

Pathogenic Agents Fungi Associated with Leaf Necrosis and Desiccation of *Vitellaria paradoxa* in Burkina Faso

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Abstract

In Burkina Faso, *Vitellaria paradoxa* C.F. Gaertn. is one of the multipurpose species that is unfortunately attacked by numerous pests. The objective of this study is to inventory the pathogens involved in the necrosis and leaf desiccation disease of *Vitellaria paradoxa* in order to develop control techniques to counter these pathogens. To achieve this, isolations on PDA culture medium were carried out from samples of infested leaves collected in the Guiriko and Bankui. Results have identified nine species of pathogenic fungi for both necrosis and leaf wilting. These are *Pestalotiopsis guepini*, *Pestalotiopsis heterocornis*, *Phoma sorghina*, *Phoma exigua*, *Fusarium culmorum*, *Fusarium moniliforme*, *Colletotrichum gloeosporioides*, *Pyricularia grisea*, and *Lasiodiplodia theobromae*. Among these pathogens, the genera *Pestalotiopsis*, *Phoma*, and *Fusarium* were strongly associated with necrosis, with incidence frequencies ranging from 11% to 50%. In addition, for leaf blight, *Pestalotiopsis* and *Phoma* were the most frequently detected genera (50%). These pathogens cause double symptoms that weaken *Vitellaria paradoxa*. With regard to the high frequency of these pathogens and the consequences for the survival of *Vitellaria paradoxa*, it would be necessary to develop less costly and effective techniques to protect the species.

Keywords

Burkina Faso, Pathogenic Fungi, Protection, *Vitellaria paradoxa*

1. Introduction

Vitellaria paradoxa Gaertn. C.F. is a keystone tree species of the Sudanian savannas of West Africa, where it constitutes one of the most socio-economically and

ecologically important resources [1]. In Burkina Faso, *Vitellaria paradoxa* is a strategic agroforestry crop that contributes substantially to rural livelihoods and national exports through the trade of kernels and derived products, particularly *Vitellaria paradoxa* butter. Beyond its economic value, *Vitellaria paradoxa* parklands provide critical ecosystem services, including soil fertility maintenance, erosion control, and the regulation of local microclimates, thereby supporting the long-term sustainability of farming systems [2]. *Vitellaria paradoxa* fruits and butter are widely consumed as staple foods and cooking oils, while *Vitellaria paradoxa* derivatives are increasingly sought after by the cosmetic and pharmaceutical industries due to their bioactive compounds and moisturizing properties.

Despite its importance, the productivity and regeneration of *V. paradoxa* are increasingly constrained by both abiotic stresses (e.g., drought, soil degradation, and climate variability) and biotic pressures, notably fungal fungi associated with leaf spot diseases [3]. Leaf spot symptoms, characterized by necrotic lesions that expand and coalesce, can lead to premature leaf fall, thereby reducing photosynthetic capacity and fruiting potential. Recent surveys in Burkina Faso have reported the widespread occurrence of leaf spot infections in *Vitellaria paradoxa* parklands, but most investigations remain geographically limited and fail to account for highly affected areas [4] [5]. Such gaps in coverage hinder the establishment of effective monitoring and management strategies.

Given the increasing severity of fungal infections across unsurveyed parklands, there is an urgent need to broaden the knowledge of pathogenic agents associated with *Vitellaria paradoxa* decline. Expanding pathogen inventories across different agroecological zones will provide essential baseline data for the development of integrated disease management strategies. This study therefore aims to identify and characterize the fungal species associated with leaf spot disease of *V. paradoxa* in diverse agroecological sites of the Guiriko and Bankui region of Burkina Faso, thereby contributing to the protection and sustainable management of this emblematic tree species.

2. Materials and Methods

2.1. Study Site

The study sites (Figure 1) are located in the Guiriko region, specifically in the municipality of Guiguima, Dande, and include Koundougou and Samendeni. Located in western Burkina Faso, the Guiriko region is limited to the north by the Bankui region, to the south by the Tannounyan region, to the east by the Djôrô region, and to the west by the Republic of Mali. The region is important and includes mineral, plant, and wildlife resources. With a total area of 25,479 km², representing 9.4% of the national territory, the region's population is estimated at 2,572,600 inhabitants and a density of 102 inhabitants/km². Thus, these sites were selected due to the documented presence of leaf spot disease affecting *V. paradoxa*. Furthermore, as part of the major *V. paradoxa*-producing areas of Burkina Faso, they provided suitable locations for the collection of diseased *V. paradoxa* leaves.

Also, Selle, located in the Bankui region, was chosen as the study site because of the significant presence of leaf spot disease on *V. paradoxa* s. Located in the west of the country, this region occupies a strategic position for agriculture and livestock farming, with significant fishing, forestry, and craft potential. With an area of 34,333 km² and an estimated population of 2.12 million inhabitants, the Bankui region is characterized by a relatively flat landscape, savannah areas and open forests. Woody species such as *Vitellaria paradoxa*, *Parkia biglobosa*, *Daniellia oliveri*, *Terminalia* spp., etc. are found there [6].

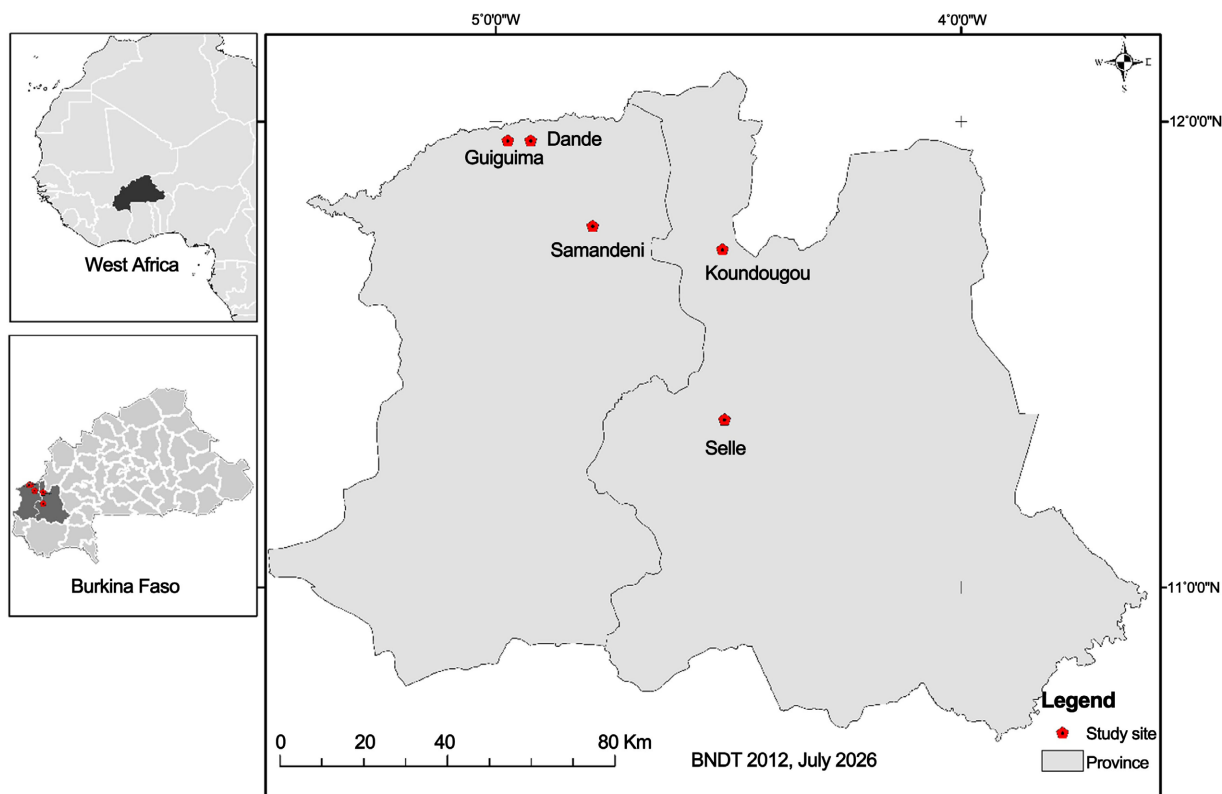


Figure 1. Study sites.

2.2. Biological Material

The biological material consists of diseased *Vitellaria paradoxa* leaves exhibiting necrosis and desiccation. These symptomatic leaves were collected between October and December 2024 from the parklands of the study sites listed in [Table 1](#). During this period, the infested leaves clearly displayed characteristic symptoms, notably dark brown and pale brown fungal spots ([Figure 2](#)).

For the collection of biological material, sampling consisted of identifying a few representative stands, surveying the entire area, and randomly collecting ten (10) diseased leaf samples per *Vitellaria paradoxa*, with ten (10) trees sampled per site. Direct field observations revealed that leaves were either simultaneously affected by necrosis and desiccation, or exhibited necrosis or desiccation alone. In this study, however, sampling was conducted using distinct leaf specimens. The sam-

ples obtained were pooled by site, placed in plastic bags, and labeled. They were subsequently dried and stored in kraft paper in the laboratory. These samples were then used for laboratory analyses, with forty (40) Petri dishes of 9 cm in diameter prepared for each site, at a rate of twenty (20) Petri dishes per symptom.

Table 1. Features of sites and observed symptoms of collection of *Vitellaria paradoxa* leaf samples.

Sample ID	X (UTM)	Y (UTM)	Date of sample collection	Collection sites	Symptom
E1	335,398	1,256,184	23/10/2024	Selle	Dark brown
E2	304,771	1,302,296	23/10/2024	Samandeni	Dark brown
E3	290,377	1,322,676	20/10/2024	Dande	Dark brown
E4	285,021	1,322,713	20/12/2024	Guiguima	Pale brown
E5	335,117	1,296,586	20/12/2024	Koundougou	Dark brown

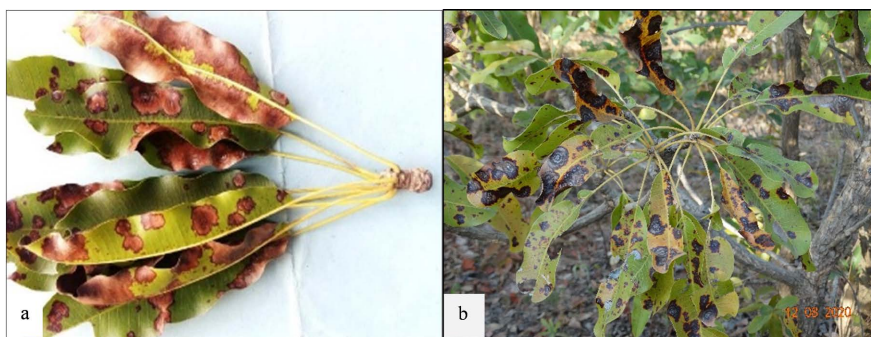


Figure 2. Manifestation of wilt (a) and necrosis (b) on shea leaves.

2.3. Methods

2.3.1. Culture Medium, Isolation and Purification of Pathogens

Forty-two grams (42 g) of PDA powder were dissolved in one liter of distilled water and homogenized using a magnetic stirrer. The resulting solution was sterilized in an autoclave at 120°C for 30 minutes. After cooling to approximately 60°C under a laminar flow hood, the medium was aseptically dispensed into Petri dishes at a volume of 25 mL per plate.

Pathogen isolation was performed from *Vitellaria paradoxa* leaves exhibiting typical symptoms of mycoses. Symptomatic tissues were excised into fragments of approximately 1 - 2 cm in length and surface-sterilized by immersion in ethanol for 30 seconds, followed by sodium hypochlorite for 1 minute. The fragments were then rinsed three times with sterile distilled water, blotted dry between two sterile sheets of filter paper, and aseptically transferred onto PDA medium in Petri dishes (5 - 6 fragments per dish). Cultures were incubated at 22°C under alternating cycles of 12 h near-UV light and 12 h darkness for 4 days, allowing colony development around the tissue fragments (**Figure 3(a)**). Subsequently, colonies were purified by transferring morphologically distinct isolates to fresh culture me-

dium using a sterile needle. At each site, thirty (30) newly purified colonies were incubated under the previously established conditions for approximately fourteen (14) days to promote fungal sporulation (**Figure 3(b)**). From 14-day-old pure colonies, slide preparations were made under aseptic conditions in a vertical laminar flow hood. Fungal identification was performed by comparing the conidia observed under the microscope with descriptions provided in standard fungal identification keys [7].

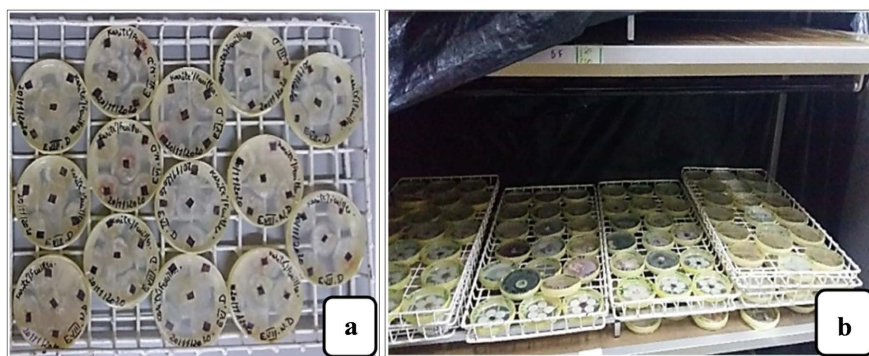


Figure 3. Isolation of parasitic fungi from shea. (a) Isolation of infected organs on PDA medium; (b) purification and incubation of the isolates at 22°C under near UV light.

2.3.2. Characterization of Pathogenic Agents

From 14-day-old pure colonies, slide preparations were made under aseptic conditions in a vertical laminar flow hood. Fungal identification was performed by comparing the conidia observed under the microscope with descriptions provided in standard fungal identification keys [7].

2.3.3. Data Processing and Analysis

Species characterization was performed using identification keys recommended by [8]-[12]. Data entry, cleaning, and organization were initially conducted using Microsoft Excel (version 2018), while the calculation of pathogen frequencies and all statistical analyses were performed using the R statistical software environment.

3. Result

3.1. Inventory of Pathogens Associated with Leaf Necroses

The field observations revealed that leaf necrosis in *Vitellaria paradoxa* initially appears as small, isolated lesions scattered across the leaf lamina. These lesions are generally circular to irregular in shape and exhibit a dark brown to blackish-brown coloration (**Figure 4**). As the disease progresses, the lesions enlarge and coalesce, resulting in extensive necrotic areas that progressively cover a substantial portion of the leaf surface. This tissue deterioration leads to the destruction of affected cells, reducing the photosynthetically active area of the leaf. In advanced stages of infection, severely damaged leaves become distorted, curl inward, and eventually undergo premature abscission. The fungal isolates recovered from necrotic *Vitellaria*

paradoxa leaves exhibited distinct morphological characteristics that facilitated their identification at the genus and species levels. Morphological examination and Mycological analyses conducted on symptomatic leaves exhibiting necrotic lesions led to the isolation and identification of nine pathogenic fungal species belonging to six genera (**Table 2**) associated with the disease in the Guiriko and Bankui region of Burkina Faso. These fungal taxa identified are *Pestalotiopsis guepinii*, *Pestalotiopsis heterocornis*, *Phoma sorghina*, *Phoma exigua*, *Fusarium culmorum*, *Fusarium moniliforme*, *Colletotrichum gloeosporioides*, *Pyricularia grisea*, and *Lasiodiplodia theobromae*.

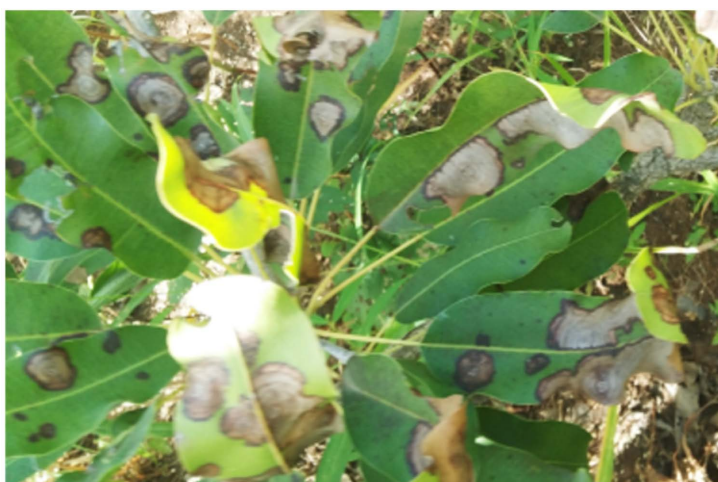


Figure 4. Dark brown necroses observed on the leaves of the shea tree.

Table 2. List of pathogenic agents inventoried on shea leaf necroses.

No.	Species	Class	Order	Family
1	<i>Pestalotiopsis guepinii</i> (Desm.) Steyaert	Sordariomycetes	Amphisphaeriales	Sporocadaceae
2	<i>Pestalotiopsis heterocornis</i> Speg.	Sordariomycetes	Amphisphaeriales	Sporocadaceae
3	<i>Phoma sorghina</i> (Sacc.) Boerema, Dorenb. & Kesteren	Dothideomycetes	Pleosporales	Didymellaceae
4	<i>Phoma exigua</i> Desm.	Dothideomycetes	Pleosporales	Didymellaceae
5	<i>Fusarium culmorum</i> (W.G. Smith) Sacc.	Sordariomycetes	Hypocreales	Nectriaceae
6	<i>Fusarium moniliforme</i> J. Sheld.	Sordariomycetes	Hypocreales	Nectriaceae
7	<i>Colletotrichum gloeosporioides</i> (Penz.) Penz. & Sacc.	Sordariomycetes	Glomerellales	Glomerellaceae
8	<i>Pyricularia grisea</i> (Cooke) Sacc.	Sordariomycetes	Magnaporthales	Pyriculariaceae
9	<i>Lasiodiplodia theobromae</i> (Pat.) Griffon & Maubl.	Dothideomycetes	Botryosphaeriales	Botryosphaeriaceae

Overall, the morphological observations summarized in **Table 3** corroborated the taxonomic identification of the isolates and highlighted the diversity of fungal pathogens associated with leaf necrosis of *Vitellaria paradoxa* in the Guiriko and Bankui region of Burkina Faso.

Table 3. Main morphological characteristics of fungal pathogens associated with leaf necrosis.

No.	Species	Main morphological characteristics	Symptoms reported on plants
1	<i>Pestalotiopsis guepinii</i>	Fusiform conidia with 5 cells, multiple apical appendages	Main symptoms reported on host plants
2	<i>Pestalotiopsis heterocornis</i>	Pigmented conidia, well-developed apical and basal appendages	Leaf spots, necrosis, blight and premature leaf senescence
3	<i>Phoma sorghina</i>	Globose black pycnidia, hyaline unicellular conidia	Leaf necrosis and tissue desiccation
4	<i>Phoma exigua</i>	Ostiolate pycnidia, hyaline ovoid conidia	Leaf spots, seed discoloration, tissue necrosis
5	<i>Fusarium culmorum</i>	Robust falciform macroconidia with multiple septa	Necrotic lesions, stem and leaf blight
6	<i>Fusarium moniliforme</i>	Abundant microconidia in chains, thin macroconidia	Leaf blight, crown rot, vascular discoloration
7	<i>Colletotrichum gloeosporioides</i>	Acervuli with black setae, hyaline cylindrical conidia	Leaf chlorosis, necrosis, vascular infections
8	<i>Pyricularia grisea</i>	Pyriiform conidia with 2 - 3 septa	Anthrachnose, leaf necrosis, shoot dieback
9	<i>Lasiodiplodia theobromae</i>	Dark brown conidia at maturity with longitudinal striations	Leaf blast, necrotic lesions and desiccation

3.2. Degree of Pathogen Infestation

Figure 3 presents a heatmap coupled with a hierarchical clustering analysis illustrating the distribution and relative abundance of pathogenic fungi isolated from necrotic *Vitellaria paradoxa* leaves in the five locations studied. The colour gradient, from light yellow to dark red, reflects a low and high frequency of occurrence of fungal species, respectively. The species identified mainly belong to four families known for their involvement in foliar diseases in tropical environments: Sporocadaceae, Didymellaceae, Nectriaceae and Botryosphaeriaceae. The analysis highlights a high spatial variability of the fungal community associated with the necrosis and drying of *Vitellaria paradoxa* leaves, revealing a non-uniform distribution of pathogens between the different localities.

The dendrogram of species distinguishes two major groups (**Figure 5**). The first includes the least common fungi, including *Fusarium culmorum*, *Colletotrichum gloeosporioides*, *Pyricularia grisea* and *Lasiodiplodia theobromae*. These species have a restricted distribution and are mainly observed in certain locations. *Colletotrichum gloeosporioides* is particularly abundant at Koundougou, while *Pyricularia grisea* and *Lasiodiplodia theobromae* are almost exclusively found there. This limited distribution could reflect ecological specialization, dependence on particular microclimatic conditions, or a secondary role within the disease complex studied.

The second group includes the dominant species of the fungal complex, namely *Pestalotiopsis guepinii*, *Pestalotiopsis heterocornis*, *Phoma sorghina* and *Phoma exigua*. These species are the most frequent and abundant in several study sites. The observed proximity between *Pestalotiopsis guepinii* and *Phoma sorghina* suggests a regular co-occurrence, probably related to similar ecological requirements

or to concomitant colonization of necrotic leaf tissues. Similarly, the association between *Pestalotiopsis heterocornis* and *Phoma exigua* reflects comparable distribution patterns.

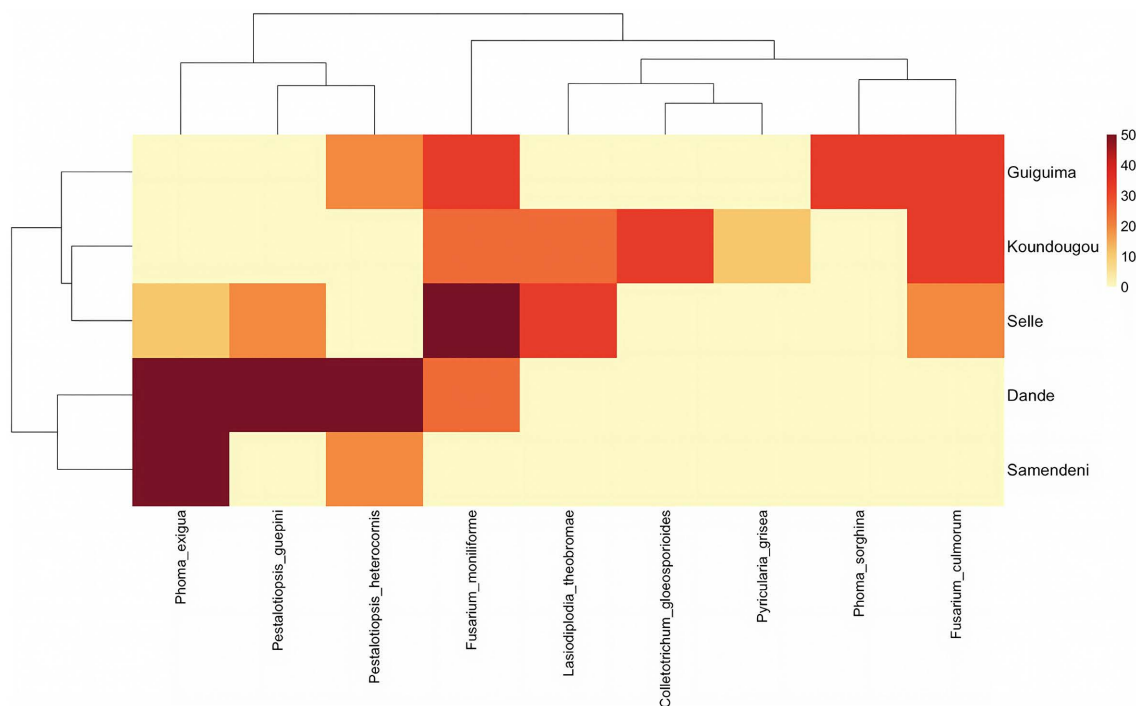


Figure 5. Heatmap and hierarchical grouping analysis of pathogenic fungi associated with shea leaf necrosis in five localities in western Burkina Faso.

The observed frequencies confirm the predominance of the genus *Pestalotiopsis* and *Phoma* in the development of *Vitellaria paradoxa* leaf symptoms. *Phoma sorghina* reaches a frequency of 50% in Dande and Guiguima, compared to 20% in Selle. For its part, *Pestalotiopsis heterocornis* has frequencies of 50% in Dande and Samandéni and about 20% in Selle. In the latter locality, several species, including *Pestalotiopsis guepinii*, *Phoma sorghina*, *Phoma exigua* and *Fusarium culmorum*, have similar frequencies (about 20%), reflecting a more diverse pathogenic composition. The dendrogram of the localities highlights three distinct geographical areas. The first is made up of Dande, which is distinguished by a strong dominance of *Pestalotiopsis guepinii*, associated with high abundances of *Phoma sorghina* and *Pestalotiopsis heterocornis*. The second corresponds to Selle, whose pathogenic profile is close to that of Dande but with lower frequencies, which explains their similarity in the grouping analysis.

The third group includes Guiguima, Koundougou and Samandenu. Guiguima is characterized by the importance of *Fusarium moniliforme* and *Pestalotiopsis guepinii*, while Koundougou has the highest species diversity with the simultaneous presence of *Fusarium moniliforme*, *Fusarium culmorum*, *Colletotrichum gloeosporioides*, *Pyricularia grisea*, *Lasioidiplodia theobromae*, *Pestalotiopsis guepinii* and *Phoma exigua*. Samandeni is distinguished by a high abundance of *Pestalo-*

tiopsis heterocornis and *Phoma exigua*, accompanied by a moderate presence of *Fusarium moniliforme*. In Koundougou, nearly all pathogens were associated with necrosis and desiccation.

Overall, the results show that species of the genera *Pestalotiopsis* and *Phoma* constitute the dominant nucleus of the pathogenic complex associated with *Vitellaria paradoxa* necrosis and leaf desiccation in western Burkina Faso. Conversely, the genera *Fusarium*, *Colletotrichum*, *Pyricularia* and *Lasiodiplodia* appear as secondary agents or fungi associated with whose importance varies according to local ecological conditions.

3.3. Pathogenic Agents Associated with Leaf Droughts of *Vitellaria paradoxa*

The results indicate that leaf desiccation is characterized by the appearance of pale-brown necrotic lesions, primarily initiating at the margins of the leaf blades. These lesions are irregular in shape and often expand progressively toward the internal leaf tissues (Figure 6). Mycological analysis of the affected leaf samples revealed the presence of nine (9) distinct fungal pathogens, suggesting a complex fungal community associated with the observed leaf symptoms and potentially contributing to the progression of the necrotic process. The results (Figure 7) reveal a clear spatial structuring and differential abundance of pathogenic fungi associated with leaf desiccation across the five study sites. Overall, infection frequencies varied considerably, with a small number of taxa showing broad distribution and high prevalence, while others remained localized or sporadic.

Among the characterized genera, *Pestalotiopsis* and *Phoma* were identified as the predominant taxa, being both widespread and abundant, with infestation rates reaching up to 50% across the surveyed sites. This strong prevalence across sites suggests a central role in the observed foliar necrosis. It is closely associated with the dominant group formed by *P. guepinii* and *P. heterocornis*, which were also widely distributed and particularly abundant in Dande, Samandéni, and Koundougou, indicating similar ecological requirements and frequent co-occurrence on symptomatic leaves. A second group of pathogens displayed intermediate frequencies and more restricted distributions, notably *P. sorghina* and *F. culmorum*. The former was confined to Guiguima, whereas the latter occurred mainly in Koundougou and Guiguima, suggesting a stronger dependence on local environmental conditions.

In contrast, a third group composed of less frequent species, including *C. gloeosporioides*, *P. grisea*, *P. exigua*, and *L. theobromae*, was largely restricted to Dande and Selle. Their limited occurrence and lower abundance suggest a secondary or opportunistic role in the disease complex. These patterns are consistent with the hierarchical clustering results, which separated the study area into three main assemblages: Dande and Samandéni formed a cluster dominated by *Pestalotiopsis* spp.; Guiguima exhibited an intermediate profile characterized by a mixture of *Phoma* and *Fusarium* species; while Koundougou grouped with Selle, showing higher fungal diversity and the presence of rarer taxa. Overall, the inte-

grated analysis highlights the predominance of *Pestalotiopsis* species and *Phoma* in the *Vitellaria paradoxa* leaf necrosis complex, whereas *Colletotrichum*, *Pyricularia*, and *Lasiodiplodia* appear to act mainly as secondary or opportunistic pathogens influenced by local environmental conditions.



Figure 6. Illustration of pale brown necrosis or leaf desiccation of shea tree leaf.

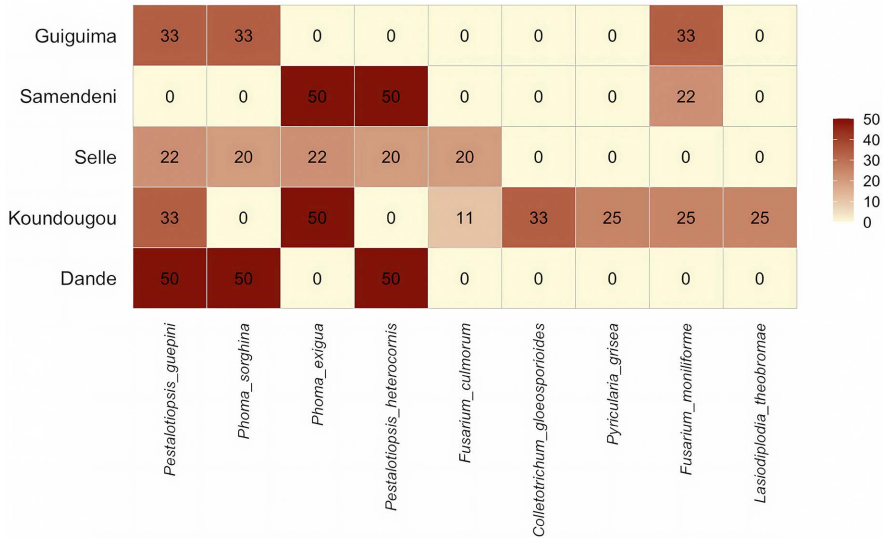


Figure 7. Thermal map of pathogenic fungi associated with *Vitellaria paradoxa* leaf desiccation.

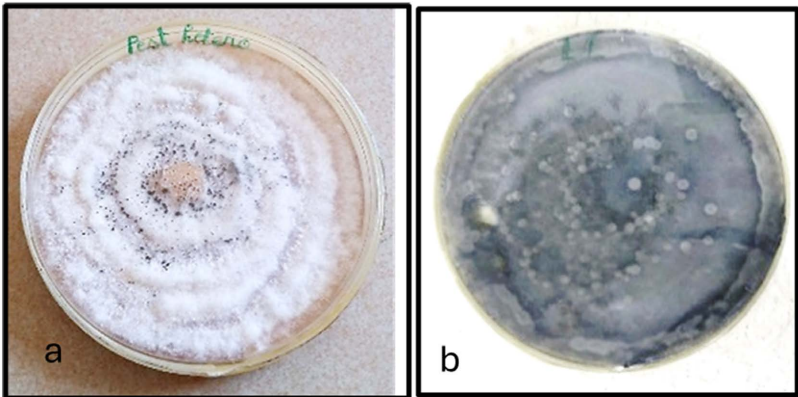


Figure 8. Mycelia of *P. heterocornis* (a) and *L. theobromae* (b).

Figure 8 shows representative examples of mycelia of *P. heterocornis* (a) and *L. theobromae* (b). **Figure 9** presents representative examples of conidia of *P. heterocornis* (a) and *L. theobromae* (b) observed under the electron microscope.

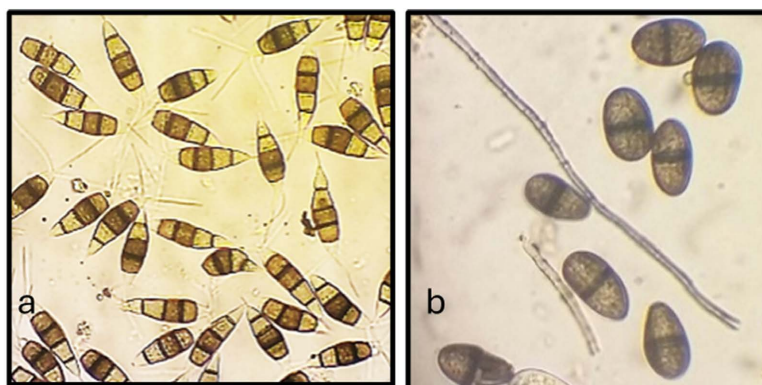


Figure 9. Conidia of *P. heterocornis* (a) and *L. theobromae* (b) observed under electron microscopy.

4. Discussion

The inventory of pathogens conducted through the isolation of pathogenic agents has allowed for the identification of nine (09) species of fungi responsible for the necroses (leaf spots) observed on the leaves of *V. paradoxa*. These same species have been inventoried for leaf desiccation. This means that these species create a double symptom on *V. paradoxa* leaves (drying and necrosis), leading to a reduction in photosynthesis, a disruption of transpiration, and a change in growth, resulting in the weakening of the plant. In either case, the ones most frequently encountered in all analyzed samples were: *P. guepini*, *P. sorghina*, *P. exigua*, *P. heterocornis*, *F. moniliforme*, and *L. theobromae*. The dominance of these species could be explained by the fact that their conidia production is earlier and more abundant. This allows the pathogen to spread very quickly, hence the significant presence of these species in most sites. The other species, such as *C. gloeosporioides*, *P. grisea*, etc., which are infrequent, can be explained by the fact that they take longer (at least 14 days) to produce their conidia. Similar results were obtained by [13], who identified 35 isolates of *Pestalotiopsis* spp., 7 isolates of *Lasiodiplodia* spp., and other saprophytic and parasitic fungi from 90 samples of *V. paradoxa* (brown necrosis) collected in Bole, Ghana. Moreover, [14]-[16] also isolated *Pestalotiopsis* sp., *L. theobromae*, and *C. gloeosporioides* as the main pathogenic agents of *V. paradoxa* butter in Nigeria and Benin, respectively. Similar results were found by [4], who had inventoried some of these species on *V. paradoxa* leaf spots in the central, central-western, and high basin regions in Burkina Faso. These same authors had shown that these pathogens were also found in other species such as *Daniellia oliveri* and also highlighted their fungal associations. Also, [17]-[21] have recorded some of these species concerning the wilting of the mango leaves with a high rate of disease infestation. Thus, the association of pathogenic fungi could be explained by the high frequency of these species. Our

results corroborate those of [22], who established a link between the high frequency of these pathogens and their associated fungi. The same applies to [23] and [19], who indicated the fungi associated with species, highlighting their concurrent presence. They also pointed out that this could be explained by contamination from dispersal agents such as the wind and birds, which allow for the rapid contamination of plant species. Indeed, as the sampling was carried out in agrosystems, the crop pests have spread and infested the *V. paradoxa* population that the producers maintain in association with the crops, thus causing symptoms on the leaves. Results obtained by [5] showed through the pathogenicity test that *P. guepini* and *P. sorghina* were the pathogenic agents responsible for dark brown necroses, and that *P. heterocornis* and *L. theobromae* were revealed to be pathogenic but induced black necroses. This confirms our results on the symptoms caused by pathogenic fungi. These pathogens could have an impact on *V. paradoxa* fruit production, contribute to its aging, and lead to the extinction of the species. Arbuscular mycorrhizal fungi have been found to be effective against these pathogens and have also enhanced the growth of *V. paradoxa* seedlings for better regeneration of the parks, according to [5]. However, the availability of these CMA could pose an obstacle to their contribution to the protection of the species. It is then necessary to develop more accessible and efficient methods to minimize the consequences of these pathogens on *V. paradoxa*. This should be done by combating the most virulent species, that is to say those that have shown a significant frequency, in order to contribute to better protection of *V. paradoxa*. Nevertheless, we suggest for disease management the use of resistant varieties accompanied by good field management practices for the regeneration of the species. Also, mechanical control could help reduce the damage caused by these pathogenic fungi, as [24] did on Loranthaceae in *V. paradoxa*.

5. Conclusion

Characterization of the samples allowed for the identification of 9 species of fungi for both spots (leaf necroses) and leaf wilting in Guiriko and Bankui municipalities. Among these incriminated species, *P. guepini*, *P. heterocornis*, *P. sorghina*, *L. theobromae*, and *F. moniliforme* were the most abundant and were nearly present at all collection sites. This indicates that most *Vitellaria paradoxa* parks in Burkina Faso are suffering from attacks related to species of pathogenic fungi. From these results, it also emerged that these pathogenic fungi cause both drying and spots on the leaves of the *V. paradoxa*, thus leading to harmful consequences for the health of the *Vitellaria paradoxa*. Considering the significant impact of these pathogens on the survival of the species, it becomes imperative to develop cost-effective and more efficient management strategies to ensure the sustainable protection of *V. paradoxa*.

Author Contributions

Haro Hadou and Ali Bene revised the manuscript; Kadidia Semde and Somda

Konoyaon designed the experimental setup, data collection, and the preparation and writing of the manuscript.

Conflicts of Interest

The authors declare that there are no competing interests for this article.

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