Original article

# Variation of Loranthaceae impact on *Vitellaria paradoxa* C. F. Gaertn. fruit yield in contrasting habitats and implications for its conservation

Thierry D. Houehanou[1*], Valentin Kindomihou[1], Tariq Stevart[2], Brice Tente[1], Marcel Houinato[1], Brice Sinsin[1]

[1] Lab. Appl. Ecol., Fac. Agron. Sci., Univ. Abomey Calavi, 01 BP 526, Cotonou, Benin, houehanout@yahoo.fr

[2] Mo. Bot. Garden, P.O. Box 299, St. Louis, MO 63166-0299, U.S.A.

* *Correspondence and reprints*

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## Variation of Loranthaceae impact on *Vitellaria paradoxa* C. F. Gaertn. fruit yield in contrasting habitats and implications for its conservation.

**Abstract – Introduction**. Shea tree (*V. paradoxa* C.F. Gaertn.), a species endemic to the Sudanian savanna woodlands, is dominant in the parklands of West Africa where it is of great socioeconomic importance. However, shea tree has been reported in recent decades to be threatened by plant parasites, Loranthaceae. Our study aimed to assess possible variation of the impact of these parasites on shea tree fruit yield in two contrasting habitats. **Materials and methods**. We selected 41 weakly and 41 heavily infected shea tree individuals, of similar size, in a protected area as well as in its adjacent parklands. Shea tree traits such as diameter at breast height, canopy diameter, tree height, canopy height, number of fruit yielded, number of parasite stumps per tree and an impact index ratio were assessed on each shea tree individual. Two-way ANOVA was performed to compare parasite impact on shea tree fruit yield in relation to habitat. Hierarchical cluster, canonical discriminant and one-way ANOVA analyses were used to show quantitative traits that characterize shea tree groups from habitats. **Results**. Loranthaceae did not reduce fruit yield significantly either in the parklands or in the protected area. Quantitative traits tended to discriminate all pooled shea trees in relation to habitats. Shea tree individuals in parklands were characterized mostly by the highest value of number of infected stumps per tree and of the impact index ratio, suggesting that many shea tree individuals in parklands were sensitive to Loranthaceae impact on their fruit yield. **Conclusion**. These findings were helpful for implementing some shea tree conservation plans.

**Benin / *Vitellaria paradoxa* / fruits / yield / Loranthaceae / parasitism / colonizing ability / habitats**

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## Variation de l'impact des loranthacées sur le rendement en fruits de *Vitellaria paradoxa* C.F. Gaertn. dans des habitats différentiés et implications pour sa conservation.

**Résumé – Introduction**. Le karité (*V. paradoxa* CF Gaertn.), une espèce endémique des forêts de la savane soudanienne, prédomine dans les parcs d'Afrique de l'Ouest où la plante a une grande importance socio-économique. Cependant, au cours des dernières décennies, le karité s'est révélé menacé par des loranthacées, parasites de végétaux. Notre étude a cherché à comparer l'incidence de ces parasites sur le rendement en fruits d'arbres de karité dans deux habitats différentiés. **Matériel et méthodes**. Nous avons sélectionné 41 individus de karité faiblement infectés et 41 individus fortement infectés, de taille similaire, dans deux habitats : une zone de végétation protégée et des parcelles adjacentes non protégées. Certaines caractéristiques des karités comme le diamètre des troncs à hauteur de poitrine, le diamètre de la canopée, la hauteur des arbres, la hauteur de la canopée, le nombre de fruits récoltés, le nombre de souches de parasites par arbre et un indice calculé évaluant l'impact du parasite sur la production de l'arbre ont été mesurés sur chaque individu de karité sélectionné. Une ANOVA à deux voies a été réalisée pour comparer l'impact des parasites sur le rendement en fruits des karités selon l'habitat. Des analyses de classification hiérarchique, canonique discriminante et ANOVA unidirectionnelle ont été utilisées pour mettre en évidence les caractères quantitatifs caractérisant les groupes de karité dans les habitats. **Résultats**. L'impact des loranthacées sur le rendement en fruits des arbres n'a pas été significativement différent dans les deux habitats considérés. Les caractères quantitatifs ont eu tendance à discriminer des groupes d'arbres de karité dans les deux habitats. Les individus de karité des parcelles non protégées ont été principalement caractérisés par un plus grand nombre de souches de plantes parasites par arbre et par un indice d'impact sur le rendement plus fort, ce qui suggère que, dans ces parcelles, de plus nombreux plants de karité ont été sensibles à l'impact des loranthacées sur leur rendement en fruits. **Conclusion**. Ces résultats ont été utiles pour mettre en œuvre des plans de conservation des arbres de karité.

**Bénin / *Vitellaria paradoxa* / fruits / rendement / Loranthaceae / parasitisme / aptitude à coloniser / habitat**

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## 1. Introduction

*Vitellaria paradoxa* C. F. Gaertn. (Sapotaceae), the shea tree, is endemic to wooded Sudanian savannas of Africa, spreading from Senegal to Uganda [1]. Local people enjoy many products made from this species, which is a dominant component of agricultural systems in Africa [2, 3]. Fruits of shea tree are rich in nutrients. Its almonds are transformed into butter, which is highly preferred by many rural people in Africa [4]. This butter is also used for chocolate manufacturing and in the cosmetic industry [5, 6].

Nevertheless, shea trees were recently reported to be highly threatened by Loranthaceae, hemiparasitic plants [7]. According to these authors, 95% of the shea tree populations of Burkina Faso and Mali were infected by Loranthaceae. These parasites are strongly involved in the high mortality rate of shea trees observed in these countries [8, 7]. Moreover, referring to the impact of Loranthaceae species on shea tree hosts, these parasites start with a decrease in the growth vigor of the parasitized branch and gradually affect the seed yields [9]. Therefore, shea tree conservation against Loranthaceae has become important and much research [10–12] based on shea tree Loranthaceae has been undertaken.

There are different ways (for instance, quantifying variation of quantitative traits, studying genetic diversity, etc.) to define and apply conservation strategies of tree species. Thus, a good understanding of variation of species traits is necessary for conserving and sustainably managing a tree species [13–15]. Therefore, variation of shea tree traits has been addressed in relation to anthropogenic pressure [2, 16, 17] and geographical position [15, 18]. It has been shown that shea trees are more productive in parklands in comparison with natural savannas [16, 17, 19, 20].

Regarding Loranthaceae impact on host fruit production, some findings [21, 22] showed that host trees that carried a greater load of parasites produced lower fruit yields. As far as shea tree is concerned, it was previously established [23] that infected shea tree individuals carried greater parasite load in parklands compared with those in protected areas. Consequently, greater variation of Loranthaceae impact on shea tree fruit yield in parklands is expected compared with protected areas. It has also been shown that prevalence of shea tree infection by Loranthaceae (*i.e.*, shea tree infection rate) was higher in parklands than in protected areas [23]. In that respect also, higher prevalence of Loranthaceae impact on shea tree fruit yield in parklands is expected compared with protected areas.

Moreover, previous studies focusing on shea tree Loranthaceae in West Africa were related to Loranthaceae diversity and control [10, 11], Loranthaceae distribution [10], Loranthaceae impact on flowering and fruiting behavior of infected shea tree branches [12], and shea tree protection against Loranthaceae infection [23]. However, variation of Loranthaceae impact on shea tree fruit yield is seldom assessed in relation to anthropogenic pressure and should be helpful for implementing *in situ* shea tree conservation plans. Therefore, our study aimed to assess such variation in addressing two hypotheses: (1) Loranthaceae impact on shea tree fruit yield is significantly higher in parklands than in protected areas, and (2) prevalence of Loranthaceae impact on shea tree fruit yield is higher in parklands than in protected areas.

## 2. Materials and methods

### 2.1. Study species

Our study focused on *Vitellaria paradoxa* C.F. Gaertn. (Sapotaceae) as the host tree of Loranthaceae, plant parasites that live on that host in the study area. *Vitellaria paradoxa* is a tree species often reaching over 20 m in height and 50 cm diameter at breast height. Within this species, two subspecies have been distinguished, *Vitellaria paradoxa* subsp. *paradoxa* and *V. paradoxa* subsp. *nilotica*. Although it may sometimes be difficult to differentiate between them, most reports emphasized the occurrence of *V. paradoxa* subsp. *paradoxa* in West African countries, while the second subspecies is known to occur in East Africa [15]. As far as Loranthaceae are concerned, three species occur in the study area. They are *Agelanthus dodoneifolius* (DC.) Polh. & Wiens, *Tapinanthus globiferus* (A. Rich.) Van Tieghem and *Tapinanthus ophiodes* (Sprague) Danser. *Agelanthus dodoneifolius* is the most widespread on shea tree in the study area.

## 2.2. Study area

The study was carried out in the Pendjari Biosphere Reserve and in its adjacent surrounding agroforestry parklands. The reserve covers 4666.4 $km^2$ and is composed of the Pendjari National Park (2660.4 $km^2$), the Pendjari hunting zone (1750 $km^2$) and the Konkombri hunting zone (251 $km^2$). It is located in the Sudanian zone of northern Benin (10°40'–11°28' N and 0°57'–2°10' E) in West Africa. In the protected area, logging and agricultural activities are strictly prohibited. Conversely, the surrounding land areas are dominated by agroforestry parklands that are built around selection of desirable trees, with shea tree as a dominant species. The climate is tropical with an average annual, unimodal rainfall of 1100 mm. Monthly mean temperatures range from 19 °C to 34 °C. Annual potential evapotranspiration is about 1500 mm. Monthly mean values of relative moisture range from 25% to 85%. The rainy season begins in April, followed by a dry season from November to March [24]. The main soil type occurring in the Pendjari Biosphere Reserve is tropical ferruginous soil [25]. In this zone, local people valorize shea tree fruits and nuts for several purposes.

## 2.3. Sampling and data collection

During the shea tree ripening period, forty-one weakly (mean number of infection points equal to 1 and 3, respectively, in the protected area and in the parklands) and 41 heavily (mean number of infection points equal to 10 and 24, respectively, in the protected area and in the parklands) infected trees were selected in each habitat (*i.e.*, the protected area and surrounding parklands). Overall, 164 shea tree individuals (82 trees in the reserve and 82 trees in the surrounding parklands) were selected. Tree sampling and data collection were carried out from March to May, 2010. This period corresponds yearly to the green fruit phase of shea tree in the study area. Data were collected in this shea tree stage of immature green fruits in order to prevent loss of fruit due to predation by wild animals in the reserve. During this stage, fruits are not matured but are green [26, 27]. The rarity of healthy shea trees in the adjacent parklands (due to the high infection rate of shea tree in this area) [23] justified the choice of weakly parasitized individuals in the two investigated habitats instead of healthy individuals.

Six traits were measured: diameter at breast height, overall height of the shea tree, crown diameter, crown height, number of Loranthaceae stumps per shea tree and number of fruit yielded per shea tree. The number of fruit produced per shea tree was evaluated by counting it. If the number exceeded 300 fruits, twenty-five percent of shea tree branches were sampled and the result was extrapolated to the total number of branches. In that case, the branches were sampled by considering the distribution of fruit on branches using findings of previous studies [27, 28]. Tree traits such as diameter at breast height, overall height of the tree, crown diameter and crown height were similar between weakly and heavily infected trees.

## 2.4. Data processing and analysis

Traits were compared statistically between weakly and heavily infected trees in the protected area and in the parkland with Student's independent *t* test. The fruit yield and Loranthaceae stump data were log-transformed in order to normalize the distribution. To test variation of Loranthaceae impact on shea tree fruit yield between the protected area and parkland, a two-way ANOVA was performed [29]. Student's *t* test was used to compare fruit yield of weakly and heavily infected shea trees within each habitat type (protected area and parklands)

**Table I.**
Comparative shea tree traits in a protected area and in adjacent parklands in regard to Loranthaceae infection (SE: standard error; *p:* probability of Student's *t* test comparing the two paired sampled shea trees).

| Area considered | | | Tree diameter (cm) | Tree height (m) | Crown diameter (cm) | Crown height (m) |
|---|---|---|---|---|---|---|
| Protected area | Weakly infected trees | Mean | 20.15 | 6.68 | 5.06 | 3.6 |
| | | SE | 0.72 | 0.23 | 0.2 | 0.18 |
| | Heavily infected trees | Mean | 19.80 | 7.02 | 5.10 | 3.98 |
| | | SE | 0.78 | 0.19 | 0.2 | 0.17 |
| *p* | | | 0.7 | 0.2 | 0.8 | 0.1 |
| Parklands | Weakly infected trees | Mean | 23.87 | 6.97 | 6.50 | 4.12 |
| | | SE | 0.82 | 0.14 | 0.26 | 0.11 |
| | Heavily infected trees | Mean | 24.66 | 7.46 | 6.80 | 4.52 |
| | | SE | 0.82 | 0.22 | 0.24 | 0.20 |
| *p* | | | 0.3 | 0.1 | 0.9 | 0.1 |

and also to compare fruit yield of all weakly and heavily infected shea trees.

To assess the difference in prevalence of Loranthaceae impact on shea tree fruit yield, an impact index ratio (IP) was constructed as the ratio of the Loranthaceae stump number (n) to fruit yield (N) per shea tree, (IP = n/N). It was expected that the impact index ratio (IP) had a value lower than 1. Therefore, when for a shea tree individual, the IP value is higher than 1, the more likely it is that this shea tree individual is sensitive to Loranthaceae impact on its fruit yield. All shea tree individuals (164 total), with seven traits (diameter at breast height; height of the shea tree; crown diameter and crown height; number of Loranthaceae stumps per shea tree and number of fruit yielded per shea tree; impact index ratio) were used to perform hierarchical cluster analysis. Groups of shea tree individuals with similar traits were built using the Bray-Curtis distance measure and the group linkage method of Flexible Beta in PC-ORD 5.0. One-way ANOVA was used to compare shea tree traits between shea tree discriminated groups. Canonical Discriminant Analysis (using the Mahalanobis distance) was performed on groups and traits to reveal links between the traits and plot distances between groups. This analysis is a powerful test to identify the discriminative traits between entities that fall into groups [30].

Correlation among traits was performed and tested using Pearson's correlation. Since there were significant strong correlations between diameter at breast height and height of the shea tree, crown diameter and crown height, we let height of the shea tree and crown height when calculating the correlation matrix of traits. Statistical analyses were performed using SAS [31] and Minitab 14.

## 3. Results

### 3.1. Loranthaceae infection and shea tree traits

Traits of shea trees were similar ($p > 0.05$) between paired infected shea trees (weakly and heavily) both in the protected area and in the surrounding parklands (*table I*). All things being equal, a significant difference was expected between paired shea trees in terms of fruit yield.

### 3.2. Variation of Loranthaceae impact on shea tree fruit yield in relation to habitat type

Loranthaceae impact on fruit yield did not differ significantly between habitat types. Indeed, the number of fruit yielded by weakly infected shea trees did not differ significantly from the heavily infected ones in the protected area [(41.9 ± 8.4) fruits per tree *versus* (64.41 ± 16.01) fruits per tree, respectively; $p = 0.2$] or in the parklands [(171.1 ± 39.3) fruits per tree *versus* (159.5 ± 40.3) fruits per tree, respectively; $p = 0.8$] (*figure 1*). The interaction between habitat and shea tree status was also not significant ($p = 0.1$). However, the yield of fruit depended on the habitat. The number of fruit was three times higher ($p < 0.001$) in the parklands than in the protected area [(165.32 ± 28.31) fruits per tree *versus* (53.15 ± 9.07) fruits per tree]. Also, the fruit number of all weakly infected shea trees (106.51 fruits per tree) did not differ significantly ($p = 0.8$) from that of all heavily infected shea trees (111.97 fruits per tree).

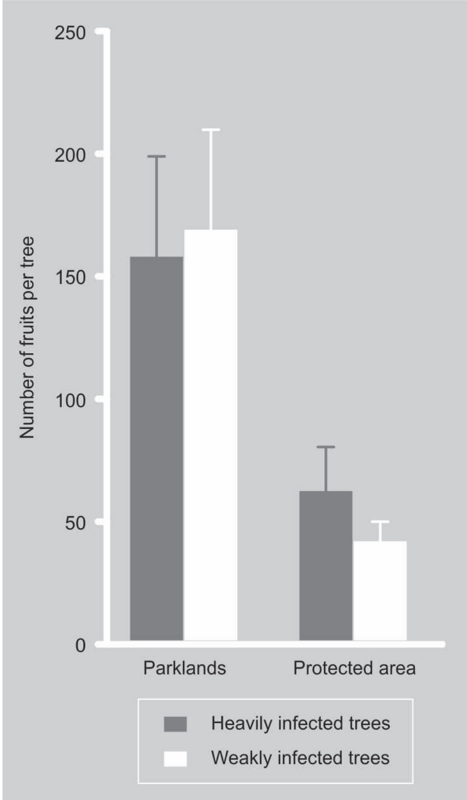


**Figure 1**. Comparative shea tree fruit yield (mean ± standard error) in regard to Loranthaceae infection in parklands and in a protected area.

### 3.3. Variation of shea tree quantitative traits in relation to habitat type

The cluster analysis grouped the 164 individuals studied into five different groups according to the seven assessed quantitative traits (*figure 2*) with 60% of overall information within each group. The composition (*i.e.*, rate of shea tree individuals of each habitat belonging to each distinguished group) of each shea tree group showed that the G2 and G4 groups were composed mostly of shea tree individuals from the parklands, while shea trees from the protected area were mostly grouped in the G1, G3 and G5 groups (*figure 3*). The canonical discriminant analysis indicated globally that the groups were significantly discriminated (Wilks' Lambda = 0.18, $p < 0.0001$) by traits. However, some traits (diameter at breast height, crown height) showed similar mean values among groups while others (crown diameter, number of Loranthaceae stumps per shea tree, number of fruit yielded per shea tree, impact index ratio) showed the opposite (*table II*).

The first two axes of canonical discriminant analysis explained 97% of the total variation ($p < 0.0001$). Axis 1 of the canonical discriminant analysis, that explained 79% of total variation, was positively linked with number of fruit yield (N), while axis 2 explained 19% of variation and was linked with number of infected stumps (n) and the impact index ratio (IP) (*table III*). Considering these results and the projection of shea tree groups onto the two axes (figure not shown), it can be concluded that shea trees in the G4 group were characterized by the highest value of fruit yield, while the G1 group showed the lowest one (*table II*). Also, shea trees in the G2 group were characterized by the highest value of number of infected stumps (n) and of the impact index ratio. This latter trait showed a value higher than 1 in the G2 group and lower than 1 in the other groups (*table II*).

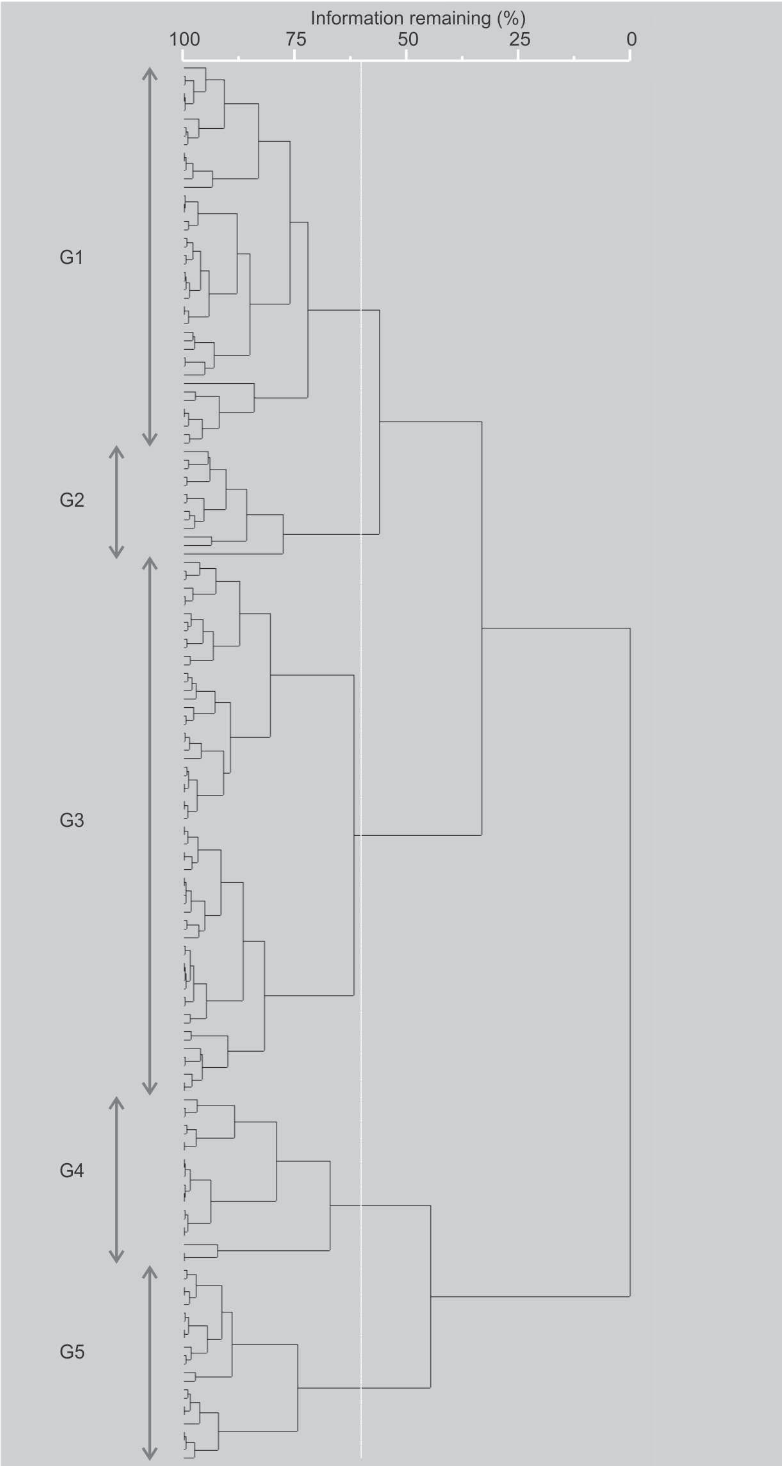


**Figure 2.**
Diagram of hierarchical cluster analysis based on 164 shea tree individuals and seven quantitative traits. Groups were built using the Bray-Curtis distance measure and the group linkage method of Flexible Beta.

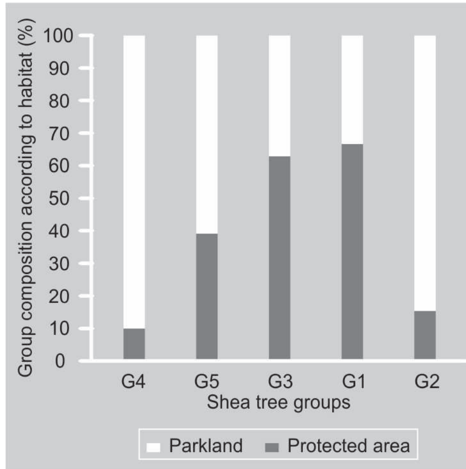


**Figure 3.**
Habitat composition of the five shea tree groups defined by cluster analysis.

### 3.4. Correlation among traits

When studying the correlation value among traits, it can be noticed that the diameter at breast height and the canopy diameter of the shea tree were positively and significantly correlated in the protected area and in the parklands (*table IV*). The number of infected stumps and the impact index ratio were also positively and significantly correlated in both habitats. Strong significant and positive correlation between shea tree diameter and number of infected stumps was observed in the parklands, while the protected area showed weak and non-significant correlation.

## 4. Discussion and conclusion

### 4.1. Variation of Loranthaceae impact on shea tree fruit yield in relation to habitat type

According to the present study, weakly infected shea trees did not show significantly higher fruit yield compared with heavily infected ones either in the parklands or in the protected area. This suggests that Loranthaceae do not significantly affect shea

**Table II.**
Mean value ± standard error of quantitative shea tree traits among groups built by hierarchical cluster analysis. The numbers in brackets represent shea tree individual numbers that fall in each group.

| Groups | Diameter at breast height (cm) | Tree height (m) | Crown diameter (m) | Crown height (m) | Number of infected stumps | Number of fruit yielded | Impact index ratio |
|---|---|---|---|---|---|---|---|
| G1 (45) | 19.25 ± 0.54 | 4.58 ± 1.67 | 4.93 ± 0.10 | 3.89 ± 3.4 | 4.53 ± 0.77 | 6.8 ± 0.51 | 0.70 ± 0.20 |
| G2 (13) | 21.82 ± 1.15 | 5.19 ± 2.12 | 5.78 ± 0.15 | 4.59 ± 2.41 | 27.46 ± 2.43 | 18.1 ± 2.33 | 3.48 ± 1.82 |
| G3 (62) | 21.54 ± 0.67 | 5.30 ± 0.48 | 5.91± 0.12 | 4.78 ± 3.78 | 8.32 ± 1.06 | 50.0 ± 2.81 | 0.18 ± 0.02 |
| G4 (20) | 21.87 ± 1.02 | 5.68 ± 0.89 | 6.41 ± 0.17 | 5.12 ± 1.23 | 12.55 ± 2.77 | 533.7 ± 70.10 | 0.02 ± 0.00 |
| G5 (23) | 21.24 ± 1.02 | 5.51 ± 1.34 | 5.99 ± 0.13 | 4.97 ± 0.07 | 11.22 ± 2.75 | 154.6 ± 8.53 | 0.08 ± 0.02 |
| Significance | ns | ns | * | ns | ** | ** | ** |

ns: Not significant ; *: significant at $p < 0.05$; **: significant at $p < 0.001$.

tree fruit yield either in parklands or in protected areas. Also, the interaction between habitats (*i.e.*, the parklands and protected area) and shea tree status (*i.e.*, weakly and heavily infected shea trees) was not significant. These results support the rejection of the first hypothesis, according to which Loranthaceae were supposed to have a higher impact on shea tree fruit yield in parklands than in protected areas. If Loranthaceae impact on shea tree fruit yield was not perceived significantly either in the parklands or in the protected area, this should be linked to the complexity of the host-parasite relation [32]. It was also revealed previously that the flowering and fruiting behavior of infected shea tree branches did not differ significantly from healthy ones [12]. However, it was found elsewhere [21, 22] that host trees that carried greater parasite load produced less fruit. Thus, Loranthaceae impact on shea tree needs to be investigated in other terms, such as physiological impact. For instance, it should be necessary to investigate the effect of Loranthaceae on photosynthetic tissues (*i.e.*, water and carbohydrate nutrients) of infected shea tree branches. Also, the impact of Loranthaceae on the morphology and composition (*i.e.*, chlorophyll concentration and biochemical composition) of shea tree fruits may be investigated in the future in the two contrasted habitats.

**Table III.**
Correlation between shea tree traits and canonical discriminant axes. Axis 1 (can1) is strongly correlated to the number of fruit yielded and axis 2 (can2) to the number of infected stumps and impact index ratio.

| Shea tree traits | Axis 1 (79%) | Axis 2 (19%) |
|---|---|---|
| Diameter at breast height | 0.117 | 0.159 |
| Tree height | 0.110 | 0.107 |
| Crown diameter | 0.238 | 0.129 |
| Crown height | 0.130 | 0.240 |
| Number of fruit yielded | 0.998 | 0.043 |
| Number of infected stumps | 0.120 | 0.906 |
| Impact index ratio | – 0.177 | 0.632 |

### 4.2. Variation of quantitative shea tree traits according to habitat type

The hierarchical cluster analysis tended to group shea tree individuals mostly on the basis of the protected area (G1 and G3) and parklands (G2 and G4). Additionally, the canonical discriminant analysis indicated that the fruit yield, the number of parasite stumps and the impact index ratio discriminated groups significantly. In a precedent finding [16], shea trees in parklands produce more than those in forests. This suggests that shea tree fruit yield is a discriminant trait

**Table IV.**
Correlation matrix between quantitative shea tree traits in a protected area and surrounding parklands.

• Protected area

| Trait studied | Diameter at breast height | Crown diameter | Number of fruit yielded per shea tree | Number of Loranthaceae stumps per shea tree |
|---|---|---|---|---|
| Crown diameter | 0.501 * | – | – | – |
| Number of fruit yielded per shea tree | 0.011 ns | 0.063 ns | – | – |
| Number of Loranthaceae stumps per shea tree | – 0.043 ns | 0.087 ns | 0.061 ns | – |
| Impact index ratio | – 0.122 ns | – 0.048 ns | – 0.146 ns | 0.317 * |

• Parklands

| Trait studied | Diameter at breast height | Crown diameter | Number of fruit yielded per shea tree | Number of Loranthaceae stumps per shea tree |
|---|---|---|---|---|
| Crown diameter | 0.33 * | – | – | – |
| Number of fruit yielded per shea tree | 0.119 ns | 0.197 ns | – | – |
| Number of Loranthaceae stumps per shea tree | 0.261 * | 0.154 ns | 0.043 ns | – |
| Impact index ratio | 0.077 ns | – 0.137 ns | – 0.165 ns | 0.214 * |

ns: Not significant; *: significant at $p < 0.05$.

between natural areas (*i.e.*, protected area) and parklands. The canonical discriminant analysis also indicated that G2 was composed of shea trees with the highest value of the number of infected stumps (n) and impact index ratio. This suggests that parklands tend to have many shea tree individuals with the highest parasite infection degree. The impact index ratio was found to be the highest in G2, with a value higher than 1. Consequently, many infected shea tree individuals in parklands carry a higher value of the IP (*i.e.,* a higher number of parasite stumps comparatively with a lower number of fruit yielded). In that respect, shea trees are more sensitive to Loranthaceae impact on their fruit yield in parklands than in protected areas. This suggests the acceptance of the second hypothesis, according to which prevalence of Loranthaceae impact on shea tree fruit yield is higher in parklands than in protected areas. Although Loranthaceae impact on shea tree fruit yield has not been significantly proved either in the protected area or in the surrounding parklands, Loranthaceae are able to induce that impact on many shea tree individuals in parklands comparatively with protected areas. This might be explained by the fact that a greater number of shea tree individuals carried greater parasite load in parklands comparatively with protected areas [23], as also shown by other authors [33] on *Alepis flavida* (Loranthaceae). Moreover, shea tree individuals that carry a greater parasite load should be more sensitive to other environmental stresses (*i.e.*, drought, light deficiency, soil nutrient deficiency, etc.) and the combined effect of Loranthaceae and environmental stress should mostly induce an impact on shea tree fruit yield.

The study also revealed that some shea tree traits (diameter at breast height, tree height and crown height) did not discriminate shea tree groups. Indeed, some groups (G2 and G4) are composed mainly of shea trees from the parklands. In West Africa, the parklands have been built on selection of desirable trees species and selected individuals [34], and are continually managed by humans. Therefore, this suggests that in a given geographical environment, human management is not able to induce phenotypic variation of those shea tree traits because of shea tree gene flow. Shea tree circumference in Ghana [15] and shea tree crown size in Benin [35] discriminated shea trees from different geographical positions. Thus, it was expected that traits such as diameter at breast height, tree height and crown height are not able to discriminate shea tree groups, because we assumed for the study conditions that the environmental effect (*i.e.*, the climate and the soil conditions are almost the same for all shea tree sampled individuals) is minimized.

### 4.3. Correlation between traits used

Positive associations between the number of infected stumps and the impact index ratio (IP) were found in both habitats (*table IV*). This means that when a shea tree has a higher number of infected stumps, it will be supposed to have a higher impact index ratio (IP) (*i.e.*, lower fruit yield than number of infected stumps) and, consequently, to be more sensitive to Loranthaceae impact on its fruit yield. Thus, Loranthaceae are able to reduce shea tree fruit yield when the parasite load increases. The positive association between shea tree diameter and number of infected stumps observed in the parkland means that large shea trees are supposed to carry a higher parasite load (number of infected stumps) in this habitat, whereas in the protected area this is not the case.

### 4.4. Implications for potential shea tree conservation

Our study offers opportunities for shea tree *in situ* and *ex situ* conservation. As the shea tree fruit yield is a desirable trait for farmers [2], the *in situ* conservation approach in parklands should aim to preserve potential individuals suitable for high productivity and, simultaneously, a low number of parasite stumps. This selection will be made among the shea tree individuals that are preserved by local people. Implementation of the shea tree *in situ* conservation plan in parklands may contribute to sustainable use of shea tree in parklands and, consequently, should decrease human pressure on the protected populations. Indeed, some protected areas exemplify degradation due to the use of plant resources [36]. However, in the protected area, the *in situ* conservation of shea tree should consist to preserve only large shea trees suitable for high productivity.

The creation of a potential breeding shea tree population is the common assumption of *ex situ* conservation of plants. Shea trees that have been selected to be preserved for *in situ* conservation in each habitat can be used as parents for selecting desired traits linked to leaves and fruits of shea trees. Indeed, there is a very low genetic relation between traits related to shea tree and those related to its leaves and fruits [15]. However, prospective investigations based on Loranthaceae impact on shea tree fruit and leaf morphology in relation to habitat will be necessary for helping in leaf and fruit trait selection.

Considering associations among traits, the impact index ratio can be used as an indicator to select shea trees for *in situ* conservation. Shea tree individuals that have a value lower than 1 of the impact index ratio will be desirable. Local people apply such a selective plan to select and maintain shea tree individuals in their farmed land. They reported that, when they noted a high fruit production potential for a shea tree individual, they cut off the parasites on it so as to maintain a lower parasite load on the individual concerned and, consequently, the value of the impact index ratio was lower than 1.

## 5. Conclusion

The current study offers information on variation of Loranthaceae impact on shea tree fruit yield in contrasting habitats. Our results showed that Loranthaceae did not significantly reduce shea tree fruit yield either in the protected area or in the surrounding parklands. The number of parasite stumps and the defined impact index ratio were revealed as significant discriminant traits of shea tree groups between the two investigated habitats. Shea tree individuals are mostly sensitive (impact index ratio higher than 1) to Loranthaceae impact on their fruit yield in the parklands compared with those in the protected area. These findings were used for defining conservation plans for shea trees. However, Loranthaceae impact on shea tree needs to be investigated physiologically in order to judge more completely Loranthaceae's effect on shea tree.

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## Variación del impacto de Loranthaceae en el rendimiento en frutos de *Vitellaria paradoxa* C.F. Gaertn en los hábitats diferenciados, e implicaciones para su conservación.

**Resumen** – **Introducción**. El karité (*V. paradoxa* CF Gaertn.), una especie endémica de los bosques de la sabana de Sudán, predomina en los parques de África occidental, donde la planta posee una gran importancia socio económica. Sin embargo, a lo largo de las últimas décadas, el karité resultó estar amenazado por Loranthaceae, parásitos de vegetales. Nuestro estudio pretendió comparar el índice de estos parásitos en el rendimiento en frutos de árboles de karité, en dos hábitats diferenciados. **Material y métodos**. Seleccionamos 41 individuos de karité poco infectados y 41 individuos muy infectados, de tamaño similar, en dos hábitats: una zona de vegetación protegida y parcelas adyacentes no protegidas. En cada individuo de karité seleccionado, se midieron ciertas características de los karités, tales como el diámetro de los troncos a la altura del pecho, el diámetro de la canopea, la altura de los árboles, la altura de la canopea, el número de frutos cosechados, el número de cepas de parásitos por árbol y un índice calculado, evaluando el impacto del parásito en la producción del árbol. Se realizó un análisis de la varianza, ANOVA, de dos vías para comparar el impacto de los parásitos en el rendimiento en frutos de karité, según el hábitat. Se emplearon análisis de clasificación jerárquica, canónica discriminante y ANOVA unidireccional para poner de manifiesto los caracteres cuantitativos que caracterizan los grupos de karité en los hábitats. **Resultados**. El impacto de Loranthaceae en el rendimiento en frutos de los árboles no fue significativamente diferente en los dos hábitats considerados. Los caracteres cuantitativos tendieron a discriminar a ciertos grupos de árboles de karité en ambos hábitats. Los individuos de karité de las parcelas no protegidas se caracterizaron principalmente por un mayor número de cepas de plantas parásito por árbol y por un índice de impacto en el rendimiento mayor, lo que sugiere que, en estas parcelas, un mayor número de plantas de karité fueron sensibles al impacto de Loranthaceae en su rendimiento en frutos. **Conclusión**. Estos resultados se emplearon para poner en marcha planes de conservación de los árboles de karité.

**Benin / *Vitellaria paradoxa* / fruitas / rendimiento / Loranthaceae / parasitismo / aptitud colonizadora / habitat**