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Inventory and Biodiversity of the Entomofauna Associated with Shea Fruits (*Vitellaria paradoxa* C. F. Gaertn), an Important Non-Timber Forest Product in the Ziro Province of Burkina Faso

Siébou François Kambou[1], Koï Wenceslas Kam[2], Mayouré Edith Ilboudo[3], Djietawendé Honoré Kientega[1,4], Antoine Sanon[1], Zakaria Ilboudo[1*]

[1]Université Joseph KI-ZERBO, Laboratoire d'Entomologie Fondamentale et Appliquée, UFR/SVT, Ouagadougou, Burkina Faso
[2]Université de Fada N'Gourma, Institut Supérieur du Développement Durable, Fada N'Gourma, Burkina Faso
[3]Ecole Normale Supérieure (ENS), Ouagadougou, Burkina Faso
[4]Direction Générale Ecole Nationale de Police, Ouagadougou, Burkina Faso
Email: *il_zakaria@yahoo.fr

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Abstract

A few studies have highlighted the degradation of shea tree fruits mainly due to insects in Burkina Faso. The insects associated with these non-timber forest products are still poorly known, hence the interest of this study. The objective of the study is to make a qualitative inventory of the biodiversity of insect pests of shea fruits during the ripening period in two different ecosystems. It was carried out in 2021 in three locations of the Ziro province. 30 shea fruit trees distributed in 9 sites listed in agrosystems and protected areas were selected for monitoring and collecting insects infested with the fruits. The inventory identified 25 species in 13 families clustered in 5 orders. The order of Diptera, composed of 6 families with 15 species recorded, is the most dominant order in this diversity. Among the different families, 3 of them, Calliphoridae, Tephritidae and Muscidae, present at least 3 species each. 7 species are mainly associated with fruit damage with a predominance of *Ceratitis silvestrii* Bezzi (Diptera: Tephritidae). 91.33% of the emergences from infested fruits and 43.41% of the individuals trapped belong to this species. *C. silvestrii*, which presents a homogeneity in its distribution between locations and ecosystems, is therefore the main pest species of shea fruits in production in this zone. The results suggest the need to determine the economic importance of Tephritidae infesting shea fruits.

Keywords

Insects, Ecosystems, Biodiversity, Shea Fruit, Burkina Faso

1. Introduction

In Burkina Faso, Non-Timber Forest Products (NTFPs) are very important for the survival of rural populations [1]. They provide rural populations with livelihoods, additional income, and employment, and contribute to their heath improvement. Indeed, NTFPs are part of the diet and nutritional balance of more than 43.4% of households, provide nearly 23% of income to rural households and are involved in the health care of 75% - 90% of the population [2]. In 2008, the contribution of all NTFPs to the national economy was estimated at 0.63% [1]. In 2011, the contribution of the shea industry was estimated at 28.991 billion FCFA, or about 0.60% of the value of Burkina Faso's GDP [1]. The same source reported that the export of shea kernels and butter contributed 20.128 billion FCFA to the national currency. But at harvest, 15% to 65% of the fruits of the shea tree may be unfitted for consumption [3]. This is due to the activity of insect pests of fruit of which fruit flies are in the forefront. In the western region of Burkina Faso, [4] identified five species of the Tephritidae family that infest shea fruits, with a predominance of the *Ceratitis* genus (98%), and in the locations of Diabo and Arbolé, [5] reported that *Ceratitis silvestrii* Bezzi and *Bactrocera dorsalis* Hendel are responsible for shea fruit pulp rot in two agroforestry parks. Given the importance of the shea industry and the negative impact of insect activity, it is essential to further investigate the diversity of these insects in order to develop effective control methods, this could increase production and make healthy shea nuts available to all stakeholders. This study aims to make a qualitative inventory of the biodiversity of insect pests of shea fruits during the ripening period in the province of Ziro. Specifically, it aims to: 1) make an inventory of the populations of insect pests of shea fruits in three locations of the province of Ziro, 2) evaluate the distribution and abundance of each species according to locations and types of ecosystems, 3) identify the main pest groups of shea fruits.

2. Methodology of the Study

2.1. Conditions and Site of the Study

The study was conducted in the province of Ziro, which is located in the center-west region of Burkina Faso. Ziro is located in the north Sudan phytogeographic sector. In this sector, rainfall varied from 700 to 900 mm and the rainy season lasts 5 to 6 months [6]. In 2021, according to data of the National Agency of Meteorology in Burkina Faso (ANAM-BF), annual rainfall and relative humidity were respectively 926 mm and 47.41%. Monthly temperatures ranged from 26.7˚C to 34.5˚C with an average of 29.77˚C. Data collection took place in three locations of the province, namely the locations of Sapouy (11˚31.169'N;

01˚46.675'W), Cassou (11˚34.361'N; 02˚02.810'W) and Bakata (11˚45.699'N; 01˚51.299'W) from March to August 2021.

2.2. Sampling Methods

2.2.1. Sampling of Trees for Monitoring: Selection and Marking

Thirty (30) shea fruit trees (*Vitellaria paradoxa*) distributed in nine (09) sites (3 reserves and 6 agrosystems) in 3 locations of the province of Ziro, were selected for monitoring and insect collection. A minimum distance of 5 km between sites was observed in order to avoid the selection of closely related individuals (clones) and to ensure the independence of observations. The land-use typology was limited to two types of terrestrial ecosystems, namely protected areas (reserves) and agrosystems (fields and fallows). Productive adult individuals were sampled in a stand of the species during the period of full flowering. The geographical coordinates of the selected individuals were taken with a GPS.

2.2.2. Sampling of Fruit Insects

Two methods were used to capture insects attached to ripe or unripe fruit: mowing with a mowing net and artisanal trapping with yellow bowls containing a mixture of soapy water and shea fruit pulp. The bowl, filled to capacity with the liquid and uncovered, is placed at the base of the tree in the presence of insects that feed on the ripe fruit that has fallen to the ground. Insects, mainly of the order Diptera, are attracted by the odor exhaled from the pulp and are attracted once in contact with the liquid. Insects captured with the net are killed or rendered inert with an insecticide. To access the fruit on the trees, we used a 1.75 m high ladder. In addition to these two methods, twenty (20) fruits showing signs of insect attack were collected at each site and then stored in plastic boxes containing sterilized sand and covered with mosquito netting, for monitoring adult emergence [7]. Incubated fruits were kept for 6 weeks under ambient laboratory conditions [4]. The different insects emerged or captured were kept in vials containing 70% alcohol for identification.

2.3. Countdown and Samples Identification

2.3.1. Sorting the Collected Samples

The collected samples (captured or trapped) were transferred to the Laboratory of fundamental and Applied Entomology of Joseph KI-ZERBO University. Preliminary sorting with a binocular loupe allowed the classification of the captured insects according to their orders and families. After sorting, samples from each batch and from infested fruits are preserved in vials containing alcohol at 70˚C. The Lepidoptera found are fixed with entomological needles and placed in collection boxes for later identification.

2.3.2. Identification of Specimens

After sorting, the different specimens were identified under binocular loupe as far as possible to the species in the Laboratory of fundamental and Applied Entomology of Joseph KI-ZERBO University. Several keys and reference documents were used for identification ([4] [8]-[13]). This identification was possible by the help of systematics specialists from the same laboratory.

2.4. Statistical Analysis

Data collected during the study were processed with Excel 2016 software. Statistical analyses were performed with R software version 3.5.2. Two levels of analysis were considered:

- A global analysis of the biodiversity of insects collected by the swath net and traps in the 9 sites: it involved assessing the presence of insects on the fruits of each tree, identifying the most representative groups, and analyzing the spatial variations according to the type of ecosystem during the year of the study.
- A more refined ecological analysis based on the presence of the most representative bio-indicator groups: in this case, the different ecosystems are compared according to each collection period in order to see the evolution of biodiversity.

The data collected were used to calculate classical ecological indices that allow to study the structure of the stands and to evaluate their biodiversity according to the space and the harvesting period. The indices calculated are:

- Insect species richness [14], determined by the total number of species recorded at each site;
- the Shannon Wiener diversity index, H' [14], which expresses the diversity of the stand. It is determined from the number of individuals per species and per site or location as a function of time by the formula $H' = -\sum\left((qi/Q)\log 2(qi/Q)\right)$ where qi represents the number of individuals of taxon i and Q, the total number of individuals in the stand. Diversity is maximal when all observed taxa have the same abundance. $H'_{\max} = \log 2S$; S is the total number of taxa in the stand. The Shannon Wiener diversity index varies between 0 and Ln(S).
- Pielou's equitability index, (J') [14] which evaluates the equi-distribution of the numbers in the stand. It makes it possible to define the regularity, which is the observed diversity compared to the maximum theoretical diversity, and to compare ecosystems that are very different in terms of their specific richness. It thus gives an idea of the quality of the structure of the stand. It is calculated by the formula: $J' = H'/H'_{\max}$

$$H_{\max} = -\sum_{i=1}^{S}\frac{1}{S}\ln\frac{1}{S} = \ln S.$$

The values of (J') are between 0 and 1; the low values of this index also indicate an unequal contribution of the different species to the community constitution.

- Jaccard's similarity index gives an idea of inter-locality and intra-locality faunal complementarities. It was calculated using the following formula: [15].

$$C_{jk} = U_{jk}/S_{jk}$$

where: $U_{jk} = S_j + S_k - 2V_{jk}$ and $S_{jk} = S_j + S_k - V_{jk}$;

S_j = total species richness of site j,

S_k = total species richness of site k,

V_{jk} = number of common species between the two sites.

The value of this complementarity varies between 0 for two locations having no species in common (C_{jk} = 0) and 1 for two locations having all their species in common (C_{jk} = 1). Complementarity can also be expressed in percentage.

- Sorensen's Similarity Index (β) which is a measure of beta diversity varying between 0 (=absence of similarity) and 1 (=perfect similarity) [16] was used to compare the biodiversity of Arthropods of the different sites in this study. It was calculated according to the formula below:

$$\beta = \frac{2C}{S_1 + S_2}$$

where: c = Number of species common to both locations;

S_1 = Species richness of site 1; S_2 = Species richness of site 2.

The diversity indices and their variations in space and time were compared in the different sites using an Analysis of Variance (ANOVA). The separation of significantly different means is done by the Kruskal-Wallis test. The Kruskal-Wallis test is a non-parametric test indicated for the analysis of independent samples whose normality is not proven: [17]. The significance level used was 5%.

3. Results

3.1. Global Analysis of the Biodiversity of the Surveyed Insects

The insects collected and identified during this study in the nine (9) sites, belong to thirteen (13) families (**Table 1**). These different families grouped in five (5) orders (Diptera, Coleoptera, Hymenoptera, Hemiptera and Lepidoptera), form a community composed of twenty-five (25) species. Nine (9) families of insects are represented mainly in two (2) sites: Bakata Reserve 1 (BR1) and Cassou Agro-system 1 (CA1). Sites BA1, BA2, CA1 and SA1 present more than half of the identified species. Sapouy Reserve 3 (SR3) has the lowest number of families, five (5), with only eight (8) species recorded, with a rate of 19.23% of families. Out of a total of 3134 specimens counted during the inventory of insects associated with shea fruits, 528 individuals were captured or trapped and 2606 adults emerged from incubated fruits. The abundance of individuals counted is observed in SA1 (499), SA2 (533) and BA2 (546) sites.

3.2. Diversity of Insects Captured or Trapped

3.2.1. Specificity of the Sampled Insects

The order of Diptera is composed of six (6) families with 15 species identified (65.22%), is the most representative. It is followed respectively by Coleoptera, Hymenoptera and Hemiptera orders (**Table 2**). The families with the highest percentage of species are: Calliphoridae (17.4%), Muscidae (13%) and Sarcophagidae (13%) (**Table 2**). Compared to these families, the others are each represented by two species or only one species.

Table 1. Abundance of insect families and species recorded by trapping or emergence at the different sites.

Locations	Sites	Number of families	Number of species	Number of individuals	
				Insects collected	Emerging Insects
Bakata	BA1	8	13	102	149
	BA2	7	15	95	451
	BR1	9	11	27	237
Cassou	CA1	9	13	40	297
	CA2	6	9	24	132
	CR2	7	12	38	63
Sapouy	SA1	7	18	70	429
	SA2	7	12	106	427
	SR3	5	8	26	421
Totals	9	13	25	528	2606

BA1 = Agrosystem 1 de Bakata, BA2 = Agrosystem 2 de Bakata, BR1 = Reserve 1 de Bakata, CA1= Agrosysteme 1 de Cassou, CA2 = Agrosystem 1 de Cassou, CR2 = Reserve 2 de Cassou, SA1 = Agrosystem 1 de Sapouy, SA2 = Agrosystem 1 de Sapouy, SR3 = Reserve 3 de Sapouy.

Table 2. Species richness of captured insects.

Orders	Families	Number of species	Proportions (%)
Diptera	Tephritidae	2	8.33
	Sarcophagidae	3	12.5
	Calliphoridae	4	16.67
	Muscidae	3	12.5
	Ulidiidae	1	4.17
	Drosophilidae	2	8.33
Coleoptera	Scarabaeidae	2	8.33
	Curculionidae	1	4.17
	Chrysomelidae	1	4.17
Hemiptera	Lygaeidae	1	4.17
Hymenoptera	Apidae	2	8.33
	Braconidae	1	3.17
Total richness	12	23	

3.2.2. Abundance of Sampled Species

Twenty-three (23) species were recorded and identified in the different study locations. The analysis of the results shows the presence of two (2) dominant species that represent approximately 57.2% of the insects captured (**Figure 1**). These are *C. silvestrii* and *S. carnaria* with 41.67% and 15.53% of individuals respectively. Among twenty-one (21) other species, six (6) (*S. argyrostoma*, *S. tibialis*,

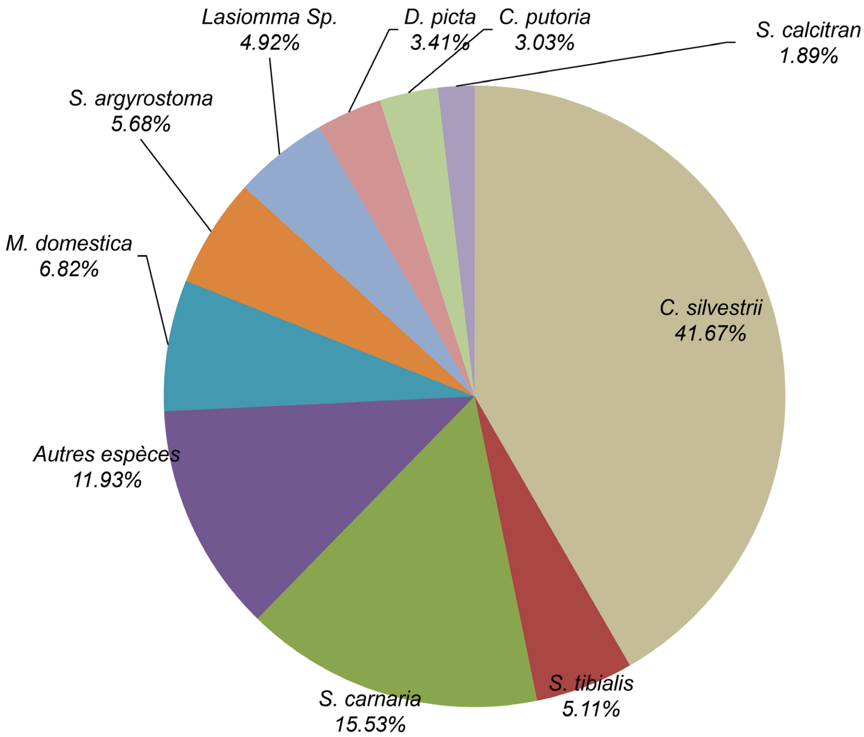

Figure 1. Proportion of species sampled with traps at all locations.

C. putoria, *M. domestica*, *Lasiomma Sp*, *D. picta*) were represented by percentages of individuals between 3% and 7%. 14 species (*S. calcitran*, *C. quinaria*, *L. cupina*, *L. sericata*, *C. vomitoria*, *P. collinsi*, *G. sanguinolenta*, *P. formosus*, *C. furcatus*, *D. cingulatus*, *A. mellifera*, *E. cruciger*, *F. caudatus*, *D. melanogaster*) were recorded with percentages of individuals less than 2%. *D. immigrans* was present in all locations with very numerous individuals (uncountable).

3.2.3. Distribution of Trapped Species According to Locations

Among the twenty-three (23) species identified, eleven (11) belonging to seven (7) genera, were captured in all locations (Table 3). These are: *C. silvestrii*, *C. quinaria*, *S. carnaria*, *S. argyrostoma*, *S. tibialis*, *C. putoria*, *M. domestica*, *Lasiomma Sp.*, *D. picta*, *D. melanogaster*, *D. immigrans*. The order of Diptera regrouping 5 families is the most represented in all the locations with most of the species. The location of Bakata presents the greatest specific richness with twenty (20) species recorded, compared to the locations of Cassou and Sapouy which presented respectively 16 and 17 species. Nevertheless, 19 species were recorded in at least two (2) locations against 4 species that were recorded only in one of the locations. Apart from Chrysomelidae and Lygaeidae families, all other families were represented in at least two (2) locations.

3.2.4. Distribution of Trapped Insect Families by Type of Ecosystem

Analysis of Figure 2 shows that the two types of ecosystems have 8 insect families in common with species in varying proportions. These are the Tephritidae, Sarcophagidae, Calliphoridae, Muscidae, Ulidiidae, Drosophilidae, Scarabaeidae,

Table 3. Distribution of species by locations.

Families	Species	Bakata	Cassou	Sapouy
Tephritidae	*Ceratitis silvestrii* (Bezzi)	+	+	+
	Ceratitis quinaria (Bezzi)	+	+	+
Sarcophagidae	*Sarcophaga carnaria* (Linné, 1758)	+	+	+
	Sarcophaga argyrostoma (Robineau-Desvoidy, 1830)	+	+	+
	Sarcophaga tibialis (Mcquart, 1851)	+	+	+
Calliphoridae	*Chrysomya putoria* (Wiedemann, 1830)	+	+	+
	Lucilia cuprina (Wiedemann, 1830)	−	−	+
	Lucilia sericata (Meigen, 1826)	+	−	+
	Calliphora vomitoria (Linnaeus, 1758)	+	−	+
Muscidae	*Musca domestica* (Linné, 1758)	+	+	+
	Stomoxys calcitran (Linnaeus, 1758)	+	−	+
	Lasiomma Sp.	+	+	+
Ulidiidae	*Delphinia picta* (Fabricius, 1781)	+	+	+
Scarabaeidae	*Pachnoda collinsi* (Rigout, 1985)	+	+	−
	Gametis sanguinolenta (Olivier, 1789)	+	−	−
Curculionidae	*Polydrusus formosus* (Mayer, 1779)	+	+	−
Chrysomelidae	*Caryedon furcatus* (Anton et Delobel)	−	+	−
Lygaeidae	*Dysdercus cingulatus* (Fabricius, 1775)	−	+	−
Apidae	*Apis mellifera* (Linnaeus, 1758)	+	+	−
	Epeolus cruciger (Panzer, 1799)	+	−	+
Braconidae	*Fopius caudatus* (Szepligeti, 1913)	+	−	+
Drosophilidae	*Drosophila melanogaster* (Meigen, 1830)	+	+	+
	Drosophila immigrans (Sturtevant, 1921)	+	+	+
Total richness	23	20	16	17

Curculionidae, Chrysomelidae, Lygaeidae, Apidae and Braconidae. Three families such as Scarabaeidae, Curculionidae and Chrysomelidae are present in the agrosystems and are absent in the reserves. Howerver, only one family (Lygaeidae) is recorded in the reserves but absent in the agrosystems. The diversity of families varies according to the ecosystems.

3.2.5. Distribution of Trapped Species Based on Ecosystems

According to the distribution of species based on ecosystems (Table 4), 22 species were predominantly recorded in the agrosystems while 12 species were fund in the reserves. As a result, we note a greater specific richness (95.65% of species) in the agrosystems. Agrosystems also had the most important diversity of families (11) compared to the reserves, which had only eight (8) families.

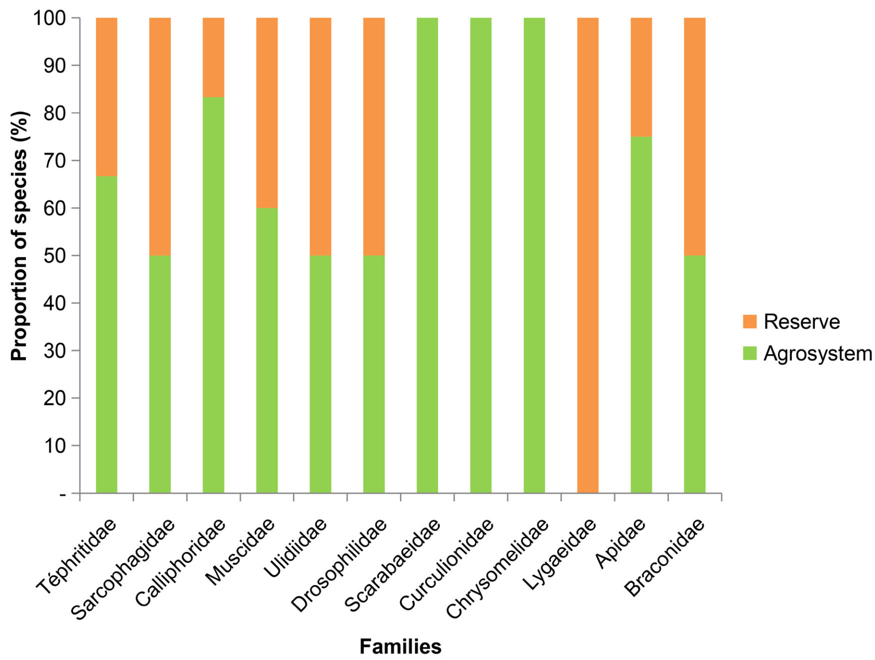

Figure 2. proportion of species sampled on fruits according to different families and types of ecosystems.

Table 4. Distribution of species by type of ecosystems.

Families	Species	Agrosystem	Reserve
Tephritidae	*Ceratitis silvestrii* (Bezzi)	+	+
	Ceratitis quinaria (Bezzi)	+	–
Sarcophagidae	*Sarcophaga carnaria* (Linné, 1758)	+	+
	Sarcophaga argyrostoma (Robineau-Desvoidy, 1830)	+	+
	Sarcophaga tibialis (Mcquart, 1851)	+	+
Calliphoridae	*Chrysomya putoria* (Wiedemann, 1830)	+	+
	Lucilia cuprina (Wiedemann, 1830)	+	–
	Lucilia sericata (Meigen, 1826)	+	–
	Calliphora vomitoria (Linnaeus, 1758)	+	–
Muscidae	*Musca domestica* (Linné, 1758)	+	+
	Stomoxys calcitran (Linnaeus, 1758)	+	–
	Lasiomma Sp.	+	+
Ulidiidae	*Delphinia picta* (Fabricius, 1781)	+	–
Scarabaeidae	*Pachnoda collinsi* (Rigout, 1985)	+	–
	Gametis sanguinolenta (Olivier, 1789)	+	–
Curculionidae	*Polydrusus formosus* (Mayer, 1779)	+	–
Chrysomelidae	*Caryedon furcatus* (Anton et Delobel)	+	–
Lygaeidae	*Dysdercus cingulatus* (Fabricius, 1775)	–	+

Continued

Apidae	*Apis mellifera* (Linnaeus, 1758)	+	+
	Epeolus cruciger (Panzer, 1799)	+	−
Braconidae	*Fopius caudatus* (Szepligeti, 1913)	+	+
Drosophilidae	*Drosophila melanogaster* (Meigen, 1830)	+	+
	Drosophila immigrans (Sturtevant, 1921)	+	+
Total richness	23	22	12

+: present; −: absent.

3.2.6. Shannon-Wienner Diversity Index (*H'*) and Piélou Equitability Index (*J'*) of Trapped/Captured Insects by Locations and Type of Ecosystem

The analysis of specific diversity according to locations and ecosystems revealed high values of Shannon's diversity and Pielou's equitability indices (Table 5). Shannon diversity indices vary between 1.85 and 2.22 depending on locations; 1.93 and 2.11 based on ecosystems. These values are all higher than the calculated theoretical value (H'_{max} = 1.69). This indicates a great diversity of population in the different location and ecosystems sampled. As for Pielou's equitability indices, the values are also high and vary between 0.67 and 0.82 depending on the locations; 0.68 and 0.78 depending on the ecosystems. This suggests an almost equitable contribution of species to the constitution of this biodiversity.

3.2.7. Similarity Index of Species between Locations and Ecosystems

Jaccard's similarity index (C_{jk}), which gives an idea of faunal complementarities, revealed a similarity of more than half the species between Bakata-Sapouy and Bakata-Cassou locations with 0.75 and 0.62 values respectively (Table 6). The highest similarity was noted between the Bakata and Sapouy locations and the lowest one was observed between the Cassou and Sapouy locations (C_{jk} = 0.48) with only 11 species in common. The insect communities identified in the different ecosystems showed a low similarity (C_{jk} = 0.5) with 11 common species of the 23 identified (Table 6). These results reflect a low homogeneity of species between the two ecosystems studied.

3.3. Distribution, Abundance, Diversity, and Distribution of Insects Emerging from Incubated Fruit

Two thousand six hundred and six (2606) adult insects of seven (7) species in five (5) families emerged from the infested fruits after incubation. Five (5) species (*C. silvestrii*, *C. quinaria*, *S. argyrostoma*, *F. caudatus*, *E. cautella*) were recorded in all the locations and two (2) species (*B. dorsalis*, *M. domestica*) inventoried in the different ecosystems of the location of Bakata and of Sapouy (Table 7). The agrosystem of Sapouy presents the greatest specific richness with a representativeness of all species. This location is followed by Bakata's reserve which presents six (6) species. The Cassou reserve has the lowest specific richness with only three (3) species recorded. The rest of the ecosystems showed intermediate

Table 5. Species biological diversity indices per location and ecosystem.

Locations and Ecosystems	Shannon-Wienner indexes (H')	Piélou's equitability indexes (J')
Bakata	2.04	0.7
Cassou	2.22	0.82
Sapouy	1.85	0.67
Agrosystem	2.11	0.69
Reserve	1.93	0.78

NB: Shannon-Wienner diversity index varies between 0 and Ln(S) = 3.13 and the equitability index equitability index (J') between 0 and 1.

Table 6. Jaccard's Similarity Index per location and ecosystem.

Locations and ecosystems compared	Jaccard Similarity Indexes (C_{jk})
Bakata-Cassou	0.62
Bakata-Sapouy	0.75
Cassou-Sapouy	0.48
Agrosystème-Reserve	0.50

Table 7. Specific richness and distribution of species from infested fruit incubation by sampling locations and ecosystems.

Families	Specific	Bakata		Cassou		Sapouy	
		Agros.	Reser.	Agros.	Reser.	Agros.	Reser.
Tephritidae	*Ceratitis silvestrii*	+	+	+	+	+	+
	Ceratitis quinaria	−	+	+	+	+	+
	Bactrocera dorsalis	−	+	−	−	+	+
Muscidae	*Musca domestica*	+	+	−	−	+	+
Sarcophagidae	*Sarcophaga argyrostoma*	+	−	+	−	+	−
Braconidae	*Fopius caudatus*	+	+	+	+	+	+
Pyralidae	*Ephestia cautella*	−	+	+	−	+	−
Total richness	7	4	6	5	3	7	5

Agro = agrosystem; Reser = reserve.

species richness. Apart from *B. dorsalis* and *E. cautella*, species, the others had already been captured by the traps.

3.3.1. Diversity and Representativeness of Insects Emerging from Incubated Fruits

Figure 3 presents the proportions of individuals of each species identified from the incubation of infested fruits. Seven (07) species were responsible for the damage on the fruits: *C. silvestrii* (2380 individuals), *C. quinaria* (58), *B. dorsalis* (25), *S. argyrostoma* (15), *M. domestica* (58), *F. caudatus* (65), *E. cautella* (5). The analysis of the figure reveals a very high proportion (91.33%) of individuals

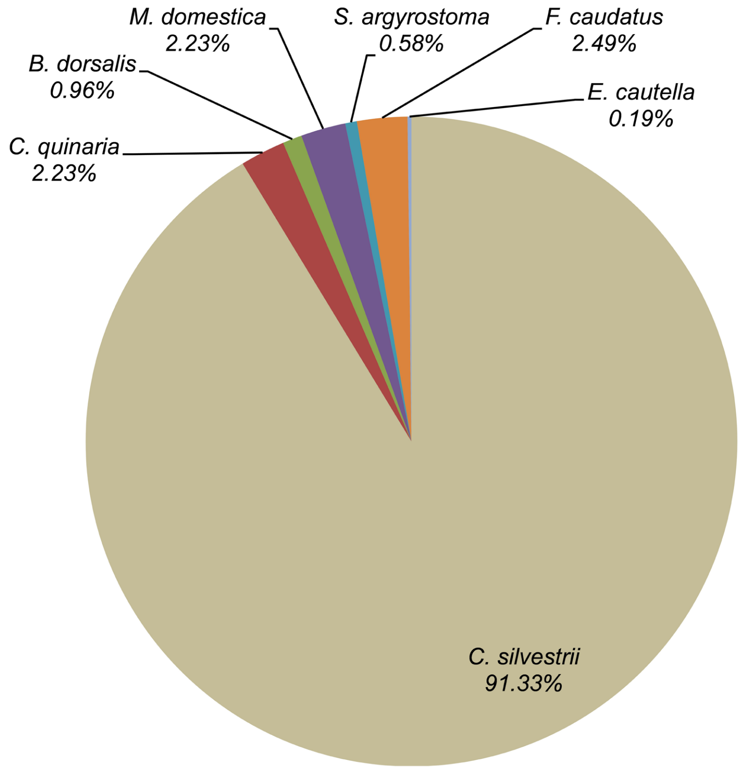

Figure 3. Proportions of species identified from infested fruit.

of *C. silvestrii* compared to the other 6 species which present low proportions of individuals between 0.2% and 2.5%.

3.3.2. Species Distribution Depending on Locations

Considering the emergence rates of the species from infested fruits during the monitoring period depending on locations, we note that *C. silvestrii* is the most abundant species in all locations (**Table 8**). Two (2) species, *B. dorsalis* and *M. domestica*, were not recorded from the incubation of fruits in Cassou location. The other species were recorded in all the locations but at low proportions of individuals. With respect to the abundance of individuals of each species identified, there was no significant difference between locations ($P > 0.05$).

3.3.3. Species Distribution According to Sampling Periods

According to the sampling periods, the results mentioned in **Table 9** show a difference in proportion and appearance of species. Indeed, three species, *C. silvestrii*, *C. quinaria* and *F. caudatus*, appeared at all the sampling periods with relatively important variable proportions at the end of the collection season (end of August month). *B. dorsalis*, *M. domestica*, *S. argyrostoma*, were recorded only at the end of the season, contrary to *E. cautella* recorded at the beginning of the season (mid-June) of fruit collection. For all monitoring periods, a higher abundance of *C. silvestrii* was noted. There was no significant difference ($P > 0.05$) in terms of abundance of individuals between periods except for *E. cautella* ($P = 0.03$) and *S. argyrostoma* ($P = 0.04$).

Table 8. Emergence rate of the different species according to locations.

Locations	Emergence rate (%) of different species						
	Ceratitis silvestrii	*Ceratitis quinaria*	*Bactrocera dorsalis*	*Musca domestica*	*Sarcophaga argyrostoma*	*Fopius caudatus*	*Ephestia cautella*
Bakata	93.19	1.43	1.31	1.31	0.72	1.79	0.24
Cassou	95.12	1.02	0.00	0.00	0.81	2.85	0.20
Sapouy	88.65	3.21	1.10	3.68	0.39	2.82	0.16
P-value	0.15	0.26	0.28	0.19	0.95	0.53	0.95

Table 9. Proportion of emergence of different species based on sampling periods.

Species from infested fruits	Proportion of insects (%) during the 2 sampling periods		P-value
	EPS	EFS	
Ceratitis silvestrii	57.52	42.48	0.51
Ceratitis quinaria	13.79	86.21	0.27
Bactrocera dorsalis	0.00	100	0.12
Musca domestica	0.00	100	0.12
Sarcophaga argyrostoma	0.00	100	0.04
Fopius caudatus	13.85	86.15	0.05
Ephestia cautella	100	0.00	0.03

EPS: Peak Season Sampling; EFS: End of Season Sampling.

3.3.4. Abundance of Emerged Insect Species Based on Ecosystems

The proportions of individuals of each species resulting from the hatching of pupae associated with infested fruits are higher in agrosystems (**Figure 4**). *S. argyrostoma* was absent from the protected areas. However, the proportions of *B. dorsalis* and *M. domestica* individuals are almost identical in both ecosystems. 72% of this biodiversity emerged from infested fruits from the agrosystems with a high representation of *C. silvestrii*.

3.3.5. Index of Diversity of Insects from Incubated Fruits per Location

Table 10 presents the results of the analysis of the biological diversity indices of the species from incubated fruit. These results show low values of Shannon's diversity indices between sampling periods and even among locations. The values are lower than the calculated theoretical diversity ($H'_{\max}$ = 1.94). Therefore, the analysis reveals a significant variation in stand diversity between periods. Pielou's equitability indices by period are also low and deviate greatly from the maximum value (1). They reflect an unequal contribution of the different species to the constitution of the community. However, the species richness is higher at the end of the season for the locations of Bakata and Sapouy.

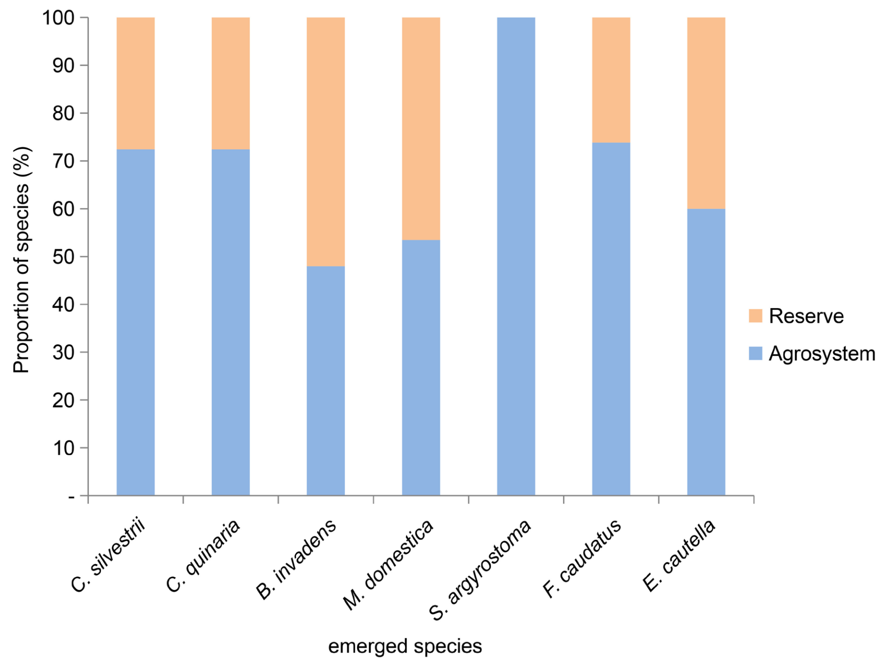

Figure 4. Proportion of species from fruit incubation depending on ecosystems.

Table 10. Biodiversity indices of emergent species per sampling period based on locations.

Periods	Bakata		Cassou		Sapouy	
	EPS	EFS	EPS	EFS	EPS	EFS
Specific richness	2	6	4	4	4	6
Shannon Index (H')	0.03	0.66	0.13	0.45	0.12	0.75
Piélou equitability index (J')	0.04	0.37	0.09	0.33	0.09	0.42

EPS: Peak Season Sampling; EFS: End of Season Sampling.

3.3.6. Index of Insect Diversity from Incubated Fruit per Type of Ecosystem

Table 11 presents the diversity indices per ecosystem. The values of Piélou's equitability indices, determining the regularity of the stand, are below 0.5. As for the Shannon diversity index, it remains low. Therefore, there is not an even distribution of species in terms of abundance between ecosystems within all study locations.

3.3.7. Similarity of Incubated Fruit Species Based on Locations, Ecosystems, and Sampling Periods

Jaccard's coefficient of similarity determined for species from the different locations based on pupal hatching, reveals perfect similarity between the locations of Bakata and Sapouy (C_{jk} = 1). A fairly strong and identical similarity (C_{jk} = 0.71) was also observed between the locations of Bakata and Cassou and Cassou and Sapouy, which have the same number of species (Table 12). Similarly, there was a high degree of similarity in species communities between ecosystems (C_{jk} = 0.86)

Table 11. Index of biological diversity of emergent species per ecosystem type based on locations.

Ecosystem	Bakata		Cassou		Sapouy	
	Agro.	Reser.	Agro.	Reser.	Agro.	Reser.
Specific richness	4	6	5	2	7	5
Shannon Index (*H'*)	0.17	0.68	0.25	0.25	0.60	0.32
Piélou equitability index (*J'*)	0.12	0.38	0.16	0.37	0.31	0.20

Agro: Agrosystem; Reser: Réserve.

Table 12. Species similarity indices between locations, ecosystems, and sampling periods.

comparison between locations, ecosystems and sampling periods	Coefficients of Similarity of Jaccard (C_{sj})
Bakata-Cassou	0.71
Bakata-Sapouy	1.00
Cassou-Sapouy	0.71
Agrosystems-Reserves	0.86
EPS-EFS	0.43

with 6 common species of the 7 identified. This reflects the homogeneity of species communities between locations. However, there was low similarity (C_{jk} = 0.43 < 0.5) of the communities compared between the 2 sampling periods with less than half the species (3 species in common). This reveals significant species heterogeneity between sampling periods.

4. Discussion

This study on the biological diversity of insects associated with shea fruits in the province of Ziro in Burkina Faso, reveals the presence of twenty-five (25) species of which seven (7) are mainly associated with fruit damage. These identified species belong to five (5) orders forming a community of thirteen (13) families. In general, Diptera order composed of 6 families with 15 species recorded, is the most diversified order. The representativeness Diptera in all locations is explained by the availability of host plants, namely shea and many other fruit species. The family Tephritidae belonging to this order was recognized as the main family of insect pests of mango in western Burkina Faso [18] and of shea fruits in agroforestry parks [5]. The families Calliphoridae, Muscidae and Sarcophagidae, is composed of in necrophagous individuals that feed on decaying pig corpses but also on fruit pulp. These families had been identified mostly on pig carcasses in China by [19], in Ivory Coast by [20] and in Burkina Faso by [13]. Four species of the family Muscidae, among which were *M. domestica*, *S. calcitran* listed in this study, had been identified in infested fruits of *Ziziphus mauritiania* Lam., (Rhamnaceae) [21]. *C. furcatus* belonging to the family Chrysomelidae, considered as one of the rare species inventoried in this study, had been identified in previous studies as an insect pest of *Senegalia macrostachya* seed stocks in Senegal ([22]), and Burkina Faso [23].

The similarity of insect families observed between locations could be explained by a very small variation in climatic conditions such as temperature, humidity, and rainfall. This is because the locations concerned by the study are located in the same phytogeographic sector of the North Sudanese type. The greater diversity observed in the distribution of families and species in agrosystems can be explained by agricultural practices that favor the productivity of host plants, thus making food resources available to pests. Indeed, agricultural practices are known to be factors that stimulate flowering and fruit production of woody species [24]. [25] reported that anthropogenic activities have a positive influence on fruit production of woody species. This positive effect is thought to result primarily from the interaction of agricultural practices including land clearing, plowing, organic amendments, and selection of trees to preserve in the field [25]. During land clearing, farmers systematically destroy non-utilitarian woody species, which significantly reduces woody density and, as a result, the spared trees have more access to light, water, and nutrients for reproduction ([26] [27]). In contrast, in protected areas, the strong competition linked to the high density of woody plants and the late bush fires that appear during the period of full flowering negatively impact the fruit production of trees in these areas [28].

In terms of abundance of individuals collected, *C. silvestrii* and *S. carnaria* were the most abundant species and showed homogeneity of distribution in all locations. This suggests that the ecological requirements of these insects are met in all environments studied. Most of the species from infested fruit had already been recorded in trap collections but with relatively low numbers of insects. Among the species identified from infested fruits, *C. silvestrii* was also the most abundant (91.33%). Our results corroborate those of [5] who had also noted the abundance of maggots of this species in infested shea fruits (4 pupae/fruit). The development of Tephritidae species depends on environmental conditions (temperature and humidity), availability of resources (host plants) and their suitability to the needs of the species [29]. Indeed, the abundance of food resources for Tephritidae offers them favorable conditions for their reproduction [30] and thus contributes to an increase in their population. The abundance of shea trees, which are one of the main hosts of *C. silvestrii*, and the adaptation of this species to the environmental conditions of this zone favor the development of the population of this insect, hence its abundance in the locations and ecosystems studied. *C. silvestrii* appears at the beginning of the ripening of the shea fruits and remains until the end of the collections. This species had been identified on infested mangoes and shea fruits collected in orchards in western Burkina Faso [4]. The characteristics of the fruits (fleshy) of these woody species justify their infestation by Tephritidae. According to [31], the predisposition of the fruits of host plants for oviposition and development of fruit fly larvae explains the attraction of flies to these fruits. The abundance of this species on shea may also be due to the scarcity of mangoes in this province. Other authors had highlighted the presence of the genera *Bactrocera* and *Ceratitis* in ripe fruits of *Z. mauritiania* [32].

The species recorded in the agrosystems are also found in the protected areas. Indeed, the strong similarity of Tephritidae communities between the different sites is related to the homogeneity of climatic conditions and vegetation in the study area [33], which favors the development of the same species in the different sites. The presence of species that are not common to all locations, such as *B. dorsalis* and *M. domestica*, could be explained by their inability to take advantage of the available resources. The former had been recorded on mangoes and on shea fruits by [4] at the end of the mango season in Burkina (July and August) and by [5] on infested shea fruits. According to [34], *B. dorsalis* (ex. *invadens*) prefers wetter conditions compared to ceratite species that are more adapted to dry conditions. [4] noted that *B. dorsalis* (ex. *invadens*) was the most economically important species in terms of the amount of damage to mangoes during the year of his study in the area. According to this author, shea is one of the host plants of this species. The low proportion of individuals of the other six (6) species associated with infested fruit damage compared to *C. silvestrii*, could be explained by the climatic conditions and ecological requirements of each species [11]. Then, the difference in physico-chemical characteristics of the fruits may explain the differences in damage and infestation rate caused by the different species [35]. Previous studies by [4] have highlighted the infestation of mangoes and shea fruits by *C. quinaria*, *F. caudatus*, recorded among the emergences is an ovo-pupal parasitoid of Tephritidae [36]. *E. cautella* of the Pyralidae family, listed at the end of the emergences, is a Lepidoptera that infests dried fruits. The uneven distribution of species between periods of infested fruit collection and locations is explained by the scarcity or abundance of food resources at sites [30].

In the study area, *C. silvestrii*, *C. quinaria*, *B. dorsalis*, *M. domestica* and *S. argyrostoma*, identified on infested fruits, represent insect pests of shea tree fruits. But the damage caused to fruits could be attributed to the first three species belonging to the order Tephritidae whose biological activities on fruits have already been demonstrated. The abundance of *C. silvestrii* and its ability to persist on the fruit throughout the collection period indicate that it is the cause of significant shea fruit rots.

5. Conclusion

This inventory of the entomofauna of the shea fruit allowed us to identify twenty-five (25) species distributed in thirteen (13) families grouped in five (05) orders. This study reveals an important biological diversity regarding the number of species that are attached to the shea fruit alone. Diptera order, composed of six families with fifteen species, is the most dominant of this diversity. The strong similarity of the Tephritidae, Calliphoridae and Muscidae communities between the different locations is related to the homogeneity of the climatic conditions and vegetation in the study area. Not all the species identified are pests. Indeed, seven species are mainly associated with fruit damage. However, fruit damage is thought to be caused by the reproductive activity of Tephritidae which perforate young fruits to lay their eggs. *C. silvestrii* belonging to this family is the most abundant species. It is homogeneous in its distribution among ecosystems. *C. silvestrii* is therefore responsible for the pulp rot of shea tree fruits. The results suggest the need to determine the economic importance of the Tephritidae infesting shea fruits as well as the biological parameters of the main pest in order to consider an adequate control.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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