Heliyon 8 (2022) e10492

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Occurrence and ecological habitat effect on *Vitellaria paradoxa* (C. F. Gaertn.) parasitism: implication for pest management and plant conservation

Dossou Seblodo Judes Charlemagne Gbemavo [a,b,*], Anicet Dassou [c], Médard Gbemavo [d], Christine Ouinsavi [d]

[a] *Unité de Biostatistique et de Modélisation (UBM), Ecole Nationale Supérieure des Biosciences et Biotechnologies Appliquées (ENSBBA), Université Nationale des Sciences, Technologies, Ingénierie et Mathématiques (UNSTIM), BP 14 Dassa-Zoumé, Benin*

[b] *Laboratoire de Biomathématiques et d'Estimations Forestières, Faculté des Sciences Agronomiques, Université d'Abomey-Calavi, 04 BP 1525 Cotonou, Benin*

[c] *Laboratory of Biotechnology, Genetic Resources and Plant and Animal Breeding (BIORAVE), Ecole Nationale Supérieure des Biosciences et Biotechnologies Appliquées (ENSBBA), Université Nationale des Sciences, Technologies, Ingénierie et Mathématiques (UNSTIM), BP 14 Dassa-Zoumé, Benin*

[d] *Laboratoire d'Etudes et de Recherches Forestières, Faculté d'Agronomie, Université de Parakou, Benin*

ARTICLE INFO

Keywords:
Ecology
Estimation
Pest management
Shea trees
Stem borers
Tapinanthus sp.

ABSTRACT

This study determines the prevalence of shea butter tree attack by the African mistletoe and stem borers, explores statistical relationship between prevalence, land use and tree morphological traits. In a the Bohicon shea parklands in Benin, a total of 258 shea butter trees was examined and measured in ten inventory plots in fallows, ten inventories plot in savannah, and ten inventory plots in cropped fields (Agroforestry systems). The classic inference was used to estimate the prevalence of shea trees attacks and Generalized Linear Models (GLMs) of the Binomial and Beta families were used, respectively, to model the relationship between the morphological traits and the attack risk, and the relationship between the land uses and the prevalence. The overall prevalence of pest attack in shea butter trees was 28.7% (CI = 23.3–34.7%), with a prevalence of African mistletoe of 24.8% (CI = 19.7–30.5%) and stem borers had attacked 6.2% (CI = 3.6–9.9%). These prevalence rates are lower than what has been reported from other sites before.

1. Introduction

Life communities in forest landscapes play a fundamental role in the health status of trees and therefore in their productivity. Savannas, fallows and fields are among the list of landscapes that abound in a diversity of useful indigenous trees (World Agroforestry Centre, 2008). The shea tree (*Vitelleria paradoxa* (C. F. Gaertn.)) is one of the useful indigenous trees which is cultivated in several different agroecological zones, and the tree's distribution is related to the land use types. The shea butter tree, known by the botanical name of *Vitelleria paradoxa* (CF Gaertn.) is a tree of the Sudanese savannas whose distribution area is endemic to the region from Senegal to Ethiopia (Pye, 1985) crossing 21 countries (Boffa, 2015; Naughton et al., 2015) over a ceinture of 6000 km (Okullo et al., 2004; Sanou et al., 2004), Shea butter is part of the short list of privileged agro-forestry speculations that has caught the attention of leaders of West African countries in general and Benin in particular for agricultural development (N'Djolossè et al., 2012) and a reduction of the poverty in local environment through the creation of income-generating activities. Shea trees plays the three roles of natural resources, namely: (i) economic role through the enhancement of shea butter (Baziari et al., 2019); environmental role through the fertilizing power of its leaves in agroforestry systems and (iii) social role as a plant of the traditional pharmacopoeia (Tom-Dery et al., 2018). The organs of shea trees, and important parts of the tree such as the trunk, are used to produce raw materials for modern medicine, cosmetics and crafts (Bayala et al., 2002).

The shea tree very early caught the attention of scientists from various specialties who conducted various research works on the species for the purpose of its sustainability. Tom-Dery et al. (2018) review state-of-the-art knowledge of the morphology and genetic diversity; germination and initial growth (Sanou et al., 2004); ecology and population structure (Okullo et al., 2004); chemical composition and

* Corresponding author.
E-mail address: cgbemavo@yahoo.fr (D.S.J.C. Gbemavo).

https://doi.org/10.1016/j.heliyon.2022.e10492
Received 15 February 2022; Received in revised form 10 May 2022; Accepted 25 August 2022

nutritional values (Okullo et al., 2010; Maranz et al., 2004); socio-economic importance (Ani et al., 2012) and poverty alleviation potential of shea (Salawu, 2014). Recent studies on shea butter trees have addressed aspects related to the influence of climate on the fruit production (Bondé et al., 2009a; Bondé et al. 2009b) and distribution of the species (Dimobe et al., 2020; Okurut et al., 2020). Also, its use in pharmacology (Ojo et al., 2021) and its influence on the cultures in associations (Ogwok et al., 2019) have been documented. Studies to assess (Aleza et al., 2018) and improve fruit production (Stout et al., 2018) as well as that to estimate the biomass produced (Sanogo et al., 2021) have also been carried out in recent years on the species. Some studies have highlighted the economic importance of shea trees for countries within its range (Seghieri, 2019; Wardell et al., 2021). Choungo Nguekeng et al. (2021) summarizes information about the ecology, population structure, and genetic diversity of the species, also considering compositional variation in the pulp and kernels, management practices, and efforts towards its domestication. According to Choungo Nguekeng et al. (2021) despite the great potential of the shea butter tree, there are some gaps in the understanding of the genetics of the species. These research gaps on shea butter trees will be supplemented by pest management strategies studies but detailed inventory of insects associated with shea trees in central and northern Benin (N'Djolossè et al., 2012) is done. The decline in shea trees is now a major threat to parkland (Lovett and Phillips, 2018). One of the major reasons for this decline in shea trees is attack by insects and parasitic plants (N'Djolossè et al., 2012). Shea tree pests can lead to total loss of yield or death of tree. Parasitism is one of the main reasons why present stands of Shea trees are declining. Indeed, one of the methods used by farmers to deal with shea parkland pest attack (parasitic plants or stem borers) is pruning or rogueing of infested shea trees. As studied by Bayala et al. (2002) twenty years ago, the traditional parkland management practice of 'pollarding' has three functions: it increases light for crops that benefit from the fertile soil, it provides firewood, and it re-sets the clock on increasing mistletoe populations in the tree canopy. This technique constantly reduces the density of shea trees. Scientific research work on a natural resource of economic importance such as shea is essential for a sustainable and rational management in time and space of the existing potential of the species. The application of the research results will allow a perpetuation of the species and thus an improvement in the income of farmers and (Gouwakinnou et al., 2011). The identification of habitats which better protect shea trees against attacks by parasites and pests is a prerequisite for carrying out appropriate biological control on the species (Shea et al., 2000). Likewise, knowledge of the risk associated with parasitic attacks due to the morphological characteristics of shea trees can also make it possible to know the periods of intervention to carry out the fight efficiently. Studies on the prevalence of shea trees attack by pests (African mistletoe and stem borers) were carried out in Benin (Houehanou et al., 2010), Nigeria (Odebiyi et al., 2004) and Burkina Faso (Boussim et al., 1993). These studies did not examine the potential role of land uses forms on the degree of pest attack. The land use forms can be a potential avenue to bring out the methods of combating shea butter pests mainly African mistletoe and stem borers. These two pests cause damage to shea trees and reduce their production. The African mistletoe (*Tapinanthus* sp.) is an obligate parasitic plant with a root system branching into the branches of shea trees (Lamien et al., 2006). The stem borer (*Neoplocaedaerus* spp.) is the most damaging insect species occurring on the trunk of shea trees (N'Djolossè et al., 2012). This endoparasite is often developed in the cortex of shea trees, particularly in the xylem, before growing outside. The outer parts encircle the infected branch and grow along it. Stem borers have a very low dispersion mode. The larvae, which cause enormous damage to the stems, move very little. Winged adults move more than larvae but cannot fly far. The architectural complexity of the plants could constitute an obstruction to the dispersal of the pest.

The aims of this study were to analyze the relationship between shea trees pest attack and the land use forms. The specific objectives are to (i) determine the prevalence of shea butter trees attack by the African mistletoe and the stem borers, (iii) identify the relationship between the land use forms and the prevalence of shea butter trees pest attack and (iii) identify the agro-morphological traits associated to the shea trees risk of infestation by the African mistletoe and the stem borers were identified.

2. Materials and methods

2.1. Environment study

In Benin, shea trees are distributed from the altitude of Atchérigbé (7°52 north and 2°03 west) to Malanville (11°52 north and 3°23 ouest) in a relatively natural habitat gradient to anthropogenic sectors (Gbédji, 2003). It is not surprising to see isolated shea trees in other regions of Benin. The present study was carried out in the Bohicon shea parkland. In total, there are (5) five shea parkland areas in Benin according to Gnangle et al. (2012): the Bohicon, Savè, Parakou, Bembèrèkè and Kandi parklands. The Bohicon shea parkland is one of the two threated shea parklands of Benin. It extends over latitudes 7° N and 8° N and gathers all the shea population stretching from Bohicon to Dassa-zoumè. The average annual rainfall in this parkland varies between 900 and 1200 mm distributed over two rainy seasons (March–July) and (August to October). The mean annual temperature varies between 25 °C and 32 °C with a sub-equatorial climate tending towards the Sudano-Guinean in the northern parts. Companion species of shea trees in agroforestry systems are: *Parkia biglobosa (Benth)*, *Elaeis guineesis* Jacq, *Tectona grandis* L.f., *Anacardium occidentale* L., *Mangifera indica* L. (Gnangle et al., 2012). Within this parkland there is a strong pressure on the shea tree. The tree is cut to make charcoal; and firewood; It is also used in the construction of granaries and apatam in the field (Gnangle et al., 2012).

2.2. Sampling and data collected

The present study was conducted in the shea butter parkland of Bohicon. Shea trees was examined and measured in ten inventories plots in fallows (100 m × 100 m), ten inventories plot in savannah (100 m × 100 m), and ten inventory plots in cropped fields (agroforestry systems). The dimensions of the plots are those recommended by the study of Fonton et al. (2011). In each inventory plot or crop field, the presence-absence of African mistletoe or stem borers was noted in each Shea tree (Figure 1(a,b)). The agro-morphological traits such as the diameter at breast height (dbh), the crown diameter (Dc), the total height (Ht) and the bole height (Hfut) was measured on each Shea tree in the inventory plot or in the crop fields (Figure 2). The Shea tree agro-morphological traits were chosen from the list of descriptors of shea tree developed by IPGRI current Bioversity International (IPGRI and INA, 2006). The global Positioning Systems (GPS) (Garmin 78) was used to record the geographical coordinate of each plot end each field. The GPS was also used to track each field in the main to calculate the area. A total of 258 Shea trees was examined and measured in the present study.

2.3. Data analysis

The non-parametric test of Mann Whitney (since the assumption of normality did not hold) was used to compare Shea trees agro-morphological traits between infestation status (Infested and Uninfested).

The prevalence (p) of shea trees infestation by the two pests, by the African mistletoe and by stem borers was estimate using formula (1):

$$p = k/n \quad (1)$$

where k the number of shea trees is infested (in each situation) and n is the total number of shea trees examined ($n = 258$).

Figure 1. Shea trees infested in the Bohicon parkland: a) Mistletoe infestation; b) Stem borers attack.

The confidence interval (*CI*) of each prevalence was determined using formula (2):

$$CI = \left[p - u_\alpha\sqrt{\frac{p(1-p)}{n}}\ ;\ p + u_\alpha\sqrt{\frac{p(1-p)}{n}}\right] \quad (2)$$

where u_α is the normal approximation of the binomial distribution for the probability α. The confidential interval was determinate at $\alpha = 5\%$ level. The two main assumptions $np \geq 10$ and $n(1-p) \geq 10$ to use formula (2) are hold.

Prevalence is calculated by plot per each land use form (field, fallow and savannah) the generalized linear model of the *Beta* family was performed to test whether the land use forms is associated to the prevalence of shea trees infestation by the two pests examined in this study. The simple generalized linear model with binomial family was also used to identify the morphological traits associated to shea trees probability attack by the African mistletoe and the stem borers. The odds ratio was calculated in each case of modelling to see the direction of variation in the probability of prevalence and risk to attack. Before using the GLM of Binomial family the correlation between each of the morphological traits of shea trees was examined using the Pearson correlation test.

The generalized linear model of Beta family was established using the function *betareg* of package *betareg* (Zeileis et al., 2010). The *glm* function was used to perform the GLM with Binomial family test, the packages broom (Robinson and Hayes, 2018) and ggplot2 (Wickham, 2016) were used to graph the odds ratio. The package corrplot (Wei and Simko, 2017) was used to perform the correlation test and to represent the matrix of correlation test. The analyses were performed in R software (R Core Team, 2020).

3. Results

3.1. Shea trees difference in agro-morphological traits according to infestation status

The diameter at breast height (Dbh), the crown diameter (Dc), the bole height (Hfut) and the total height (Ht) of shea trees were not

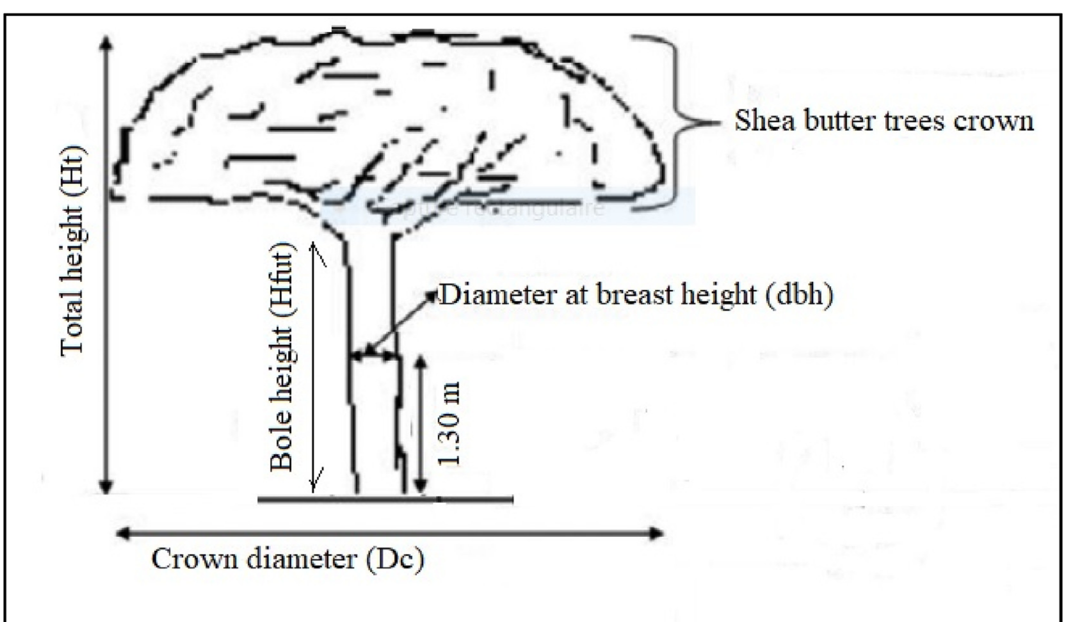

Figure 2. Agro-morphological traits of shea butter measured. Legend: Blue dot-represents positive correlation and red negative. The larger the dot the larger the correlation.

Table 1. Comparison of agro-morphological traits between infested and non-infested shea trees.

Traits	Infested		Un-infested		Prob.
Mistletoe attacks					
	Mean	*Standard error*	*Mean*	*Standard error*	
Dbh (cm)	20.115	0.938	18.073	0.405	0.1174 ns
Dc (cm)	4.616	0.177	4.1943	0.0981	0.0611 ns
Ht (m)	7.102	0.128	6.9180	0.0745	0.1234 ns
Hf (m)	2.2300	0.0664	2.2085	0.0371	0.9446 ns
Stem borers attacks					
Dbh (cm)	20.66	1.94	18.442	0.391	0.2848 ns
Dc (m)	4.552	0.356	4.2821	0.0891	0.4244 ns
Ht (m)	7.159	0.266	6.9507	0.0664	0.4552 ns
Hf (m)	2.073	0.131	2.2231	0.0333	0.4626 ns

ns = non-significant. Prob.: Probability value.

significantly different (P < 0.05) between infestation status (Table 1) regardless of the pest considered (African mistletoes or stem borers).

3.2. Prevalence and factors associated to shea trees pests (African mistletoes and stem borers)

In total, 64 shea butter trees were infested by the African mistletoes, 16 were attacked by stem borers and 3 were co-infested (African mistletoes and stem borers). Table 2 presents the attack rate of *Vitellaria paradoxa* (C. F. Gaertn.) by mistletoes and stem borers. The overall pest infestation prevalence in shea butter trees was 28.68% (CI = 23.32–34.68). The prevalence of infestation by the African mistletoes was 24.80% (CI = 19.66%–30.54%). Prevalence of shea trees attack by stem borers was 6.20 % (CI = 3.6 %–9.9%). These results showed that shea trees are most vulnerable to the African mistletoes than stem borers attack. The infestation rate of shea tree by the African mistletoes is respectively to 16/41 (39.02 %) in crop fields, 11/41 (26.83 %) in fallows and 37/176 (21.02 %) in savannah. The abundance of shea trees infestation is not depending statistically to the land use form (X-squared = 5.8842, df = 2, p-value = 0.05276).

The results of the GLMs with Beta family showed that the land use form was not significantly (Prob >0.05) associated with the prevalence of the African mistletoes parasitism and stem borers attack (Table 3). Indeed, fallows and savannah do not show any significant difference (Prob.> 0.05) compared to fields. The dispersion parameter (Phi-1 = 0.519 and Phi-1 = 0.128, respectively for the prevalence of shea trees infestation by the African mistletoes and by stem borers) indicates the good quality of the beta regression models.

The result of correlation test showed that none of shea trees morphological traits are correlated with one another (Figure 3).

Table 2. : *Vitellaria paradoxa* (C. F. Gaertn.) rate attack by mistletoes and stem bores.

Habitat	Occurrence of *Vitellaria paradoxa* (C. F. Gaertn.) parasitism			
	African mistletoes		Stem bores	
	Proportion (%)	CI (%)	Proportion (%)	CI (%)
Savannah	21.02	15.25–27.79	-	-
Fallow	26.83	14.22–42.99	-	-
Fields	39.02	24.20–55.49	-	-
Overall, by pest	28.68	23.32–34.68	6.20%	3.6%-9.9%
Overall, all pests	28.68% (CI = 23.32–34.68)			

Note: The number of trees attacked by stem borers being very low, the prevalence of infestation was not calculated by habitat.
Legend: CI = Confidence Interval.

Table 3. Beta regression results: land uses forms effect on the prevalence of Shea trees pest attack.

Variable	Sources of variation	Mean model		
		Coefficients	Standard.Error	Prob.
Prevalence of the mistletoes parasitize	Intercept	−0.320	0.354	0.366 ns
	Fallow	−0.650	0.502	0.195 ns
	Savannah	−0.674	0.502	0.179 ns
	Source of variation	Model accuracy		
		Coefficients	Std.Error	Prob.
	Phi	1.926	0.443	0.000
Variable	Sources de variation	Mean model		
		Coefficients	Standard Error	Prob.
Prevalence of stem bores attack	Intercept	−2.691	0.347	0.000***
	Fallow	0.214	0.420	0.610 ns
	Savannah	0.288	0.419	0.491 ns
	Source of variation	Model accuracy		
		Coefficients	ET	Prob.
	Phi	7.792	2.311	0.001**

***Significant at the 0.1% threshold; ** Significant at the 1% threshold; ns = non-significant. Prob.: Probability value.

The results of the simple GLMs with binomial family showed that none of the shea trees morphological traits were significantly associated (Prob >0.05) with the prevalence of the African mistletoes parasitism and stem borers attack (Table 4). The simplest hypothesis that the prevalence of the African mistletoes parasitism and stem borers attack is not related to tree size or habitat can be accepted. Nevertheless, the interpretation of the regression coefficients shows that there is positive negligible (statistically insignificantly) relationship between, the diameter at breast height (dbh), the crown diameter (Dc), the bole height (Hfut), the total height (Htot) and trees attack by the African mistletoe (Figure 4(a)). Also, there is positive negligible (statistically insignificantly) relationship between the diameter at breast height (dbh), the total height (Htot) and trees attack by stem borers (Figure 4(b)), while, there is negative negligible (statistically insignificantly) relationship between the bole height (Hfut) and trees attack by stem borers (Figure 4(b)).

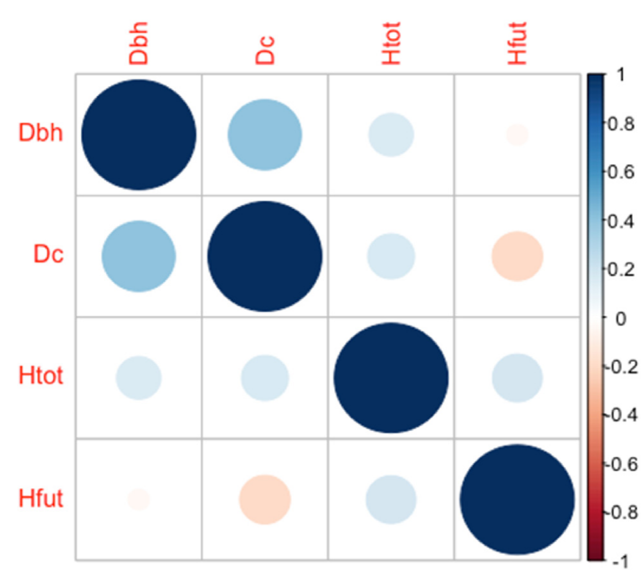

Figure 3. Correlation matrix plot of shea trees morphological traits. Note: Dbh: Diameter at breast height; Dc: Crown diameter; Ht: Total height; Hfut: Bole height. Legend: Positive correlations are displayed in blue and negative correlations in red. The intensity of the color and the size of the circles are proportional to the correlation coefficients. On the right of the correlogram, the color legend shows the correlation coefficients and the corresponding colors.

Table 4. Beta regression results: land uses forms effect on the prevalence of shea trees pest attack.

Source of variation	Estimate	Std.Error	Pr (>|z|)
Infestation by mistletoes			
(Intercept)	−3.40446	1.20647	0.00478**
Diameter at breast height (dbh)	0.03530	0.02476	0.15404
Crown diameter (Dc)	0.14451	0.11753	0.21887
Total height	0.09482	0.14718	0.51942
Height to branching	0.14523	0.29377	0.62104
Stem borers attack			
(Intercept)	−3.38373	2.12002	0.110
Diameter at breast height (dbh)	0.04822	0.04216	0.253
Crown diameter (Dc)	-0.04655	0.21022	0.825
Total height (Htot)	0.21157	0.24955	0.397
Height to branching (Hfut)	−0.72600	0.59087	0.219

***Significant at the 0.1% threshold.

4. Discussion

4.1. Shea trees infestation by the African mistletoe *and stem borers*

The prevalence of shea trees infestation by the African mistletoes was 24.80 % (CI = 19.66 %–30.54%). This infestation rate, whatever the habitat, is not negligible, especially for shea trees in the Sudanian regions. In effect, a study of the principal morphogenetic consequences of theses parasites on the host showed that African mistletoe (*Tapinanthus*) in combination with drought can cause the host to die (Boussim et al., 1993). Farmers recognize, thanks to their experience, that African mistletoes are often responsible for the decline in their fruit harvests, particularly shea and citrus (Boussim et al., 1993). The infestation rate of shea trees by the African mistletoes was 39.02% in field (agroforestry parklands). This infestation rate is lower than the infestation rate found in the peripheral agroforestry parklands of the protected area in Benin (80%; Houehanou et al., 2011), in similar areas in Nigeria (81%; Odebiyi et al., 2004), in similar areas in Burkina Faso (94.9%; Boussim et al., 1993) and in other area in Ghana (50% infestation in Maluwe region and 84% infestation in Gindabo region (Asare et al., 2019). The low rate of infestation obtained in the present study could be explained by the fact that farmers practice endogenous methods to fight against the proliferation of its parasitic plants on the shea trees in the fields. These include the manual destruction of infested branches or the confession of fans (human status) in the fields to influence the birds involved in the dissemination and predation of seeds. But the method which consists in destroying the infested branches, when it is not well applied, is less effective even if it contributes to diminish the hearths of infestation and to reduce the stock of grain of parasite. Indeed, the simple removal of the tufts of the parasite does not spare the insertion point of the parasite which very quickly regenerates new branches of African mistletoes (Boussim et al., 1993).

The present study showed that shea trees are most vulnerable to the African mistletoes (plant parasite) than stem borers attack. There are also reports that shea trees growing in protected areas are better protected against African mistletoe plant parasites than those on cultivated land (Houehanou et al., 2011). One of the reasons may be the dispersal mode of the parasite. Indeed, birds and pruning equipment are the two most mode of dispersal of the parasitic African mistletoe (Asare-Bediako et al., 2013). Effect of the two modes of dispersal will be pronounced more in fallow and in crop fields than savannah because of trees density. In theory of spatial density dependence in parasitoids, most models either explicitly or implicitly assume that when spatially density dependent parasitism occurs, it is due to individual parasitoids actively aggregating in areas with more hosts (Walde and Murdoch 1988). Anthropogenic pressures may also facilitate the infestation of shea trees by African mistletoes (Houehanou et al., 2011). The bird *Pogoniulus chrysonocus* is responsible for the dispersal of the parasite (Boussim et al., 1991). There are also reports that birds play a subsequent role in long-distance dispersal (Hawksworth and Wiens, 1998) and African mistletoes generally are regarded as bird dispersed (Calder and Bernhardt, 1983). Therefore, future investigations should be required on behaviour of the main bird disperser of African mistletoe on shea trees. The spread of the parasite by pruning equipment is also corroborated by another scientist (Asare-Bediako et al., 2013). Effective control of the African mistletoe is therefore important for a good sanitary state of the plant.

There is positive negligible (statistically insignificantly) relationship between, the diameter at breast height (dbh), the crown diameter (Dc), the bole height (Hfut), the total height (Htot) and shea butter trees attack by the African mistletoe. There are also reports that there was positive relationship between African mistletoe infestation and tree diameter (Asare et al., 2019). Large trees hosted African mistletoes and this could be due to the fact that large trees serve as better perches for birds that disseminate seeds of African mistletoes (Reid, 2000).

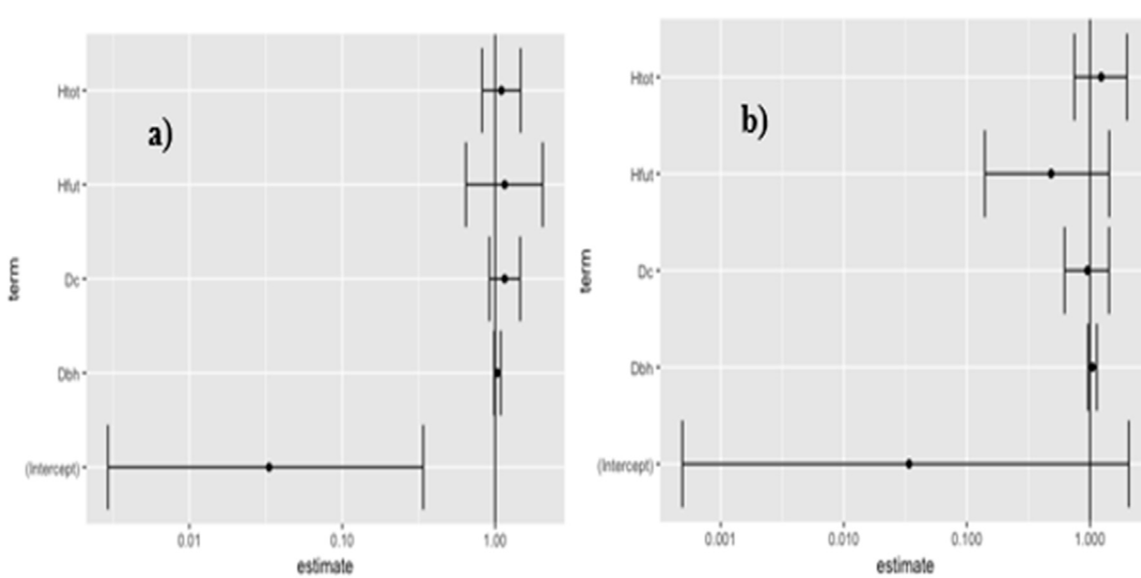

Figure 4. Graphical representation of odds ratios: a) *Infestation by mistletoes;* b) *Stem borers attack.*

The shea trees are attacked by the stem borers in fallows, field and savannah. There are also reports N'Djolossè et al. (2012) that the shea trees are attacked by the stem borers in all of the five (5) parkland whatever the land use form (habitat).

4.2. Study implication for shea trees pest management

The present study shows that the shea trees infestation by pests is a health problem for shea populations in view of the infestation rate obtained in this study, especially for the African mistletoe infestation. Further studies need to be conducted to determine the distribution, severity and impact of African mistletoes on the productivity of the shea trees (Asare et al., 2019). This study shows that the species habitat and morphological traits are not the associated factors with the shea trees infestation. This allows research programs on pest management of the species to open up other fields of studies in order to identify the associated factors. Climate change, pruning equipment (Asare-Bediako et al., 2013) and forestry practices can be factors favoring pests spread which can be tested in another study. The results of this study give a signal about the urgency of fighting for the conservation of the species, which is in view of the infestation rates is threatened. It indicates that the ecosystems of the savannah seem to play a major role in protecting shea trees against pests. As indicated by N'Djolossè et al. (2012), control methods developed for cerambycid stem borers on some tree species in northern Africa, Asia and Europe can possibly be applied to control shea stem borers.

5. Conclusion

The results of this study show that the rate of attack on shea trees by mistletoes and stem borers reduced by more than half in less than twenty years in the West African region. This reflects that control efforts are made but the evil is still not eradicated. We can afford to say that the methods currently used to fight against the proliferation of the two pests are not completely effective. Savannas seem to be habitats that slow down the proliferation of the two pests on shea trees. It was also shown through this study that the two pests attack the oldest shea trees more. Studies to elucidate the reasons and their valuation are necessary for a good health status of shea trees for good fruit yield. Biological control seems to be a research axis to eradicate the proliferation of these two pests in this context of climate change considered as a factor accelerating the mortality of shea trees attacked by mistletoe. Through the present study the simplest hypothesis that prevalence of the African mistletoes parasitism and stem borers attack is not related to tree size or habitat can be accepted.

Declarations

Author contribution statement

Gbemavo Dossou Seblodo Judes Charlemagne & Gbemavo Médard: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Ouinsavi Christine: Analyzed and interpreted the data; Conceived and designed the experiments; Wrote the paper.

Dassou Anicet: Analyzed and interpreted the data; Performed the experiments; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

The authors do not have permission to share data.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements:

The authors thank their colleagues who have read this manuscript before the submission.

References

Aleza, K., Villamor, G.B., Nyarko, B.K., Wala, K., Akpagana, K., 2018. Shea (Vitellaria paradoxa Gaertn CF) fruit yield assessment and management by farm households in the Atacora district of Benin. PLoS One 13 (1), e0190234.

Ani, D.P., Aondona, G., Soom, A., 2012. Economic analysis of shea butter plant in Ukum local Government, Benue state, Nigeria. Am.-Eurasian J. Agron. 5 (1), 10–18. http://idosi.org/aeja/5(1)12/3.pdf.

Asare, E.K., Avicor, S.W., Dogbatse, J.A., Anyomi, E.W., 2019. Occurrence of mistletoes on shea trees in Northern Ghana. Afr. Crop Sci. J. 27 (4), 679–686.

Asare-Bediako, E., Addo-Quaye, A.A., Tetteh, J.P., Buah, J.N., Van Der Puije, G.C., Acheampong, R.A., 2013. Prevalence of mistletoe on citrus trees in the Abura-Asebu-Kwamankese district of the Central Region of Ghana. Int. J. Sci. Technol. Res. 2 (7), 122–127. https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.637.6197&rep=rep1&type=pdf.

Bayala, J., Teklehaimanot, Z., Ouedraogo, S.J., 2002. Millet production under pruned tree crowns in a parkland system in Burkina Faso. Agrofor. Syst. 54 (3), 203–214.

Baziari, F., Henquinet, K.B., Cavaleri, M.A., 2019. Understanding farmers' perceptions and the effects of shea (Vitellaria paradoxa) tree distribution in agroforestry parklands of Upper West Region, Ghana. Agrofor. Syst. 93 (2), 557–570.

Boffa, J.M., 2015. Opportunities and challenges in the improvement of the shea (Vitellaria paradoxa) resource and its management. In: Occasional Paper, 24. http://apps.worldagroforestry.org/downloads/Publications/PDFS/B17800.pdf.

Boussim, J.I., Sallé, G., Guinko, S., 1993. Tapinanthus parasite du Karité au Burkina Faso. 1ère partie identification et distribution. Bois Forets Tropiques 238, 45–52.

Boussim, J., Salle, G., Raynal Roques, A., 1991. Identification, distribution and biology of Tapinanthus species parasitizing shea trees in Burkina Faso. In: 5. International Symposium of Parasitic Weeds, Nairobi (Kenya), 24-30 Jun 1991. CIMMYT.

Calder, M., Bernhardt, P., 1983. The Biology of Mistletoes. Academic Press.

Dimobe, K., Ouédraogo, A., Ouédraogo, K., Goetze, D., Stein, K., Schmidt, M., et al., 2020. Climate change reduces the distribution area of the shea tree (Vitellaria paradoxa CF Gaertn.) in Burkina Faso. J. Arid Environ. 181, 104237.

Fonton, N.H., Atindogbe, G., Hounkonnou, N.M., Dohou, R.O., 2011. Plot size for modelling the spatial structure of Sudanian woodland trees. Ann. For. Sci. 68 (8), 1315–1321.

Gbédji, E.K.Y., 2003. Caractérisation morphologique et structurale des parcs à néré (Parkia biglobosa (Jack;) R. Br. Ex. G. Dom.) au Bénin. *Diplôme d'Ingénieur Agronome*, 105. Université d'Abomey-Calavi.

Gnangle, P.C., Egah, J., Baco, M.N., Gbemavo, C.D., Kakaï, R.G., Sokpon, N., 2012. Perceptions locales du changement climatique et mesures d'adaptation dans la gestion des parcs à karité au Nord-Bénin. Int. J. Brain Cognit. Sci. 6 (1), 136–149.

Gouwakinnou, G.N., Lykke, A.M., Assogbadjo, A.E., Sinsin, B., 2011. Local knowledge, pattern and diversity of use of Sclerocarya birrea. J. Ethnobiol. Ethnomed. 7 (1), 1–9.

Hawksworth, F.G., Wiens, D., 1998. Dwarf Mistletoes. DIANE Publishing.

Houehanou, T.D., Kindomihou, V., Sinsin, B., 2011. Effectiveness of conservation areas in protecting Shea trees against hemiparasitic plants (Loranthaceae) in Benin, West Africa. Plant Ecol. Evol. 144 (3), 267–274.

Lamien, N., Boussim, J.I., Nygard, R., Ouédraogo, J.S., Odén, P.C., Guinko, S., 2006. Mistletoe impact on Shea tree (Vitellaria paradoxa CF Gaertn.) flowering and fruiting behaviour in savanna area from Burkina Faso. Environ. Exp. Bot. 55 (1-2), 142–148.

Lovett, P., Phillips, L.D., 2018. Agroforestry Shea Parklands of Sub-saharan Africa: Threats and Solutions. Profor, Washington, DC.

Maranz, S., Kpikpi, W., Wiesman, Z., De Saint Sauveur, A., Chapagain, B., 2004. Nutritional values and indigenous preferences for shea fruits (Vitellaria paradoxa CF Gaertn. F.) in African agroforestry parklands. Econ. Bot. 58 (4), 588–600.

Naughton, C.C., Lovett, P.N., Mihelcic, J.R., 2015. Land suitability modeling of shea (Vitellaria paradoxa) distribution across sub-Saharan Africa. Appl. Geogr. 58, 217–227.

N'Djolossè, K., Atachi, P., Gnanglè, C.P., 2012. Inventory of insects associated with shea trees (Vitellaria paradoxa)(Sapotaceae) in central and northern Benin. Int. J. Trop. Insect Sci. 32 (3), 158–165.

Odebiyi, J.A., Bada, S.O., Omoloye, A.A., Awodoyin, R.O., Oni, P.I., 2004. Vertebrate and insect pests and hemi-parasitic plants of Parkia biglobosa and Vitellaria paradoxa in Nigeria. Agrofor. Syst. 60 (1), 51–59.

Ogwok, G., Alele, P.O., Kizza, S., 2019. Influence of Shea tree (Vitellaria paradoxa) on maize and soybean production. PLoS One 14 (4), e0201329.

Ojo, O., Kengne, M.H., Fotsing, M.C., Mmutlane, E.M., Ndinteh, D.T., 2021. Traditional uses, phytochemistry, pharmacology and other potential applications of Vitellaria paradoxa Gaertn.(Sapotaceae): a review. Arab. J. Chem. 14 (7), 103213.

Okullo, J.B.L., Omujal, F., Agea, J.G., Vuzi, P.C., Namutebi, A., Okello, J.B.A., Nyanzi, S.A., 2010. Physico-chemical characteristics of Shea butter (Vitellaria paradoxa CF Gaertn.) oil from the Shea district of Uganda. Afr. J. Food Nutr. Sci. 10 (1).

Okurut, I.T., Okullo, J.B.L., Waiswa, D., Muyizzi, J., 2020. Modelling the potential distribution of Vitellaria paradoxa subsp. nilotica (CF Gaertn) across the Kidepo landscape of Uganda in the face of climate change. J. Geosci. Environ. Protect. 8 (8), 14.

Pye, N., 1985. [Review of the vegetation of Africa: a descriptive memoir to accompany the UNESCO/AETFAT/UNSO vegetation map of Africa, by F. White]. Geogr. J. 151 (1), 132–134.

R Core Team, 2020. R: A Language and Environment for Statistical Computing. R Found. Stat. Comput., Vienna, Austria.

Robinson, D., Hayes, A., 2018. Broom: Convert Statistical Analysis Objects into Tidy Tibbles. Version 0.5. 0. https://CRAN.R-project.org/package=broom.

Sanogo, K., Bayala, J., Villamor, G.B., Dodiomon, S., van Noordwijk, M., 2021. A non-destructive method for estimating woody biomass and carbon stocks of Vitellaria paradoxa in southern Mali, West Africa. Agrofor. Syst. 95 (1), 135–150.

Sanou, H., Kambou, S., Teklehaimanot, Z., Dembélé, M., Yossi, H., Sina, S., et al., 2004. Vegetative propagation of Vitellaria paradoxa by grafting. Agrofor. Syst. 60 (1), 93–99.

Seghieri, J., 2019. Shea tree (Vitellaria paradoxa Gaertn. f.): from local constraints to multi-scale improvement of economic, agronomic and environmental performance in an endemic Sudanian multipurpose agroforestry species. Agrofor. Syst. 93 (6), 2313–2330.

Shea, K., Thrall, P.H., Burdon, J.J., 2000. An integrated approach to management in epidemiology and pest control. Ecol. Lett. 3 (2), 150–158.

Stout, J.C., Nombre, I., de Bruijn, B., Delaney, A., Doke, D.A., Gyimah, T., et al., 2018. Insect pollination improves yield of Shea (Vitellaria paradoxa subsp. paradoxa) in the agroforestry parklands of West Africa. J. Pollination Ecol. 22, 11–20.

Tom-Dery, D., Eller, F., Reisdorff, C., Jensen, K., 2018. Shea (Vitellaria paradoxa CF Gaertn.) at the crossroads: current knowledge and research gaps. Agrofor. Syst. 92 (5), 1353–1371.

Walde, S.J., Murdoch, W.W., 1988. Spatial density dependence in parasitoids. Annu. Rev. Entomol. 33 (1), 441–466. https://www.annualreviews.org/doi/pdf/10.1146/annurev.en.33.010188.002301.

Wardell, D.A., Elias, M., Zida, M., Tapsoba, A., Rousseau, K., Gautier, D., et al., 2021. Shea (Vitellaria paradoxa CF Gaertn.)–a peripheral empire commodity in French West Africa, 1894–1960. Int. For. Rev. 23 (4), 511–533.

Wickham, H., 2016. ggplot2: Elegant Graphics for Data Analysis. Springer.

World Agroforestry Centre, 2008. Transforming Lives and Landscapes. Strategy 2008–2015. Nairobi.

Zeileis, A., Cribari-Neto, F., Grün, B., Kos-Midis, I., 2010. Beta regression in R. J. Stat. Software 34 (2), 1–24.