suggesting that *V. paradoxa* largely undergoes cross-pollination and some self-pollination. The plants are therefore typically out-crossed. In a similar study, Sanou and Lamien (2011) and Kwapong (2012) drew the same inference. Fruiting as a result of cross-pollination was higher than self-pollination. This supports the assertion that *V. paradoxa* largely undergoes cross-pollination (Sanou & Lamien, 2011; Kwapong, 2012).

Relative Proportion of Insect Visitors Foraging in *Vitellaria paradoxa* flowers: Results from the study indicated that, six (6) insect species of insects visited *V. paradoxa.* they included, *A. mellifera, M. ferruginea, Hypotrigona*sp.which are dominant species and flies, moths and some hemipterans which constituted the ocassional visitors. The study has revealed honey bee (*Apis mellifera*) as the most dominant pollinator of *V. paradoxa*(Table 4 & Fig. 9). In earlier studies, bees have also been reported as important pollinators of *V. paradoxa* (Chimsah *et al.*, 2013). *A. mellifera* has also been reported as a major pollinator of agricultural crops and the world's dominant pollinator taxon (Sinha *et al.,* 2015; Digby *et al.,* 2012). *Meliponula ferruginea*and *Hypotrigona* sp. (Fig. 9) have also been shown to visit *V. paradoxa* flowers. This is consistent with Kwapong (2012), who listed them among other pollinators of the Shea tree in an earlier study at Tamale. Stingless bees have been shown to have excellent ability to pollinate in glasshouses in the University of Western Sydney (Duennes *et al.,* 2017; Neumann *et al.,* 2016). Stingless bees play an important role as pollinators and they seem to be good candidates as alternatives for future commercial pollination (Duennes *et al.,* 2017; Neumann *et al.,* 2016). The populations of honey bees and stingless bees are usually found together pollinating crops, suggesting a niche complementarity among the pollinator groups (Albrecht, Schmid, Hautier & Muller, 2012). Honey bees and stingless bees are sometimes referred to, generally, as bees (Youngstead, 2012), therefore the pollinators of *V. paradoxa* could be said to be bees (Chimsah *et al*, 2013). *Apis mellifera, Meliponula ferruginea* and *Hypotrigona* sp. may be important pollinators of Shea tree because their workers are anatomically suited for pollen collection (Kwapong, Aidoo, Combey & Karikari, 2010), and were seen carrying pollen in the field.

Table 1. Variation in fruit set as a result of self and cross pollination across the three communities on landscapes

Site	Landscape	Fruit set Open pollination (unbagged)	Self-pollination (bagged)	Mean	Std. Error Mean	N	T	df	Sig. (2-tailed)
Kpalon	Farm land	1.80	0.00	1.80	0.80	5	2.250	4	0.088
	Undisturbed land	0.80	0.00	0.80	0.20	5	4.000	4	0.016*
	Burnt land	1.00	0.20	0.80	0.58	5	1.372	4	0.242
	Settlement	1.20	0.00	1.20	0.20	5	6.000	4	0.004*
Pagazaa	Farm land	1.20	0.20	1.00	0.32	5	3.162	4	0.034*
	Undisturbed land	0.40	0.00	0.40	0.24	5	1.633	4	0.178
	Burnt land	0.80	0.00	0.80	0.37	5	2.138	4	0.099
	Settlement	0.80	0.00	0.80	0.20	5	4.000	4	0.016*
Zoonayili	Farm land	4.00	0.00	4.00	0.84	5	4.781	4	0.009*
	Undisturbed land	2.00	0.20	1.80	0.73	5	2.449	4	0.070
	Burnt land	0.80	0.20	0.60	0.60	5	1.000	4	0.374
	Settlement	1.60	0.40	1.20	0.37	5	3.207	4	0.033*

Figures with asterisk (*) are significant ($p < 0.05$) at the probability level of 5%.

Table 2. Variation in Self and Cross-Pollination (ISI) and Flower Abortion (%) across the communities (Kpalon, Pagazaa and Zoonayili) and Landscapes (farm land, settlement, burnt land and undisturbed land)

LANDSCAPE	SITE Zoonayili (ISI)	Mean	FA (%)	SITE Kpalon (ISI)	Mean	FA (%)	SITE Pagazaa (ISI)	Mean	FA (%)
Farm land	0.00	35.2	97.8	0.20	27.4	96.5	0.00	38.4	98.9
Settlement	0.13	21.6	93.1	0.17	23.2	95.1	0.00	22.4	98.2
Burnt land	0.00	21.6	99.1	0.13	15.8	90.8	0.33	18.2	96.8
Undisturbed land	0.00	31.4	97.5	0.00	23.8	96.7	0.00	22.2	97.3
Mean		27.4			22.6			25.3	
LSD (0.05)		13.16			12.6			14.86	

ISI=Self- incompatibility index, FA= Flower abortion

Table 3. Proportion of flower visitors on shea flowers (*V. Paradoxa*)

Species	Common Name	Numbers	Percent	Dominance
Honey bees				
Apismillifera	Honey bees	51.74	52.20	52.20
Stingless bees				
Meliponulaferuginea	Stingless bees	21.24	21.43	21.43
Hypotrigona species	Stingless bees	17.13	17.28	17.28
Diptera *Musca species*	Housefly	4.00	4.04	4.04
Lepidoptera species	Lycaenidae (Moth)	3.00	3.03	3.03
Hemiptera species	Hemiptera species	2.00	2.02	2.02
		99.11	100	100

Pollination efficiency at Kpalon

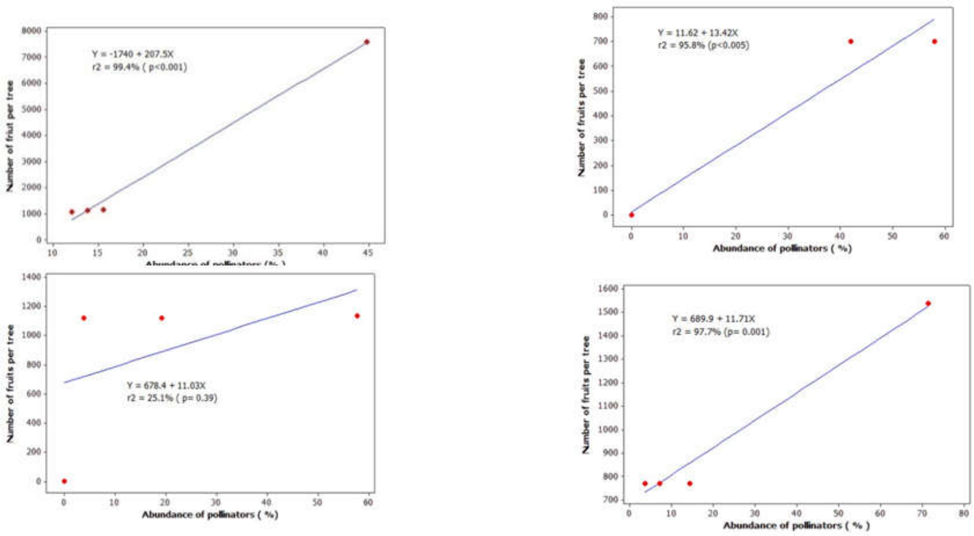

Fig. 1. Relationship between abundance of pollinators (flower visitors) and number of fruits/trees at Kpalon

Pollination efficiency at Pagazaa

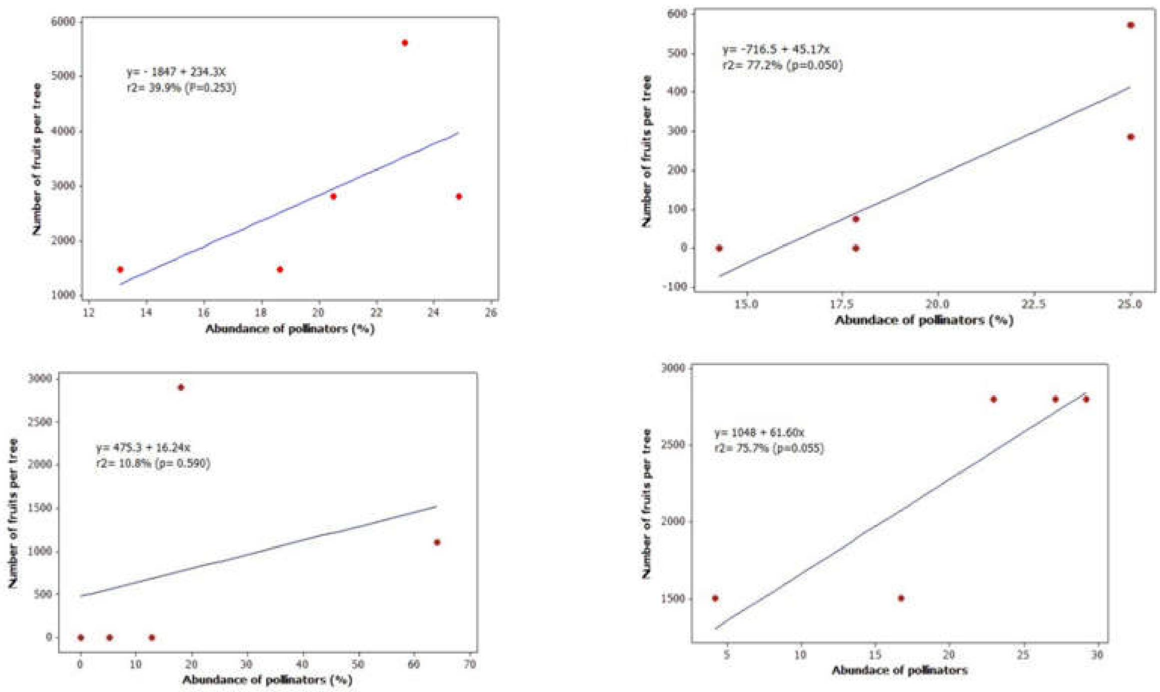

Fig. 2. Relationship between abundance of pollinators (flower visitors) and number of fruits/trees at Pagazaa

Pollination efficiency at Zoonayili

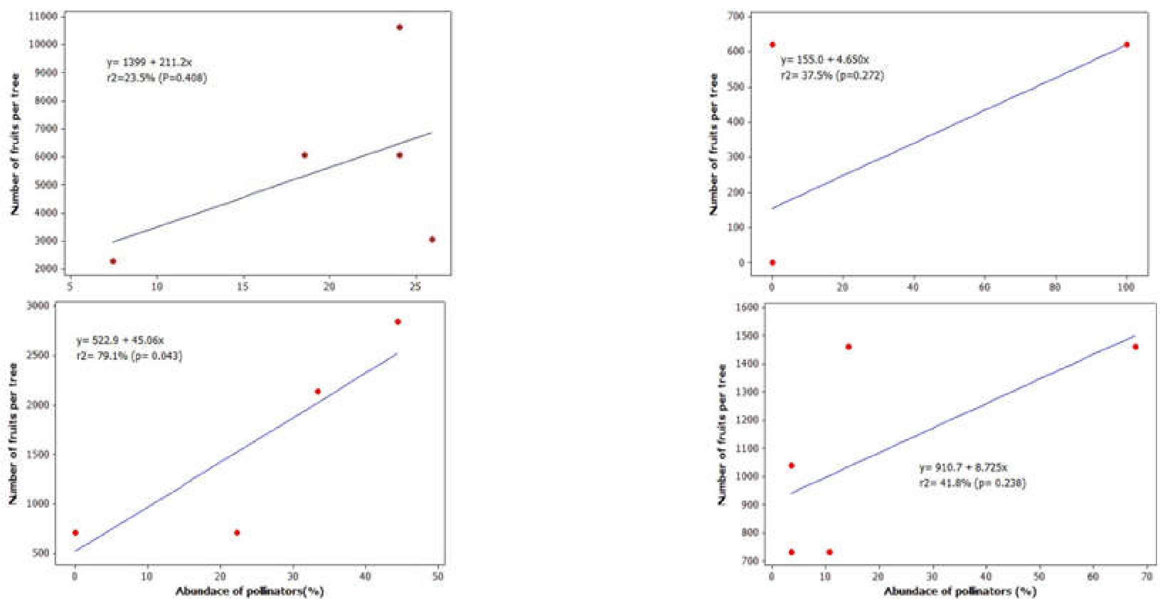

Fig. 3. Relationship between abundance of pollinators (flower visitors) and number of fruits/trees at Zoonayili

The result of this study proves the fact that pollinator-plant interaction is not obligate but forms complex pollination webs in which a single plant may receive visits from different pollinator species and each pollinator may, in turn, visit multiple plants of many different species (Duennes *et al.,* 2017).

Relationship between abundance of flower visitors and number of Shea fruits/tree: The study has shown that the number of insect visitors linearly and positively correlated with the number of fruits per Shea tree.

This means that generally, the fruiting of Shea trees was influenced by the number of pollinating insects attracted to the plant during the flowering season. This is consistent with the work of (Kwapong, 2012) that the Shea tree is generally, pollinator-dependent. The results also show that both honey bees and stingless bees contribute to pollination of Shea trees. The diversity of flower pollinators observed may be working together complementing each other's effort at pollinating the Shea trees. This is consistent with the work of Brittain, Williams, Kremen & Klein (2013) that, pollinator diversity can synergistically increase pollination service through species interactions. Kwapong, 2012 working at Tamale in Ghana, proved that all the bee species making the bee guild, visiting the Shea tree are pollinators. These insects visited *Vitellaria paradoxa* on all the sites of study and the visitation resulted in fruiting. *Apis mellifera* was dominate in Pagazaa, while *M. ferruginea* and and *Hypotrigona* sp. were dominant in Zoonagili and Kpalon respectively. The fact that different species dominance was observed at the communities (sites) of study that caused the plants to fruit supports the fact that all the bee species are pollinators. Pollinators have been reported to show high presence at areas where food and nesting sites abound (Duennes *et al.,* 2017).

Conclusion

The study revealed that, *Vitellaria paradoxa* mostly undergoes cross-pollination with little self-pollination. The insect species, *Apis mellifera, Meliponula ferruginea,* and *Hypotrigona sp*. were dominant pollinators of Shea nut tree flowers. The yield of the Shea tree was linearly and positively related to the abundance of flowers visitors/pollinators. The importance of landscapes in supporting pollination varied at the sites of study.

Conflict of Interest

The authors whose name are listed below certify that they no affiliations with any organization with financial interest or non-financial interest of the above research. They are responsible for financing this research and hold all access to data.

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