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# Spatio-temporal infestation dynamics and influence of silvicultural pruning on shea trees (*Vitellaria paradoxa* Gaertn. C.F.) to control Loranthaceae parasites in northern Côte d'Ivoire

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**Parasitic plants of the Loranthaceae family are responsible for the loss of shea trees, limiting fruit production and the survival of shea parklands in northern Côte d'Ivoire. The study aims to quantify the frequency of infestation by Loranthaceae from 2019 to 2021 and to assess the impact of silvicultural pruning techniques on the recrudescence of infestations. The methodology consisted of successively delimiting a 2 ha area in the shea parkland, recording geographical coordinates of the trees using a Global Positioning System (GPS), and assessing the level of infestation and re-infestation of the trees after treatment with three silvicultural pruning techniques (rejuvenation pruning, crown pruning, and parasite plant control pruning). The results showed that since 2019, only the Loranthaceae species *Agelanthus dodoneifolius* (DC.) Polh et Wiens was recorded. From 2019 to 2021, the new infestation rate was 24.58%. At both five and 24 months after the silvicultural pruning treatment of infested shea trees, no re-infestation by parasitic plants was observed. The average length of newly emerged branches on shea trees (potential rootstocks) after five months of pruning ranged from 8.44 to 53.40 cm. It appears that silvicultural pruning is a promising agroforestry technique for effectively controlling the Loranthaceae parasite in shea trees.**

**Key words:** Shea parkland, Loranthaceae, parasitic plant, Global Positioning System, agroforestry technique.

## INTRODUCTION

The shea tree (*Vitellaria paradoxa* Gaertn. C.F.) belongs to the Sapotaceae family and naturally thrives in the Sudanese zone, spanning from eastern Senegal to southern Sudan (Naughton et al., 2015). Mature shea trees can attain a height of 15 m, a circumference of 2.7 m, and a crown area exceeding 100 $m^2$. Shea plays a

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pivotal role in the economic development of producing countries due to the commercialization of its kernels, from which shea butter is extracted. Shea butter is utilized in the production of various items, including local foods, chocolate, cosmetics, and pharmaceuticals (Baziari et al., 2019).

Despite its economic importance, the productivity and conservation of the shea tree face constraints from various factors, including human activities such as tree cutting for firewood, bush fires, and general agriculture (Diarrassouba et al., 2020). In addition to these anthropogenic influences, natural factors contribute to the challenge, such as the attack of parasitic vascular plants belonging to the Loranthaceae family on shea agroforestry parklands. The specific diversity of parasitic plants in the Loranthaceae family varies across climatic zones. While temperate regions host 950 species in 77 genera, Africa and Arabia have recorded over 500 species (Tamene et al., 2017). Although these plant parasites are not exclusive to shea trees, they have found a favorable host in shea (Soro, 1999). Once established on their hosts, these hemiparasites weaken the trees, significantly reducing fruit productivity and threatening their conservation status (Houehanou et al., 2011; Edagbo et al., 2013). Due to these adverse impacts on the survival of shea agroforestry parks, the International Union for Conservation of Nature (IUCN) and various authors (Boussim and Nayéré, 2009; Kouyaté and Diarra, 2017; Oumar et al., 2021) classify shea as an endangered species requiring strengthened conservation efforts in the context of enhancing population resilience to climate change.This attack has been reported in many countries, particularly in Mali and Burkina Faso, where Maïga (1988, 1989) and Boussim (1991) reported that about 95% of shea trees are parasitized by five species of Loranthaceae; namely, *Agelanthus dodoneifolius* (DC.) Polh., Wiens, *Tapinanthus bangwensis* (Engl. and K. Krause) Danser, *Tapinanthus globiferus* (A. Rich.) Tieghem, *Tapinanthus ophiodes* (Sprague) Danser and *Tapinanthus pentagonia* (DC.) Tieghem.

In Côte d'Ivoire, shea agroforestry parks are not spared from these attacks and their natural regeneration is also threatened. A study by Yao et al. (2020) showed that shea agroforestry parks in the localities of Ouangolodougou and Ferkessédougou are attacked by Loranthaceae at rates of 58.66 and 65.51%, respectively. The Loranthaceae species that attack the shea trees in this region of Tchologo include the species *A. dodoneifolius* and *T. bangwensis* (Yao et al., 2020). Agricultural practices used by producers to restore existing shea parklands (non-practice of deworming, poor maintenance of shea parks, rare shea plantations, exposure of plots to humans and animals, non-practice of fallow land, *etc*.) are not appropriate. The research works carried out by the Shea breeding Program of Côte d'Ivoire based at the Peleforo GON COULIBALY University (UPGC), as part of the management of existing shea parklands, has allowed the preparation of a technical report on Assisted Natural Regeneration (ANR) (Diarrassouba et al., 2020). In order to generate additional information on the means to optimize the production of shea parklands in Côte d'Ivoire, it is necessary to explore research topics about Loranthaceae control, techniques for shea tree rejuvenation and *in situ* adult tree transformation by grafting. The use of horticultural pruning techniques can control plant parasites, increase fruit production following the physiological dormancy of the tree and induce new branches to be used as rootstocks. The present study aims to (i) evaluate the spatio-temporal infestation dynamics of shea parkland by parasitic Loranthaceae, and (ii) evaluate the influence of three silvicultural pruning techniques on the recrudescence of parasitic Loranthaceae and the induction of new branches to be used as rootstocks in *in situ* adult shea tree transformation by grafting.

## MATERIALS AND METHODS

### Study site

The study was conducted in Benfesso, a village located in the Ouagolodougou department belonging to the Tchologo region (Figure 1). The locality of Ouangolodougou is located between longitudes varying from 5°11' to 6°29' West and at latitudes varying between 9°31' and 9°35' North. The climate is of the Sudano-Guinean type with an annual rainfall alternating between 1200 and 1500 mm. The climate is marked by two seasons, one of which is rainy (May to October) and the other dry (November to April). The soils under shea stands in Ouangolodougou are of the Ferralsols type. The soil has a sandy-clayey-loamy texture with about 20-25% clay at the surface horizon and medium to low porosity (Alui et al., 2020).

### Plant material

The plant material consisted of shea trees from a natural stand located in Ouangolodougou. The shea park has a density of 37.5 trees/ha.

### Methods

#### *Study of the dynamics of Loranthaceae infestation of shea trees from 2019 to 2021*

To determine the level of infestation of shea trees by parasitic plants of the Loranthaceae family in Ouangolodougou, the 2019 data from Yao et al. (2020) on the same Ouangolodougou shea parkland were used. Two years later, the level of infestation of shea trees by parasitic Loranthaceae was reassessed to monitor the evolution of infections in time and space. Therefore, in the present study, 2 ha of the parkland were delineated and the positions of the trees within were measured using a Global Positioning System (GPS) (Figure 2a). The presence of Loranthaceae on the shea tree was also observed both by visual observation and then using binoculars to better refine the observation (Figure 2b). The health status of each shea tree was scored on a scale of 0 to 7. Non- parasitized trees or healthy trees were assigned a score of 0. At the level of parasitized individuals, the infestation intensities were 3 for "low", 5 for "medium" and 7 for "high" according to IPGRI and INIA (2006).

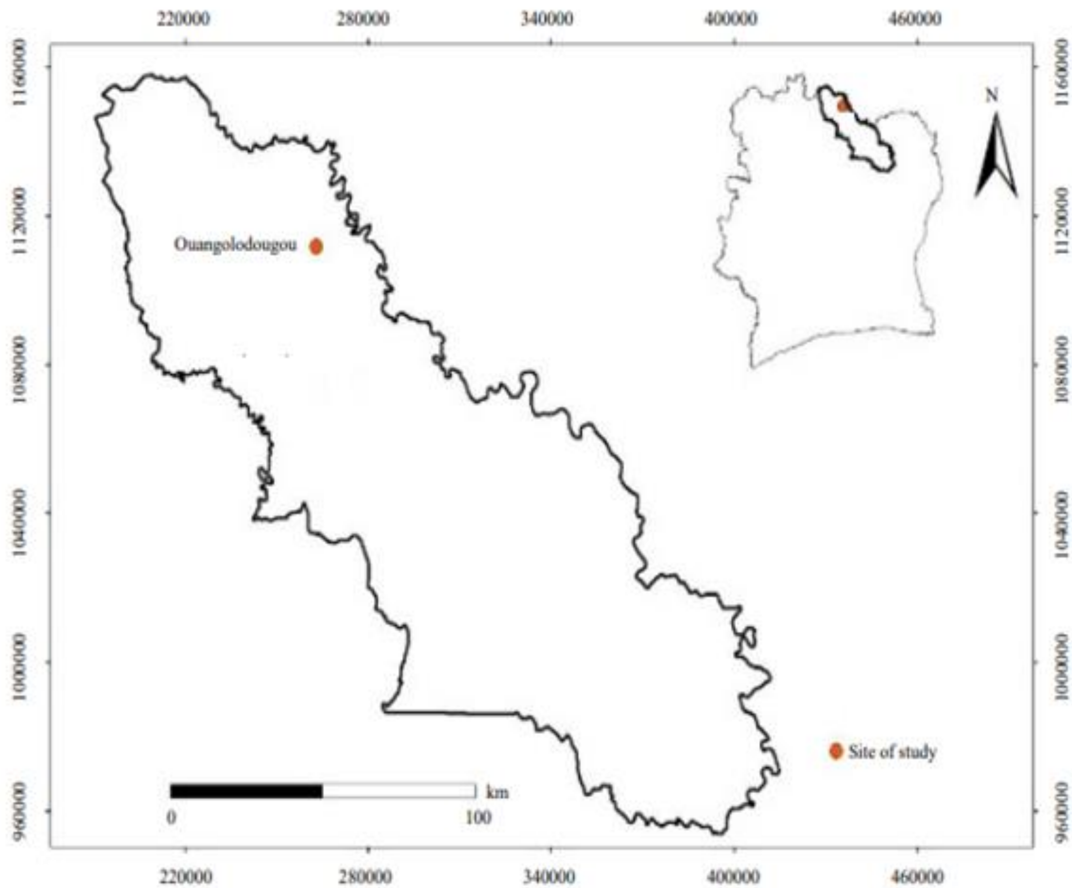



**Figure 1.** Map showing the site of study (Ouangolodougou) in Northern Côte d'Ivoire. Source: Shea breeding program of Côte d'Ivoire.
**Source:** Yao et al., 2020 updated.

***Influence of silvicultural pruning on the recrudescence of parasitic Loranthaceae***

Three silvicultural pruning techniques were applied. These are rejuvenation pruning, crown pruning and parasite plant control pruning. At both five and 24 months afterthe pruning, the number of newly recovered trees, the number of re-infested, and non-infested trees, were recorded (Figure 3). In addition, the newly emerged branches of the shea tree were measured with a tape measure (Figure 4). Four branches were taken from each direction (north, south, east, and west).

**Data statistical analyses**

To define the spatial structure of the shea tree infestation at the scale of the delimited area in the parkland, the data obtained from the GPS about the geographical coordinates of the trees were used. The quadrat method (Canard and Poinsot, 2004) was used to define the spatial structure of the infestation. The quadrat method consists in covering the study areas with K-meshes of regular shapes. The trees studied were represented as points after positioning them using geographic coordinates processed with the arcGIS software 10.1. The average number of infested or non-infested shea trees per mesh is m = A/K. The number Ai of infested or not infested shea trees was associated with each mesh Ki. Then the variance ($\delta^2$) of the number of individuals (infested or not infested shea trees) per quadrat or mesh and the average number (µ) of individuals (infested or not infested shea trees) per quadrat or mesh were estimated. Distribution index ($I = \delta^2/\mu$) of the health status of the tree (infested or not infested shea trees) was calculated. The dispersion index test was used to test the significance of the distribution index (I) with respect to the value 1 (random distribution) (Canard and Poinsot, 2004). If I value is significantly different from 1, the distribution is either aggregative ($I > 1$) or regular ($I < 1$) (Canard and Poinsot, 2004). The infestation rates (IR) of the considered plots or parklands were calculated using the formula of Yao et al. (2020):

$$IR = \frac{\mathrm{n\ x\ 100}}{\mathrm{N}}$$

with **n** the number of infested trees and **N** the total number of trees (infested or not infested shea trees)

The infestation evolution rate (IER) from 2019 to 2021 or two years later was calculated using the following formula:

$$ER\ (\%) = \frac{IR(year\ 2) - IR(year\ 1)}{IR(year\ 1)} \mathrm{x\ 100}$$


**Figure 2.** Global Positioning System (a) and binocular use for study.


**Figure 3.** Three silvicultural pruning techniques studied (a) rejuvenation pruning, (b) crown pruning and (c) parasite plant control pruning.

with IR the infestation rate.

The recovery rate (RR) of pruned trees for a given pruning technique was evaluated using the formula:

$$RR\ (\%) = \frac{\mathrm{a\ x\ 100}}{\mathrm{N}}$$

with (**a)** the number of pruned trees having resumed for a given technique and **N** the number of treated trees.

Shoot Growth Velocity (SGV) was calculated using the formula:

$$SGV\ (cm.month - 1) = \frac{\mathrm{SL}}{\mathrm{T2 - T1}}$$

with SL the shoot length and T2-T1 the time difference between two successive measurements.

## RESULTS

### Dynamics of infestation of shea trees by Loranthaceae from 2019 to 2021

From 2019 to 2021, the only Loranthaceae species encountered in the Ouangolodougou shea parkland was *Agelanthus dodoneifolius* (DC.) Polh and Wiens. The tendency for Loranthaceae infestation of shea trees to evolve and spread is increasing. The rates of not infested trees in 2019 and 2021 were 41.3 and 26.67% respectively. The parasitic infestation rate increased from 59.66% in 2029 to 73.33% in 2021 (Figure 5). The rates of low infested trees in 2019 and 2021 were 38.67 and

**Figure 4.** Measurement of a newly grown shoot on a pruned shea tree.

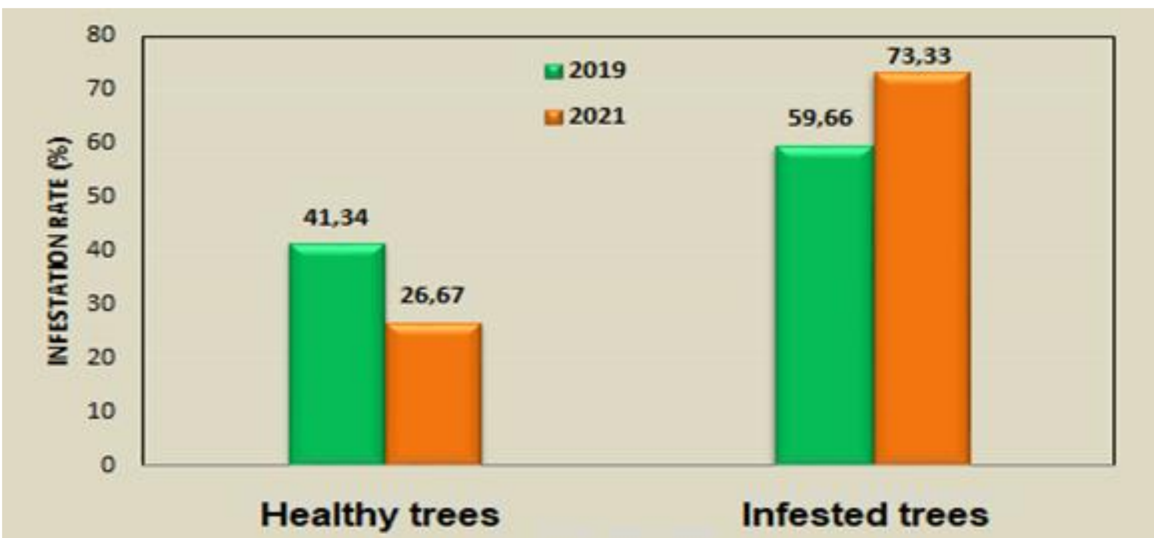



**Figure 5.** Evolution of the rate of shea tree infestation by parasitic Loranthaceae (*Agelanthus dodoneifolius* (DC.) Polh and Wiens) from 2019 to 2021.

48% respectively. The rates of moderately infested trees in 2019 and 2021 were 16 and 18.67% respectively. The rates of trees with a high level of infestation in 2019 and 2021 were as follows: heavily infested, 4 and 6.67%, respectively (Figure 6). The progression of infestation intensities showed that the proportion of high infestation levels increased by more than double (66.75%) after 2 years. In a 2-year period, the rate of new infestations reached 24.58% (Figure 7). At the scale of the shea parkland, the spatial distributions of infested and non-infested shea trees showed an aggregate structure. The distribution indices of non-infested and infested shea trees were respectively 2.67 and 4.76 (Figure 8).

## Influence of silvicultural pruning on the recrudescence of Loranthaceae

The recovery rate of shea trees, five months after silvicultural pruning was 100% for each of the three techniques applied. No pruned shea tree was re-infested by Loranthaceae 24 months after the silvicultural pruning

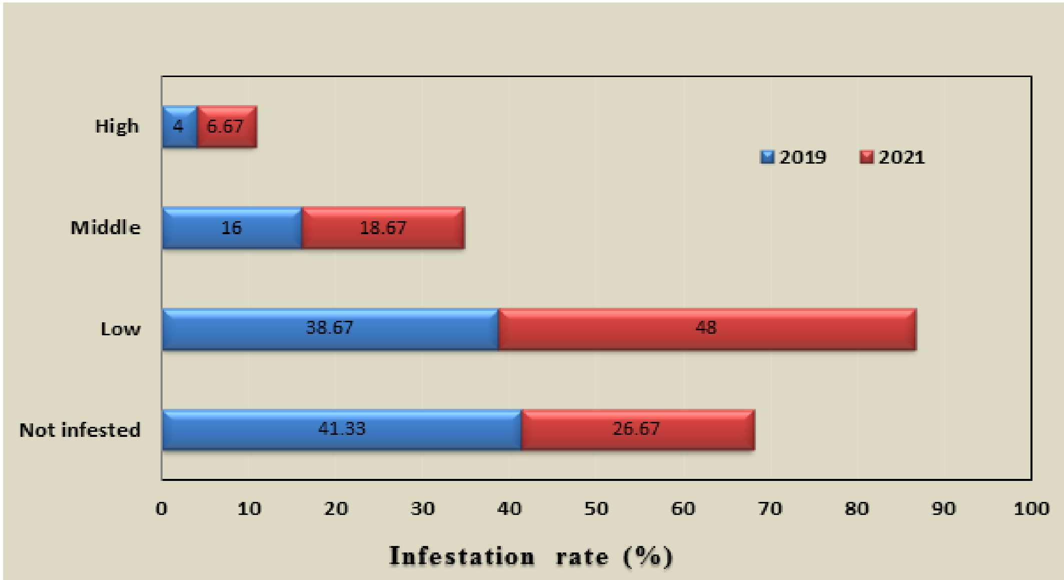



**Figure 6.** Parkland infestation intensities by parasitic plants (*Agelanthus dodoneifolius* (DC.) Polh and Wiens) in Ouangolodougou from 2019 to 2021.

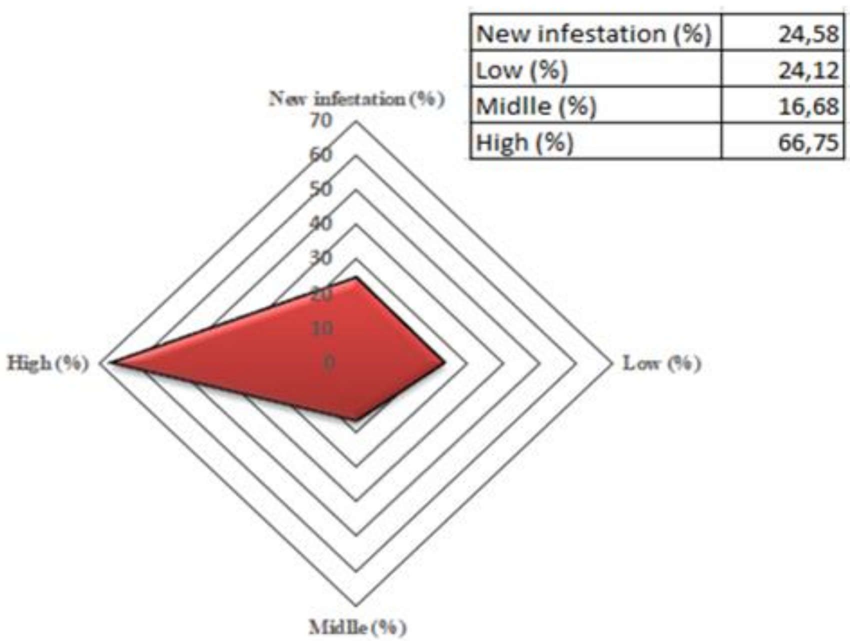
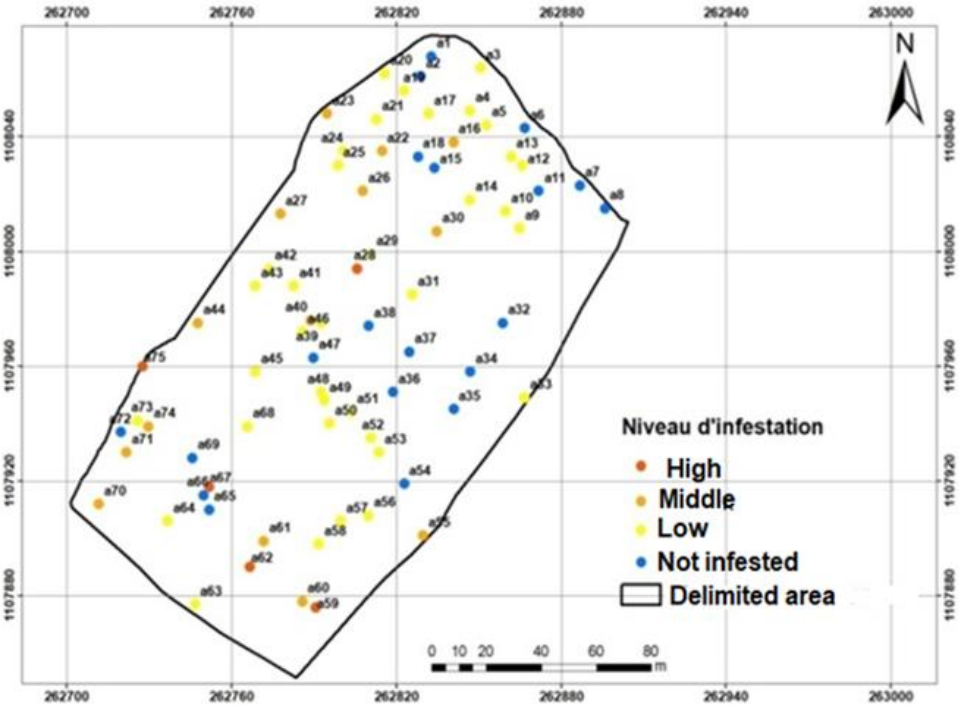



**Figure 7.** Evolution rate of infestation intensities by parasitic plants [*Agelanthus dodoneifolius* (DC.) Polh and Wiens] in Ouangolodougou from 2019 to 2021.

treatment (Figure 9).

**Influence of silvicultural pruning on the dynamics of twig emission on the shea tree**

Five months after silvicultural pruning, parasite plant control pruning gave longer twigs (53.4 ± 0.27 cm) with a higher growth rate (10.68 ± 0.18 cm. month$^{-1}$), followed by crown pruning (mean shoot length of 44.9 ± 0.18 with a growth rate of 8.98 ± 0.18 cm. month$^{-1}$). Rejuvenation pruning resulted in the lowest mean shoot lengths (8.44 ± 0.18 cm) and mean growth rates (1.68 ± 0.18 cm. month$^{-1}$) (Table 1).




| | Not infested shea trees | Infested shea trees |
|---|---|---|
| Repartition index (I) | 2,67* | 4,76* |
| Type of structure | Aggregate | Aggregate |

*Value significantly superior to 1

**Figure 8.** Infestation map showing spatial repartition (aggregate structure) of infestation levels of shea trees by parasitic plants (*Agelanthus dodoneifolius* (DC.) Polh and Wiens) in 2021 at Ouangolodougou.

## DISCUSSION

From 2019 to 2021, the health status of shea trees in Ouangolodougou has evolved in relation to the Loranthaceae parasite. From 2019 to 2021, only *Agelanthus dodoneifolius* (DC.) Polh and Wiens is the Loranthaceae species found in the Ouangolodougou shea parkland. This result suggests that although Loranthaceae species are invasive and frequent in northern Côte d'Ivoire, infesting woody plants in savannah zones, no new species have been introduced into the agroforestry parkland studied in the last 2 years. Other species such as *Globimetula braunii*, *Globimetula cupulata*, *Phragmanthera capitata*, *Tapinanthus bangwensis*, *Tapinanthus dodoneifolius*, *Tapinanthus globiferus* and *Tapinanthus pentagonia* have been reported to parasitize shea trees in northern Côte d'Ivoire (Traoré and Da, 1996; Koffi et al., 2014.). The absence of these other Loranthaceae species in the shea parkland studied shows that infestations and re-infestations are carried out at the scale of the shea parkland at Ouangolodougou from the dissemination of seeds of the species already present; namely, *A. dodoneifolius.*

In 2019, 41.33% of the shea trees were not infested and 58.67% of the trees were infested, while in 2021, 26.67% of the shea trees were not infested against 73.33% of the infested trees. This increase in infestation in 2021 is explained by the infestation of healthy shea trees that were not infested in 2019. In a short 2-year period, the rate of new infestations of shea trees by Loranthaceae has already reached 24.58%. These results reflect the strong progression of infestations, the risks of mortality of shea trees and degradation of infested shea parks if no sanitary measures are taken within sufficient time. The results of research Boussim (1991) and Maïga (1988) revealed that the area of shea parkland can be reduced to as much as one third by the damage of Loranthaceae. Traoré et al. (2003) found infestation rates of 95.97 and 96%, respectively, on shea in northern Côte d'Ivoire.

In terms of the spatial distribution of infestations, from 2019 to 2021, the distribution indices of non-infested trees varied from 2.15 to 2.67. These values, greater than 1, reflect aggregative structures. These results are consistent with those of Yao et al. (2020) in Ouangolodougou with

| Appearance of shea tree 5 months after silvicultural pruning | Recovery rate (%) | Reinfestation rate (%) 5 months after silvicultural pruning | Reinfestation rate (%) 24 months after silvicultural pruning |
|---|---|---|---|
|  **Rejuvenation pruning** | 100 | 0 | 0 |
|  **Crown pruning** | 100 | 0 | 0 |
|  **Parasite plant control pruning** | 100 | 0 | 0 |

**Figure 9.** Influence of silvicultural pruning technique on tree recovery and Loranthaceae re-infestation in the shea parkland at Ouangolodougou.

distribution indices greater than 1; they affirmed that the structure of infested and not infested shea trees in the different parks studied is aggregative. This aggregative distribution is probably due to birds which are designated in the literature as the main responsible cause for the spread of Loranthaceae seed (Boussim et al., 1993; Nierhaus-Wunderwald and Lawrenz, 1997). Increased site-wide infestation is often attributed to birds whose mechanism of eating Loranthaceae berries does not require transit through the gut. This result would explain that the birds at the origin of seed dispersal grind the Loranthaceae berries and attach them to branches so as not to consume only the pulp. Thus, these birds, unlike endozoochorous birds, would be responsible for the increased dispersal of mistletoe at the level of a host and its surroundings (Tamene et al., 2017). The dispersal of *A. dodoneifolius* seeds in the studied shea parkland would therefore be from tree to tree or even from branch to branch on the same shea tree by birds. This is reflected in the results recorded on the progression of infestation levels. Indeed the results showed that the proportion of high infestation levels increased by more than double (66.75%) after 2 years. The severity of the infestation is accentuated over time, leading to the programmed death of the tree.

However, some shea trees remained healthy despite their proximity to attacked trees as already reported (Traoré and Da, 1996. These genotypes could have had

**Table 1.** Effect of silvicultural pruning technique on twig emission dynamics in shea trees.

| Silvicultural pruning technique | Average twig length (cm.) 5 months after pruning | Shoot growth velocity (cm. month$^{-1}$) |
|---|---|---|
| Rejuvenation pruning | 8.44 ± 0.18$^{c}$ | 1.68 ± 0.18$^{c}$ |
| crown pruning | 44.9 ± 0.18$^{b}$ | 8.98 ± 0.18$^{b}$ |
| Parasite plant control pruning | 53.4 ± 0.27$^{a}$ | 10.68 ± 0.18$^{a}$ |
| F | 6.55 | 6.57 |
| p | 0.031 | 0.030 |

Mean values with the same letters in the same column are not significantly different at the 5% probability level.

candidate genes for resistance to Loranthaceae attacks (Soro, 2010); and this demonstrates the usefulness of such selection to improve the tolerance or resistance of shea to Loranthaceae attacks.

Five and 24 months after the shea pruning, the recovery trees showed no re-infestion. This shows the effectiveness of pruning in the fight against Loranthaceae. Our comments are similar to those of Boussim and Nayéré (2009) who indicate that the destruction of the parasite by cutting the host branch upstream of the parasite attachment point is definitive. No regrowth of the parasitic plant is possible after the elimination of the aerial apparatus and the endophytic system. Regarding twig emission dynamics, parasite plant control pruning gave the longest twigs and the highest growth rate followed by crown pruning. These last two modes of pruning could be indicated in the mechanical fight against Loranthaceae in shea. These two silvicultural pruning techniques for shea trees would be both the best for controlling Loranthaceae and the rapid production of new branches to be used as rootstock for *in situ* grafting of adult shea trees in the field.

## Conclusion

This research has enhanced our understanding of shea tree infestations by Loranthaceae on the scale of shea parklands. In a brief two-year period, the rate of new infestations of shea trees by Loranthaceae has already reached 24.58%. The rapid progression of the infestation suggests an increased risk of shea tree mortality and degradation of the infested shea parklands if timely sanitary measures are not implemented. The spread of the disease is primarily through the seeds of the parasitic plant, already present on the hosts, and is distributed in some cases by birds. However, for the sake of maintaining the balance of nature, controlling Loranthaceae parasites cannot target these birds. The experiment on silvicultural pruning techniques indicates that both parasite plant control pruning and crown pruning techniques can be successfully employed with shea trees. Additionally, it is recommended to combine control efforts with in situ grafting to optimize the yield of rejuvenated shea parklands. Exploring varietal resistance through the identification of tolerance genes in healthy trees close to the attacked ones is also a promising avenue for research.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.


## ACKNOWLEDGMENTS

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