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Prevalence of Loranthaceae on fruit trees in cocoa agroforestry systems in Daloa (Center-West, Côte d'Ivoire): diversity and extent of infestation

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Abstract

Floristic inventories carried out in cocoa agroforestry systems in the peri-urban zone of Daloa identified three species of Loranthaceae: *Phragmanthera capitata*, *Tapinanthus bangwensis* and *T. globiferus*. These parasites affect a diversity of 60 fruit species, divided into 44 genera and 25 botanical families. *T. bangwensis* proved to be the most frequent and most infective species. The most heavily parasitized families were the Rutaceae (seven species), followed by the Anacardiaceae, Annonaceae and Myrtaceae (six species each). The density of fruit trees in cocoa plantations is estimated at 44.25 ± 13.86 stems/ha. The average incidence of Loranthaceae was 66 ± 7.07% on fruit trees and 40.07 ± 6.93% on cocoa trees. The average severity of infestation was 34.03 ± 8.07% on fruit trees and 33.89 ± 7.29% on cocoa trees. The results revealed that the diameter and height of fruit trees significantly influence their level of infestation by these parasites. They also help to guide the choice of less susceptible fruit species, with a view to promoting sustainable cocoa agroforestry.

Keywords: Cocoa; Loranthaceae; Fruit species; Incidence; Infestation severity; Daloa

1. Introduction

Agroforestry cocoa farming systems derived from cultivated clearings are systems in which farmers combine multipurpose trees with crops [1]. In these cocoa plantations, useful trees provide significant food products and/or income supplements for farmers [2]. However, in recent decades, these trees, particularly the fruit trees present in cocoa agroforestry plots, have tended to disappear due to overexploitation and felling [3]. Moreover, these trees, like cocoa trees, due to poor agricultural practices, the expansion of Loranthaceae and the parasitic pressure they exert, particularly on trees grown in cocoa agroforestry systems, threaten both food security and crop sustainability. Loranthaceae, described by Ballé & Halle [3], are small epiphytic, chlorophyllous shrubs that live as hemiparasites on the branches of other wild or cultivated trees and shrubs. These clump-like parasitic plants, once attached to the tree branch, anchor themselves in the wood of the latter by means of a sucker that establishes functional links with the conductive apparatus of the host tree [4]. In this way, they extract the water and mineral salts it needs. Their parasitic lifestyle often causes considerable damage to the many wild and cultivated trees and shrubs they parasitize [5]. In cocoa-based agroforestry systems, Loranthaceae are widespread, infesting cocoa trees as well as slash trees and various fruit species such as citrus, avocado, cola tree and guava. Already, Sonké *et al*. [6], in an article entitled "Parasitism of avocado (*Persea americana*) by Loranthaceae in the Yaoundé region (Cameroon)," expressed concern about a massive attack on avocado trees by Loranthaceae species. Today, as a result of climate change and the abusive destruction of natural plant

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formations, these parasitic plants have become a real threat to crops, especially fruit trees and shrubs [7]. However, studies dealing with the diversity and incidence of parasitic Loranthaceae on fruit trees and shrubs in agrosystems in general and cocoa agrosystems in particular in the peri-urban zone of Daloa are almost non-existent, hence the need to conduct this study. The aim of this study was therefore to gain a better understanding of Loranthaceae in order to assess the extent of their infestation on the fruit species present in the various cocoa orchards. The aim was therefore to identify the Loranthaceae species actually present in the various cocoa farms and to measure their impact on the associated fruit species.

2. Materials and methods

2.1. Study site

The study was carried out in cocoa farms in four localities around Daloa: Zépréguhé (06°54′09.27′′ N, 06°21′28. 84′′ W), Toroguhé (06°56′41.01′′ N, 06°27′49.77′′ W), Zakoua (06°48′06.24′′ N, 06°27′07.58′′ W) and Bribouo (06°52′09.88′′ N, 06°30′20.45′′ W). Located in center-west Côte d'Ivoire, 400 km from Abidjan, the economic capital, and 140 km from Yamoussoukro, the political capital, Daloa, our study area, lies between 6°52′ and 6°87′ N latitude and between 6°27′ and 6°45′ W longitude (Fig. 1). The vegetation, once made up of immense, dense forests, is now characterized by a mosaic of various types of plant formations and forest fragments or patches [8]. The climate is sub-equatorial, with average annual rainfall of around 1,200 mm [9].

2.2. Material

The plant material consisted of samples of the various Loranthaceae species and their woody fruit hosts present in the cocoa orchards. The technical equipment consisted of a Garmin GPS, BTP tapes, a 50 m decameter, a digital camera, data collection sheets, newsprint, a Suunto dendrometer and pruning shears. The equipment used for data processing includes Excel 2013 spreadsheets and Statistica software version 7.1.

2.3. Methods

2.3.1. Floristic inventory

A floristic inventory by surface survey was carried out in the cocoa agroforestry systems in order to assess the fruit-bearing woody flora hosting Loranthaceae. In each of the four study localities, five cocoa plantations were selected. For each of them, a 50 m × 50 m plot, i.e., a surface area of 2,500 m^2 (Figure 2), was marked out to count cocoa trees and parasitized and non-parasitized fruit-bearing woody plants.

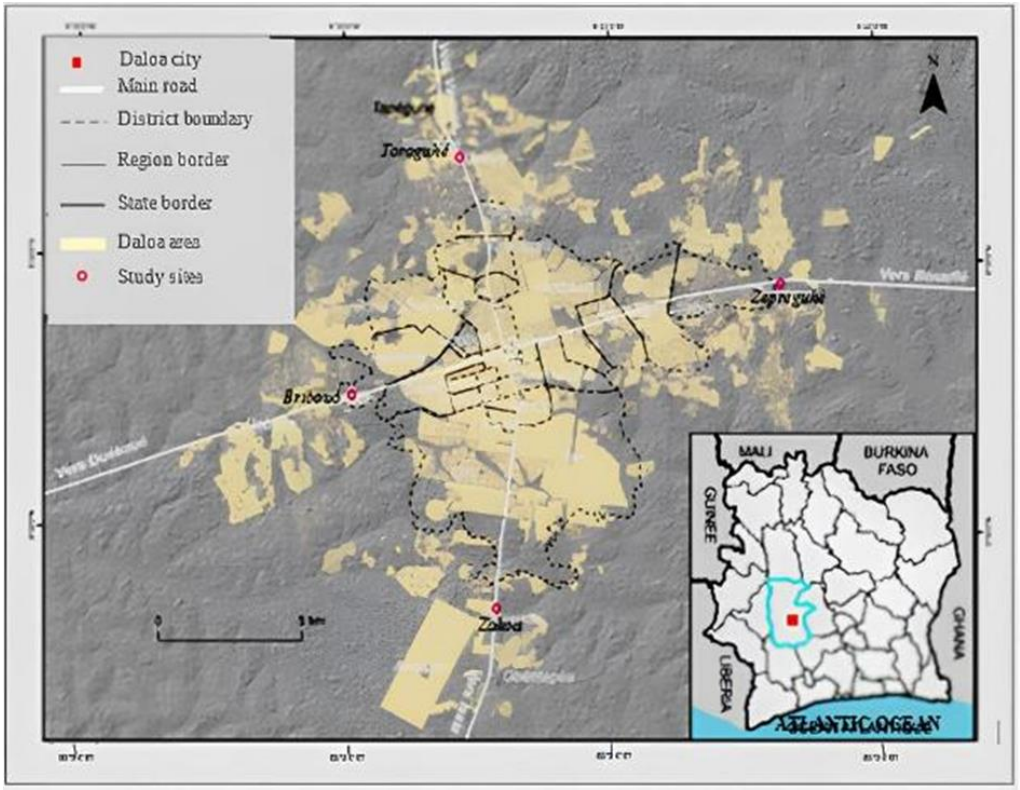
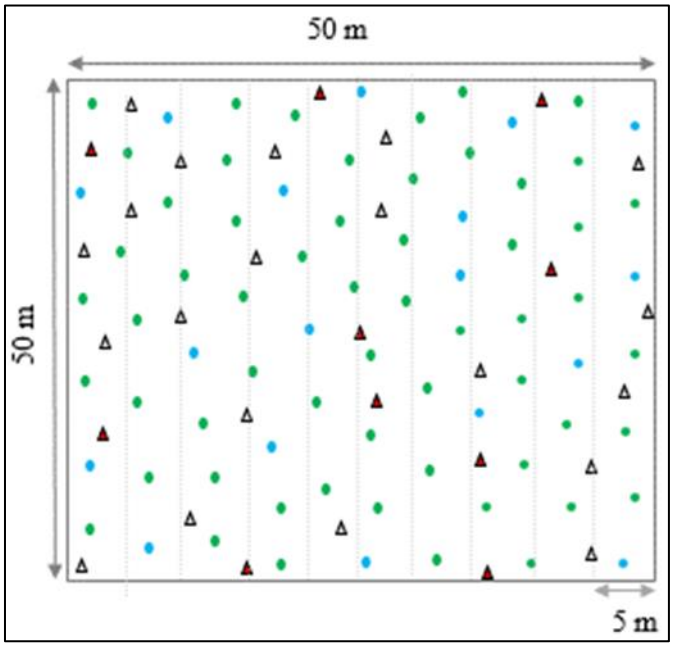


Figure 1 Map of study site



Circles represent cocoa trees in the plot (healthy trees in green, parasitized trees in blue). The triangles represent individuals of fruit trees associated with cocoa trees (healthy individuals in white, parasitized individuals in red).

Figure 2 Surface survey device

To ensure an accurate count of all cocoa trees, parasitized and non-parasitized fruit trees and Loranthaceae clumps, each plot was subdivided using BTP tape into ten 50 m × 5 m strips (Figure 2). Parasitized cocoa trees were marked in blue and parasitized fruit trees in red. To ensure that the data were representative, this method was applied twice to 20 cocoa farms selected according to a randomized Fisher design, for a total of 40 surveys. During the surveys, the number of parasitized and unparasitized cocoa and fruiting woody individuals, the number of Loranthaceae tufts present on the hosts, and the Loranthaceae taxa associated with each host were recorded. Herbarium samples of parasites and

parasitized fruit trees were also collected. The botanical nomenclature used was that adopted by Lebrun & Stork [10]. Itinerant surveys complemented the surface surveys to complete the floristic list. They were carried out in all directions in order to inventory Loranthaceae species and parasitic fruit trees encountered, based solely on their presence [11].

2.3.2. Species identification

The identification of the Loranthaceae species inventoried was carried out using the reference work by Ballé & Halle [3], documents by Boussim [5], Soro [12] and the collection of herbarium samples from the Centre National de Floristique (CNF) in Abidjan. For host fruit taxa, their identification was carried out using the papers by Arbonnier [13], Bongers et al. [14] and Aké-Assi [15]. The validity of scientific names, including specific genus and family levels as well as authors, was verified using recognized botanical databases, notably the International Plant Names Index (IPNI) and Plants of the World Online (POWO).

2.4. Analysis

2.4.1. Analysis of floristic data

Floristic composition

Floristic composition refers to the number of woody fruit species inventoried and their distribution by family and genus.

Density of fruit host taxa

The density (D) of a taxon, defined as the number of individuals per unit area [16], was calculated for woody fruit species using the following formula:

$$D = n/S$$

with n - number of host stems; S - total plot area in hectares

Structural distribution of host fruit trees

For each attacked fruit tree, the circumference was measured and converted into diameter using the formula C = 3.14 × d (where C = circumference and d = diameter). The diameters obtained were then divided into five classes [17]: DC1: ≤ 5 cm; DC2: [6-10 cm[; DC3: [11-15 cm[; DC4: [16-20 cm[and DC5: > 20 cm.

With regard to the heights of host fruit trees, three classes were defined [18]: HC1: ≤ 2 m; HC2: [3-4 m[and HC3: > 4 m.

2.4.2. Analysis of tree size

Estimation of the average number of Loranthaceae clumps

The average number of Loranthaceae clumps (AnLc) represents the average number of Loranthaceae clumps on parasitized trees in a given biotope and was estimated according to the following formula:

$$AnLc = \frac{\text{Total number of Loranthaceae clumbs}}{\text{Number of trees parasitized}}$$

Assessment of the extent of Loranthaceae on cocoa and fruit trees

The extent of Loranthaceae on cocoa and woody fruit trees in selected cocoa farms was assessed by the incidence and severity of attack.

Incidence of Loranthaceae (IL) was calculated according to the following relationship [19]:

$$IL = \frac{\text{Number of parasitized trees}}{\text{Total number of parasitized trees surveyed}} \times 100$$

To assess the severity of Loranthaceae parasitism on cocoa and woody fruit trees, 40 cocoa trees and 40 fruit trees per cocoa farm were randomly selected and examined for the presence or absence of parasitic taxa. The number of clumps, as well as the number of parasitized and unparasitized trees, was counted and the severity of parasitism was assessed using a scale from 0 to 4 [20] :

Score		Description
0	-	No infection (no parasites)
1	-	1-5 clumps/tree (low infection)
2	-	6-10 clumps/tree (moderate infection)
3	-	11-15 clumps/tree (severe infection)
4	-	≥ 16 tufts/tree (very severe infection)

The severity index (SI) for Loranthaceae parasitism was calculated using the following formula [20, 21]:

$$SI = \frac{(0 \times a) + (1 \times b) + (2 \times c) + (3 \times d) + (4 \times e)}{a + b + c + d + e} \times \frac{100}{4}$$

Where a, b, c, d and e represent the number of trees falling into the categories of increasing infestation 0-4.

2.5. Statistical processing

Numerical data were organized and plotted using Microsoft Excel 2013. The analysis of the parameters of the degree of parasitism of cocoa and fruit trees was carried out by a one-factor ANOVA using Statistica 7.1 software. In the event of significant differences between means, the Newman-Keuls test at the 5% threshold is used to compare them.

3. Results

3.1. Loranthaceae species encountered

A total of three Loranthaceae species were recorded on cocoa and woody fruit species. These were *Phragmanthera capitata* (Spreng.) Ballé (Figure 3), *Tapinanthus bangwensis* (Engl. et K. Krause) Danser (Figure 4) and *T. globiferus* (A. Rich.) Danser (Figure 5). They are divided into two genera, *Phragmanthera* and *Tapinanthus*.

Figure 3 *P. capitata* flowering shoot

Figure 4 *T. bangwensis* flowering shoots

Figure 5 *T. globiferus* flowering shoot

3.2. Average number of Loranthaeae clumps per parasitized tree

Analysis of Loranthaceae parasitism, based on the average number of tufts per tree (Table 1), reveals significant differences between parasitic taxa and host types (cocoa and woody fruit trees). *T. bangwensis* is the most dominant species, with an average of 4015.33 ± 553.94 tufts on cocoa trees and 191 ± 63.80 tufts on woody fruit trees, for a total average number of 2103.33 ± 308.87 tufts per tree. It is followed by *P. capitata* (815.50 ± 247.46 tufts) and *T. globiferus* (172.96 ± 391.65 tufts). The results show significant differences between the three parasitic species ($F = 51.36$; $p = 0.000012$).

Table 1 Average number of Loranthaceae tufts parasitizing cocoa and fruit species

Loranthaceae species	Number of clumps		Average number of clumps/parasite
	Cocoa trees	Fruit species	
Phragmenthera capitata	1504.50 ± 412.42b	126.50 ± 82.51b	815.50 ± 247.46b
Tapinanthus bangwensis	4015.33 ± 553.94c	191 ± 63.80b	2103.33 ± 308.87c
T. globiferus	335.67 ± 780.09a	10.25 ± 3.30	172.96 ± 391.65a
Average	1871.75 ± 1765.65	109.25 ± 95.25	1030.59 ± 315.99

In the columns, the means assigned the same letters are not different (Newman-Keuls test, $p < 0.05$).

3.3. Fruit species inventoried

The floristic inventory of woody fruit host species present in cocoa trees in the peri-urban zone of Daloa identified 60 host species, 35 of which are wild or spontaneous trees and shrubs (Table 2).

Table 2 Woody fruit host species of Loranthaceae in cocoa orchards

Families	**Species**	**Parasite species**		
		Tg	*Pc*	*Tb*
Anacardiaceae	*Anacardium occidentale* L.	-	+	+
	Pseudospondias microcarpa (A. Rich.) Engl.	-	+	-
	Spondias cytherea Sonn.	-	-	+
	Spondias mombin L.	+	+	+
	Spondias purpurea L.	-	-	+
	Trichoscypha acuminata Engl.	-	+	-
Annonaceae	*Annona muricata* L.	-	+	+
	Annona senegalensis Pers.	+	+	+
	Annona squarnosa L.	-	-	+
	Monodora myristica (Gaert.) Dumal	-	-	+
	Xylopia aethiopica (Dunal) A. Rich.	-	+	+
	Xylopia parviflora (A. Rich.) Benth.	-	-	+
Apocynaceae	*Calotropis procera* (Aiton) W. T. Aiton	-	-	+
	Landolphia dulcis (Sabine) Pichon	-	+	-
Bixaceae	*Bixa orellena* L.	-	+	+
Bombacaceae	*Adansonia digitata* L.	-	-	+
Burseraceae	*Dacryodes macrophylla* (Oliv.) H. J. Lam	-	+	+
Caesalpiniaceae	*Detarium microcarpum* Guill. & Perr.	-	+	+
	Tamarindus indica L.	-	+	+
Clusiaceae	*Garcinia kola* Heckel	+	+	+
Combretaceae	*Terminalia catappa* L.	-	+	+
Euphorbiaceae	*Jatropha curcas* L.	-	-	+
	Ricinodendron heudelotii (Baill.) Pierre ex Pax	-	+	+
Fabaceae	*Lonchocarpus sericeus* (Poir.) DC.	-	-	+
	Prosopis africana (Guill. & Perr.) Taub.	-	-	+
	Pterocarpus santalinoides DC.	-	-	+
Irvingiaceae	*Irvingia gabonensis* (Audrey-Lecomte ex O'Rorke) baill.	-	+	+
Lamiaceae	*Vitex simplicifolia*	-	+	-
Lauraceae	*Persea americana* Mill.	+	+	+
Loganiaceae	*Strychnos spinosa* Lam.	-	+	+
Malvaceae	*Cola gigantea* A. Cev. var. *glabrescens* Brenan & keay	-	-	+
	Cola nitida (Vent.) Schott & Endl.	-	+	+

Meliaceae	*Azadirachta Indica* A. Juss.	-	+	+
	Carapa procera DC. De Wilde	-	-	+
Mimosaceae	*Parkia bicolor* A. Chev.	-	-	+
	Tetrapleura tetraptera (Schum. & Thonn.) Taub.	-	-	+
Moraceae	*Antiaris toxicaria* subsp. *welwitshii* (Engl.) C. C. Berg.	-	-	+
	Ficus exasperata M. Vahl	-	+	+
	Ficus lutea M. Vahl	-	+	+
	Ficus vallis-choudae Del.	-	+	+
Myrtaceae	*Eugenia jambos* L.	-	-	+
	Eugenia malaccensis L.	+	+	+
	Eugenia miegeana Aké Assi	-	-	+
	Eugenia owariensis P. Beauv.	-	+	+
	Psidium guajava Linn.	-	+	+
	Syzygium guineense (Willd.) DC;	-	+	+
Olacaceae	*Coula edulis* Baill.	-	+	-
Rubiaceae	*Coffea robusta* Pierre ex A. Froehner	-	-	+
	Gardenia erubescens Stapf & Hutch.	-	-	+
	Morinda lucida Benth.	-	-	+
Rutaceae	*Citrus aurantifolia* (Christm.) Swingle	-	+	+
	Citrus aurantium L.	+	+	+
	Citrus maxima (Burm.) Merr.	-	-	+
	Citrus limon Burn. f.	-	-	+
	Citrus reticulata Blanco	-	+	+
	Citrus sinensis (L.) Osbeck	+	+	+
	Zanthoxylum zanthoxyloides Lam. Zep. & T.	-	-	+
Sapindaceae	*Blighia sapida* C. Konig.	-	+	+
Sapotaceae	*Baillonella toxisperma* Pierre	-	+	-
	Chrysophyllum albidum G. Don	-	+	+
Total		7	37	56

Meaning of abbreviations : *Pc - Phragmanthera capitata*; *Tb - Tapinanthus bangwensis*; *Tg - Tapinanthus globiferus*; (+) - Presence of parasite on host; (-) - Absence of parasite on host

These species are distributed across 44 genera and 25 botanical families. The families with the highest number of parasitized species are the Rubiaceae, with seven host species, followed by the Anacardiaceae, Annonaceae and Myrtaceae, each represented by six species. Next comes Moraceae with four species, then Fabaceae (three species), Apocynaceae, Caesalpiniaceae, Euphorbiaceae, Meliaceae, Mimosaceae, Sapindaceae and Sapotaceae, each represented by two species (Figure 6). The remaining eleven families have only one species each. Generic diversity is also high, with a total of 44 genera recorded. The *Citrus* genus is the most represented with six species (or 10% of host species), followed by the *Eugenia* genus with four host species (or 6.67%), then the *Annona, Ficus* and *Spondias* genera, each represented by three host species (or 5%). Finally, two other genera, *Cola* and *Xylopia*, each have two host species (3.33%) (Table 1). Among host species, 57 are parasitized by *T. bangwensis*, 37 by *P cacapitata* and only 7 by *T. globiferus* (Table 1).

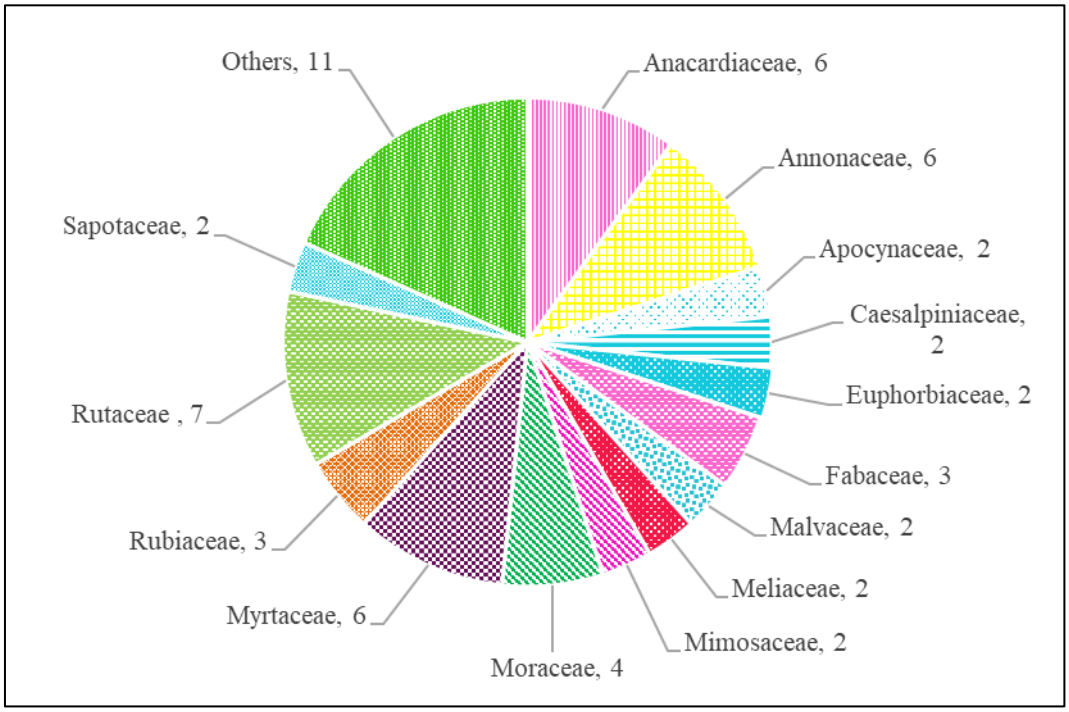


Figure 6 Distribution of Loranthaceae host fruit families in cocoa plantations

3.4. Density of host woody fruit species in cocoa plantations

The average density of Loranthaceae woody host species in cocoa orchards ranged from 30.20 ± 4.65 stems/ha in Toroguhé to 55.60 ± 4.82 stems/ha in Bribouo (Table 3). The highest densities were observed in Bribouo (55.60 ± 4.82 stems/ha) and Zépréguhé (55 ± 5.24 stems/ha), with a high concentration of Loranthaceae host fruit species. In contrast, the cocoa farms at Toroguhé (30.20 ± 4.65 stems/ha) and Zakoua (33 ± 6.96 stems/ha) have significantly lower densities. Analysis of variance (ANOVA) followed by the Newmann-Keuls test revealed a significant difference between mean densities across sites (F = 31.171; P = 0.000001), highlighting two statistically different groups (a and b). The overall average density of host fruit species recorded in all the cocoa plantations studied was 44.25 ± 13.86 stems/ha.

Table 3 Density of woody fruit host species in surveyed cocoa farms

Sites	Cocoa farms	density/fruit species (stems/ha)/ cocoa farm	Average density/fruit species (stems/ha)
Bribouo	Cac 1	60	55.60 ± 4,82b
	Cac2	57	
	Cac3	51	
	Cac4	50	
	Cac 5	60	
Toroguhé	Cac 1	31	30.20 ± 4.65a
	Cac2	35	
	Cac3	24	
	Cac4	27	
	Cac 5	34	
Zakoua	Cac 1	40	33 ± 6.96a

	Cac2	31	
	Cac3	37	
	Cac4	35	
	Cac 5	22	
Zepreguhé	Cac 1	56	55 ± 5.24b
	Cac2	59	
	Cac3	47	
	Cac4	53	
	Cac 5	60	
Average			44,25 ± 13,86

In the same column, values followed by the same letter are not significantly different at the 5% threshold.

3.5. Incidence and severity of Loranthaceae parasitism on fruit species

The incidence of Loranthaceae on fruit species inventoried in cocoa farms in the Daloa peri-urban area varies from 12.50% in *Morinda lucida* to 100% in *Cola gigantea* (Table 4). This high incidence concerns 12 species: *Cola gigantea*, *Cola nitida*, *Citrus sinensis*, *Garcinia kola, Persea americana, Lonchocarpus sericeus, Pterocarpus santalinoides, Spondias mombin, Spondias purpurea, Strychnos spinosa, Terminalia catappa* and *Vitex simplicifolia*. Of these species, three have an incidence of over 50%, while nine are between 40% and 50%. The most affected introduced species are *Cola gigantea* (100%), *Persea americana* (60.60%), *Cola nitida* and *Terminalia catappa* (50% each) and *Citrus sinensis* (42.10%). The average incidence for all species was 39.66 ± 7.07%.

Table 4 Level of attack by Loranthaceae on woody fruit trees in cocoa orchards

Families	**Species**	**Incidence (%)**	**Severity of parasitism (%)**
Anacardiaceae	**Anacadium occidentale* Linn.	19.71	25.70
	Pseudospondias microcarpa (A. Rich.) Engl.	33.33	20
	Spondias cytherea Linn.	26.32	20
	Spondias mombin Linn.	55.38	35.27
	Spondias purpurea Linn.	40	22.50
	Trichoscypha acuminata Engl.	33.33	20
Annonaceae	**Annona muricata* Linn.	27.58	25
	**Annona senegalensis* Pers.	30.76	35
	**Annona squarnosa* Linn.	33.33	10
	Monodora myristica (Gaert.) Dumal	25	20
	Xylopia aethiopica (Dunal) A. Rich.	26.67	7.50
	Xylopia parviflora (A. Rich.) Benth.	25	20
Apocynaceae	*Calotropis procera* (Aiton) W. T. Aiton	33.33	10
	Landolphia dulcis (Sabine) Pichon	33.33	30
Bixaceae	*Bixa orellena* Linn.	30	20
Bombacaceae	**Adansonia digitata* Linn.	33.33	32.50
Burseraceae	*Dacryodes macrophylla* (Oliv.) H. J. Lam	33.33	15

Caesalpiniaceae	*Detarium microcarpum* Guill. & Perr.	31.81	20
	**Tamarindus indica* Linn.	33.33	26.67
Clusiaceae	*Garcinia kola* Heckel	41.46	33.50
Combretaceae	**Terminalia catappa* Linn.	50	40
Euphorbiaceae	**Jatropha curcas* Linn.	2.17	1.67
	Ricinodendron heudelotii (Baill.) Pierre ex Pax	28.57	21.25
	Lonchocarpus sericeus (Poir.) DC.	50	20
Fabaceae	*Prosopis africana* (Guill. & Perr.) Taub.	22.22	15
	Pterocarpus santalinoides DC.	50	20
Irvingiaceae	*Irvingia gabonensis* (Audrey-Lecomte ex O'Rorke) baill.	29.41	26
Lamiaceae	*Vitex simplicifolia*	50	10
Lauraceae	**Persea americana* Mill.	60.60	52.12
Loganiaceae	*Strychnos spinosa* Lam.	40	20
Malvaceae	**Cola gigantea* A. Cev. var. *glabrescens* Brenan & keay	100	20
	**Cola nitida* (Vent.) Schott & Endl.	60	42
Meliaceae	**Azadirachta Indica* A. Juss.	25	16.67
	Carapa procera DC. De Wilde	20	10
Mimosaceae	**Parkia bicolor* A. Chev.	33.33	10
	Tetrapleura tetraptera (Schum. & Thonn.) Taub.	28.51	25
Moraceae	*Antiaris toxicaria Welwitshii* (Engl.) C. C. Berg	33.33	10
	Ficus exasperata M. Vahl	24	20
	Ficus lutea M. Vahl	24	26.67
	Ficus vallis-choudae Del.	22.22	15
Myrtaceae	**Eugenia jambos* (L.) Alston	33.33	20
	**Eugenia malaccensis* Linn.	28.12	36.67
	**Eugenia miegeana* Aké Assi	20	20
	**Eugenia owariensis* P. Beauv.	28.57	27.50
	**Psidium guajava* Linn.	30.9	27.05
	Syzygium guineense (Willd.) DC;	27.27	20
Olacaceae	*Coula edulis* Baill.	33.33	20
Rubiaceae	**Coffea robusta* Pierre ex A. Froehner	17.85	16
	Gardenia erubescens Stapf & Hutch.	33.33	15
	**Morinda lucida* Benth .	12.5	13.33
Rutaceae	**Citrus aurantifolia* (Christm.) Swingle	33.33	22.50
	**Citrus aurantium* Linn.	34.78	32.50
	**Citrus maxima* (Burm.) Merr.	18.18	25
	**Citrus limon* Burn. f.	16.67	15

	**Citrus reticulata* Blanco	32	21.25
	**Citrus sinensis* (L.) Osbeck	42.10	31.56
	Zanthoxylum zanthoxyloides Lam. Zep. & T.	25	20
Sapindaceae	*Blighia sapida* C. Konig.	19.67	15.80
Sapotaceae	*Baillonella toxisperma* Pierre	25	20
	Chrysophyllum albidum G. Don	25	16.67
Average		39.66 ± 7.07	34.03 ± 8.07

* - Introduced species

The severity of Loranthaceae infestations on fruiting species in the cocoa farms surveyed ranged from 1.67% on *Jatropha curcas* to 52.12% on *Persea americana*. From one host fruit species to another, the highest severity of parasitism was recorded on *Persea americana* (52.12%), *Cola nitida* (42%), *Terminalia catappa* (40%), *Eugenia malaccensis* (36.67%), *Spondias mombin* (35.27%), *Annona senegalensis* (35%), *Citrus sinensis* (31.56%), *Adansonia digitata* and *Garcinia kola* (each represented 33.50%) and *Citrus aurantium* (32.50%). The average severity of parasitism for all species combined is estimated at 34.03 ± 8.07%.

3.6. Incidence and severity of Loranthaceae parasitism on cocoa trees

The average incidence of Loranthaceae on cocoa trees varied significantly between study sites, from 34.35 ± 5.56% in Toroguhé to 45.90 ± 3.49% in Zepreguhé (Table 5). The incidence was relatively high in Bribouo (44.80 ± 4.45%) and Zepreguhé, but lower in Zakoua (35.23 ± 4.97%) and Toroguhé. The overall average incidence of Loranthaceae on all cocoa trees studied in the zone was 40.07 ± 6.93%.

Table 5 Evaluation of the incidence and severity of Loranthaceae infestations on cocoa trees according to study sites

Sites	Cocoa farms	Incidence (%)	Average incidence (%)	Severity of parasitism (%)	Average severity of parasitism (%)
Bribouo	Cac1	48.28	44.80 ± 4.45b	40.25	40.53 ± 1.84b
	Cac2	40.28		39.87	
	Cac3	39.97		38.54	
	Cac4	45.95		40.45	
	Cac5	49.52		43.56	
Toroguhé	Cac1	38.86	34.35 ± 5.56a	30.17	27.33 ± 3.82a
	Cac2	39.41		30.67	
	Cac3	32.10		26.50	
	Cac4	35.51		28.15	
	Cac5	25.88		21.16	
Zakoua	Cac1	37.77	35.23 ± 4.97a	29.16	27.35 ± 1.51a
	Cac2	39.05		30.05	
	Cac3	31.02		27.87	
	Cac4	39.55		28.19	
	Cac5	28.77		21.48	
Zepreguhé	Cac1	49.30	45.90 ± 3.49b	40.52	40.36 ± 2.90b
	Cac2	44.52		41.60	
	Cac3	40.96		36.35	

	Cac4	45.52		39.15	
	Cac5	49.21		44.19	
Global average			40.07 ± 6.93		33.89 ± 7.29

In the columns, means marked with the same letters indicate no difference (Newman-Keuls test, p > 0.05).

In addition, Table 5 shows the mean values for the severity of Loranthaceae parasitism, as assessed by the severity index of their attacks on cocoa trees. These values range from 27.33 ± 3.82% to 40.53 ± 1.84%, with more severe infestations recorded in Bribouo (40.53 ± 1.84%) and Zepreguhé (40.36 ± 2.90%). Conversely, the cocoa farms at Toroguhé (27.33 ± 3.82%) and Zakoua (27.35 ± 1.51%) had significantly lower levels of severity. Analysis of variance reveals a significant difference between means, according to the Newmann-Keuls test (P = 0.000001; F = 30.129), for the expression of parasitism severity. The overall average incidence in the study area was 33.89 ± 7.29%.

3.7. Incidence and severity index of Loranthaceae parasitism on fruit trees according to diameter and height classes

Table 6 shows the incidence and severity of Loranthaceae parasitism as a function of host fruit diameter classes. There is a progressive increase in the incidence and severity of attacks as trunk diameter increases, reflecting the greater vulnerability of older, more developed host taxa. Individuals belonging to the 11-15 cm, 16-20 cm and > 20 cm diameter classes, respectively, showed average incidences of 28.48%, 39.61% and 44.84%, associated with severity indices of 15.95%, 29.28% and 37.39%. These values are significantly lower in the smaller diameter classes (≤ 5 cm and 6-10 cm), with mean incidences of 12.56% and 18.43%, respectively, and mean severities of 6.11% and 10.25%. Analysis of variance (F = 14.25; p = 0.00005) revealed three statistically distinct groups for incidence classes (a, b and c) and two groups for infestation severity (a and b).

Table 6 Variation in incidence and severity of Loranthaceae parasitism as a function of as a function of host fruit tree diameter classes

Diameter classes (cm)	**Woody fruit species**	
	Incidence (%)	Severity (%)
≤ 5	12.56 ± 3.30a	6.11 ± 3.04a
[6 - 10]	18.43 ± 5.01a	10.25 ± 4.34a
[11 - 15]	28.48 ± 7.94b	15.95 ± 8.43a
[16 - 20]	39.61 ± 8.50c	29.28 ± 9.28b
> 20	44.84 ± 6.84c	37.39 ± 7.57b

In the columns, the means assigned the same letters are not different (Newman-Keuls test, p < 0.05).

Table 7 shows that the incidence and severity of Loranthaceae parasitism on woody fruit species increase progressively with height class. The incidence and severity averages vary significantly between classes, indicating greater susceptibility in taller individuals. The results show that individuals belonging to the height class less than or equal to 2 m, corresponding to the youngest and least developed fruit-bearing individuals, are significantly less parasitized, with an average incidence of 12.41 ± 1.37% and a severity index of 6.19 ± 0.77%.

Table 7 Variation in incidence and severity of parasitism of Loranthaceae as a function of height classes according to height classes

Height classes (m)	**Woody fruit species**	
	Incidence (%)	Severity (%)
≤ 2	12.41 ± 1.37a	6.19 ± 0.77a
[3 - 4]	24.54 ± 3.67b	16.96 ± 2.14b
> 4	37.72 ± 3.16c	27.73 ± 2,72c

In the columns, the means assigned the same letters are not different (Newman-Keuls test, $p < 0.05$).

On the other hand, individuals in height classes between 3-4 m and above 4 m show significantly higher levels of Loranthaceae parasitism. The analysis reveals highly significant differences in parasitism from one class to another according to the Newman-Keuls test, with three statistically distinct groups (a, b and c) for both incidence classes ($F = 75.626$; $p = 0.000002$) and infestation severity classes ($F = 110.183$; $p < 0.05$).

4. Discussion

Three species of Loranthaceae (*Phragmanthera capitata* (Sprengel) S. Balle, *Tapinanthus bangwensis* (Engler) Danser and *T. globiferus* (A. Rich.) Danser) were recorded on cocoa trees and fruiting woody plants in cocoa farms in the study area. This number is similar to that obtained by Sako [22], who recorded three species in the riparian plantations of Jean Lorougnon Guédé University, but lower than the five species identified by Soro [12] in Oumé, Gagnoa and Soubré, in west-central Côte d'Ivoire. This difference could be explained by the variable number of cocoa farms surveyed and the climatic conditions specific to each zone, which influence the distribution of Loranthaceae [5, 23]. Among these parasitic species, *T. bangwensis* was particularly abundant on fruit and cocoa trees. This parasite's predominance in cocoa plantations could be explained by its ubiquitous nature in tropical African cocoa orchards, particularly in Côte d'Ivoire [12, 24]. Moreover, these same species have already been reported by Mrankpa [18] at the Jean Lorougnon Guédé University site in Daloa in west-central Côte d'Ivoire and by Amon [25] in Sud-Comoé, in the southeast of the country. The presence of these species on these fruit-bearing woody plants in cocoa plantations in the Center-West would depend on their wide distribution in Africa and particularly in Côte d'Ivoire [26, 27]. Sixty Loranthaceae woody fruit host species belonging to 44 genera and 25 families were inventoried in the cocoa farms studied in the peri-urban zone of Daloa. These fruiting species showed good generic and specific diversity compared with the 14 fruiting host species surveyed by Sako [22] and the 23 species of Soro [12] Assessment of the incidence of Loranthaceae on woody fruit trees showed that they are heavily attacked, in particular well-known fruit trees such as *Persea americana* (60.60%), *Spondias mombin* (55.38%), *Cola nitida* and *Terminalia catappa* with 50% each and *Citrus sinensis* (42.10%). Similar observations have been reported elsewhere in Africa, notably in Ghana by Cleck [28] on *Cola nitida* and in Cameroon by Dibong et al. [23] on *Persea americana* and Houenon et al. [29] on *Citrus sinensis*. Among these fruit crops, *Persea americana* (60.60%) is the most heavily parasitized species. Sonké et al. [6], in Cameroon, obtained a rate of 69.44% on *P. americana*, pointing to the polyphagous nature of Loranthaceae on this fruit species, in which they found a preferred target. The presence of this species in cocoa orchards under the influence of Loranthaceae should be monitored and controlled. The incidence of Loranthaceae recorded on cocoa trees and woody fruit species in the Daloa peri-urban zone is 33.89 ± 7.29% and 39.66 ± 7.07%, respectively. This incidence value is lower than the 35% obtained by Sako [22] on cocoa trees in the riparian zones of Jean Lorougnon Guédé University but higher than the 26.90% recorded by Soro [12] in Oumé. The results also showed that mean incidence values for Loranthaceae are high in fruit trees belonging to the large-diameter classes (11-15 cm, 16-20 cm and > 20 cm) and in those of the taller classes (between 3-4 m and > 4 m). These results corroborate those of Traoré et al. [7], who had already reported that birds disseminating the seeds of these parasites prefer, for safety reasons, the branches of taller woody individuals as perches.

5. Conclusion and Recommendations

The present study was carried out to gain a better understanding of Loranthaceae and assess the extent of their infestation on the woody fruit species present in the various cocoa plantations. Floristic inventories identified three species of Loranthaceae: *Phragmanthera capitata*, *Tapinanthus bangwensis* and *T. globiferus*. Of these, *T. bangwensis* was found to be predominant on woody fruit and cocoa trees. The spectrum of fruit hosts parasitized by Loranthaceae comprises 62 species, spread across 44 genera and 25 botanical families. The families most affected are Rutaceae (7 host taxa), followed by Anacardiaceae, Annonaceae and Myrtaceae (6 host taxa each), Moraceae (4 host taxa), Fabaceae and Rubiaceae (3 host taxa each). The results showed that some well-known fruit species were heavily parasitized, notably *Persea americana* (60.60%), *Spondias mombin* (55.38%), *Cola nitida* (50%), *Terminalia catappa* (50%), *Citrus sinensis* (42.10%) and *Garcinia kola* (41.46%). The average incidence of Loranthaceae on fruit trees was 39.66 ± 7.07%, with an average severity of 34.03 ± 8.07%. For cocoa trees, the average incidence observed was 40.65 ± 4.26%, and the average severity of parasitism was 35.43 ± 5.56%. The results indicate that the diameter and height of fruiting woody individuals significantly influence their level of infestation by Loranthaceae in cocoa plantations. These results suggest that fruit species less susceptible to Loranthaceae should be identified and preferred for association with cocoa trees in order to limit their infestation.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest with respect to this article.

Statement of informed consent

Informed consent was obtained from all authors of this study.

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