sInternational Journal of Agriculture and Biosciences 2024 13(4): 639-648.
https://doi.org/10.47278/journal.ijab/2024.171

RESEARCH ARTICLE
eISSN: 2306-3599; pISSN: 2305-6622

Identification of the Pathogens Responsible for the Primary Fungal Infections Linked to Soy Seeds in Burkina Faso

Teendbwaoga Merlène Prisca Ouedraogo [1,2*], Abalo Itolou Kassankogno [2], Elise Sanon [1], Aïdatou Kafando[1,2], Seydou Barro[3], Bonwendson Clément Nikiema[2], Hawa Sohoro[2] and Issa Wonni [2]

[1]Université Joseph-KI ZERBO, Ecole doctorale Sciences et Technologie, Laboratoire Biosciences, Equipe Phytopathologie et Mycologie tropicale, 03BP : 7021 Ouagadougou 03, Burkina Faso
[2]Centre National de Recherche Scientifique et Technologique (CNRST), Institut de l'Environnement et de Recherches Agricoles (INERA), 01 BP : 910 Bobo Dioulasso 01, Burkina Faso
[3]Ecole Nationale de Formation Agricole de Matourkou (ENEFA-Matourkou), Ministère de l'Agriculture, BP :130 Bobo Dioulasso, Burkina Faso
*Corresponding author: oued_merlene@yahoo.fr

ABSTRACT

The fungi associated with soybean seeds can decrease seed quality decrease seed quality andalso serve as the primary inoculum for many soybean diseases. The identification of these fungi is the first step towards the development of an effective control method that will have a significant impact on crop yields. This study was initiated at the Institute for the Environment and Agricultural Research of Farako-Bâ in 2021 with this objective in mind. A total of 17 samples of two varieties from four regions of Burkina Faso were identified using the paper blotting and Potato Dextrose Agar (PDA) culture methods. The observations were made using a binocular microscope and an optical microscope. The morphological characteristics of fungi revealed that the genera *Aspergillus* (27.24%; 50.24%), *Fusarium* (10.88%; 20.47%), *Phoma* (3.72%; 8.82%), *Cladosporium* (3.48%; 4.77%), *Macrophomina* (2.3%; 4.66%), and *Curvularia* (2.05%; 6.12%) were the most frequent and abundant. The results of the pathogenic power analysis revealed that the isolates from Kari, Bobo Dioulasso 2 and 3, including *Curvularia* (CuE4, CuE1, CuE10, CuE3, CuE5, CuE8, CuE9, CuE13), *Macrophomina* (MpE7, MpE5, MpE10, MpE1, MpE4, MpE9, MpE12), and *Fusarium* (FuE7, FuE10, FuE1, FuE4), exhibited high levels of aggressiveness. Various isolates of *Fusarium* and *Phoma* showed moderate aggressiveness and had different effects on seeds, depending on the varieties and locations. Two *Phoma* isolates (PhE5 and PhE7) were non-aggressive. This study highlights a wide range of fungal pathogens associated with soybean in Burkina Faso, offering potential for the development of effective control strategies.

Keywords: *Glycine max* L., Identification, Pathogenic fungi, Seeds, Burkina Faso

Article History
Article # 24-732
Received: 01-Aug-24
Revised: 23-Aug-24
Accepted: 24-Sep-24
Online First: 17-Oct-24

INTRODUCTION

Soybeans, scientifically known as *Glycine max* L., are the world's leading oilseed and protein crop, accounting for 68% of global oilseed production and 28% of total oil production (Chang et al., 2020). Its oilcake accounts for around two-thirds of the world's traded oilcake (Dabat et al., 2001). Soybeans also have the ability to fix atmospheric nitrogen, which improves soil fertility and benefits other crops (CAE, 2001). The USDA-FAS (2024) reported that global soybean production amounted to 395.122 million tons in 2023. Brazil, the United States, and Argentina are the primary producers, together responsible for 80% of global production (USDA-FAS, 2024). In contrast, Africa's contribution is less than 2% (OECD/FAO, 2022).

In Burkina Faso, soybean cultivation was initially established in the 1970s. However, it has been characterized by intermittent and limited growth, primarily confined to research stations (Picasso et al., 1984).

Cite this Article as: Ouedraogo TMP, Kassankogno AI, Sanon E, Kafando A, Barro S, Nikiema BC, Sohoro H and Wonni I, 2024. Identification of the pathogens responsible for the primary fungal infections linked to soy seeds in Burkina Faso. International Journal of Agriculture and Biosciences 13(4): 639-648. https://doi.org/10.47278/journal.ijab/2024.171

A Publication of Unique Scientific Publishers

Nevertheless, the growing significance of soybean has sparked a fresh impetus at the national level, bolstered by governmental efforts targeted at achieving food self-reliance (SIATOL, 2016). Agricultural policies aimed at providing incentives have been put into effect to assist industry participants, resulting in soybeans becoming the fourth most cultivated crops, following cotton, peanuts, and sesame (DSSE/DGESS/MARAH, 2024). The consumption of this culture, which is currently strategic, has risen from 44% in 2012 to 52% in 2021 (MARAH/DGESS/EPA, 2021). However, the production of crop in Burkina Faso is hindered by illnesses such as mycoses, bacterioses, and reducing viruses, which result in a decrease in yield ranging from 10 to 30% (Akem, 1992). Gilbert (2011) states that mycoses are the predominant illness, comprising 85% of cases. Nevertheless, in order to enhance soybean production, it is crucial to identify the pathogenic fungi that cause different diseases. The aim of this study is to identify the fungal species present in seeds in order to improve our knowledge of pathogens and propose more effective and sustainable control strategies.

MATERIALS & METHODS

Study Site

The samples were collected in 5 localities in Burkina Faso, namely the Houet, Kénédougou, Cascades, Tuy, and Kadiogo provinces (Fig. 1). The research was conducted under controlled and semi-controlled conditions at the research station of the Institute of Environment and Agricultural Research (INERA) at Farako-Bâ. This station is located 10 km southwest of Bobo-Dioulasso, on the Bobo-Banfora axis, at 11°60'00'' North and 04°20'00'' West, with an altitude of 405 meters (Fig. 1).

Equipment

Plant Materials

The plant material consists primarily of soybean seeds from the G196 and G197 varieties, as well as four accessions from the Tuy, Comoé, Houet, Kénédougou, and Kadiogo provinces (Table 1).

Table 1: Distribution of soybean seed samples by province.

Codes	Provinces	Locations	Temperature (°C)		Rainfall (mm)		Seeds
			Min	Max	Water height	Number of rainy days	
ET1	Tuy	Kari	22	34	1022.9	52	G197
EB2	Comoé	Banfora 1	21.2	33.1	1400.2	73	G196
EB3	Comoé	Banfora 2	21.2	33.1	1400.2	73	Rise
EB4	Houet	Bobo Dioulasso 1	25.6	30.7	1233.9	100	G196
EO5	Kadiogo	Ouagadougou 1	25.2	33.2	939.1	71	Rise
EB6	Comoé	Banfora 3	21.2	33.1	1400.2	73	Rise
EB7	Houet	Bobo Dioulasso 2	25.6	30.7	1233.9	100	G197
EB8	Comoé	Banfora 4	21.2	33.1	1400.2	73	Rise
EB9	Houet	Niénéta	25.6	30.7	1233.9	100	Rise
EB10	Houet	Bobo Dioulasso 3	25.6	30.7	1233.9	100	G196
EB11	Comoé	Niangoloko	21.2	33.1	1400.2	73	G197
EO12	Kadiogo	Ouagadougou 2	25.6	33.2	939.1	71	G196
E13	Houet	Farako-Bâ	25.6	30.7	1233.9	100	G197
E14	Kénédougou	Orodara	21.2	33.1	1410.1	71	G196
E15	Comoé	Kiribina	21.2	33.1	1667.2	71	G196
E16	Houet	Bobo Dioulasso 4	25.6	30.7	1233.9	100	G196
E17	Houet	Kongolékan	22	34	1022.9	52	G196

Source: (ANAM-BF, 2022 ; INSD, 2023)

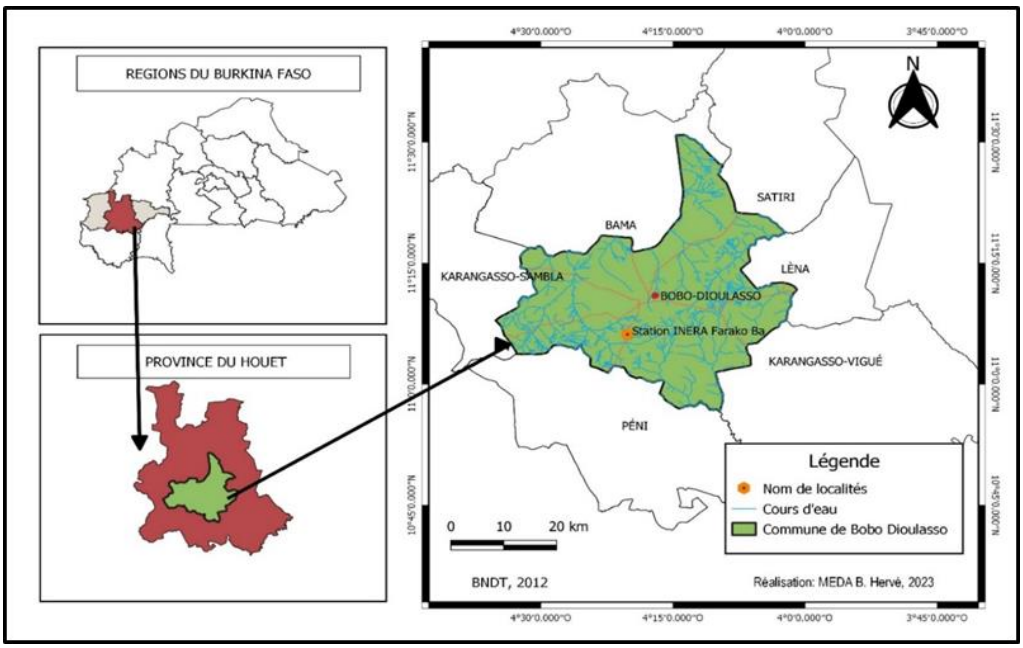


Fig. 1: Map of the study area (Meda, 2023).

Methods

Analysis of Soybean Seeds

Seventeen samples, each containing 400 seeds picked using the "hand halving method," were divided into four lots of 100 seeds each (with 4 repetitions). These lots were then incubated on blotting paper following the procedure specified by the International Seed Testing Association (ISTA) as described by Mathur et Kongsdal (2003). Previously, the seeds underwent a disinfection process involving immersion in a 1% sodium hypochlorite (NaOCl) solution for one minute, followed by exposure to 70°C alcohol for 30s. Subsequently, they were rinsed twice with distilled water. In conclusion, a total of 25 seeds were carefully inserted within each Petri dish, resulting in four Petri dishes per trial and per sample. The boxes were placed in a 25°C chamber and incubated for a period of 4 to 7 days. During this time, the boxes were exposed to 12 hours of near ultraviolet light, followed by 12 hours of darkness.

Identification of Soybean Seed Fungi

The process was conducted in two phases: first using magnifying glass, and then utilizing the optical microscope. The incubated seeds were individually inspected using an Optika binocular magnifying glass from the 4th to the 7th day after incubation. Using the "Common Laboratory Seed Health Testing Methods for Detecting Fungi" key by Mathur et Kongsdal (2003), some fungi were identified in the first stage. The name of the fungus observed on each seed was noted in pencil next to it. The number of occurrences of each fungal species per box, per repetition and per sample was recorded.

Subsequently, each individual fungus was separated and placed on a culture medium known as Potato Dextrose Agar (PDA). The Euromex Microscopes-Holland DC.5000F CMEX 5 camera light microscope was used to study pure isolates. The morphological characteristics of the hyphae and conidia were meticulously examined and captured in photographs. The shape and color of the spores, the presence or absence of partitions, and radial growth on the PDA medium were observed. This data enabled the strengthening of the identifications made from the magnifying glass and correct of them using Mathur et Kongsdal (2003).

Pathogenic Power of Strains

The Koch postulate was employed to assess the pathogenicity of the detected fungal species on soya seeds of the G197 and G196 varieties, which were disinfected using 1% NaOCl and 70% alcohol. In order to achieve this objective, we employed the Naeem et al. (2019) technique for seed soaking. The spores were suspended by rinsing the isolates, which were at least 21 days old, with 4 ml of distilled water. The final concentration was strained, and the spores were collected in a test tube. A total of 30 fungal isolates were used. The final concentration was calibrated by quantifying the spores with the Malassez cell at a rate of 250 spores/µl. The soybeans were surface sterilized with a 1% sodium hypochlorite solution for 1 minute and with 70% alcohol for 30s, rinsed three times in sterile distilled water, and dried on sterile filter paper under aseptic conditions before inoculating. 10 ml of each mixture was used as an inoculum to coat 1 kg of seeds for each variety. The coated seeds were then dried under a hood for 24 hours. Next, 25 seeds of each variety were placed in a Petri dish. The bottom of the dish was lined with sterile absorbent paper soaked in distilled water. All the seeds were then incubated in a chamber at a temperature of 25°C with a cycle of 12 hours of darkness followed by 12 hours of light. During the period from the 4th to the 7th day after inoculation (DAI), we observed the symptoms on the soybeans with a magnifying glass. We also measured the percentage of mycelium covering the surface of the seeds (PSM) and recorded the germination rate using the Rojas et al. (2017) (Table 2). A total of 31 isolates from four fungal genera were tested with two untreated controls (TNT), with each test repeated three times. Each Petri dish was considered a repetition.

Table 2: Severity rating scale.

Note	Types of symptoms	Percentage of Seed Covering Surface of Mycelium
0	Germination of healthy seeds	0
1	A negligible or non-existent discoloration	25
2	Germination with isolated lesions	26 to 50
3	Development with fused lesion	51 to 75
4	Seeds colonized without germination	> 75

Source : (Rojas et al., 2017).

Evaluated Parameters

The infection rate of each fungal species is calculated by dividing the number of grains infected by the species by the total number of seeds tested in the seed sample. The seed infection rate by species (Ti) is determined using the formula: Ti (%) = ((Ngi / N) X 100, where Ti represents the seed infection rate, Ngi represents the number of grains infected by the species, and N represents the total number of seeds analyzed in the seed sample.

Relative abundance is calculated by dividing the number of individuals in each species by the total number of individuals across all species. The calculation for AR (Abundance Ratio) is determined by the formula: AR (%) = (ni/Ni) x 100, where Ni represents the number of individuals of a particular species and Ni represents the total number of individuals across all species.

The frequency (F) or percentage of specimens contaminated by the species can be computed using the formula: F (%) = Ei/Et x 100 F (%), where Ei represents the number of specimens infected with the species and Et represents the total number of investigated specimens.

The disease severity index (IGM) was computed using the following formula:

IGM = (∑ (Numerical notation for the germination rate is denoted by x.) / (total number of seeds x highest degree of gravity) x 100

The aggressiveness of the isolates was evaluated using the Boka et al. (2018) scale, which relies on the illness severity index (Table 3).

Table 3: Rating scale of the level of aggressiveness of isolates.

Class of Disease Gravity Indices	Aggressiveness level of the isolate
IGM > 50	Extremely aggressive
25 ≤ IGM ≤ 50	Moderately aggressive
IGM < 25	Non-aggressive

Source : (Boka et al., 2018).

Statistical Analysis of Data

The software Excel version 2016 was utilized to input and process the collected data. The data on the frequency and infection rate of fungi associated with seeds have been processed and analyzed. The parameters of pathogenic power were the disease index, germination rate, and the percentage of seed surface covered by mycelium. The analysis of variances for these parameters was conducted using R software version 4.3.1. 2022. The comparison of means was conducted using the Newman-Keuls (SNK) test at a significance level of 5%.

RESULTS

Diversity of Fungi Associated with Soybean Seeds

Out of a total of seventeen samples from five provinces, 13 fungi species were identified on the seeds. The infection rate and relative abundance of these fungi are presented in Fig. 2. The results indicated that *Aspergillus* was the most abundant (27.24%; 50.24%) among the 13 recorded genera, whereas *Colletotrichum* had the lowest rates (0.04%; 0.18%) (Fig. 2). It was followed by *Fusarium* (10.88%; 20.47%), *Phoma* (3.72%; 8.82%), *Cladosporium* (3.48%; 4.77%), *Macrophomina* (2.3%; 4.66%), and *Curvularia* (2.05%; 6.12%). *Botrytis, Rhizopus, and Botryodiplodia* accounted for a relatively low fraction of (0.88%; 1.02%), (0.77%; 1.44%), and (0.58%; 1.80%) of the total number of fungi, respectively. The least reported fungi in the samples were *Penicillium* (0.52%; 2.14%), *Cercospora* (0.176; 0.17%), *Bipolaris* (0.05%; 0.17%), and *Colletotrichum* (0.04%; 0.18%).

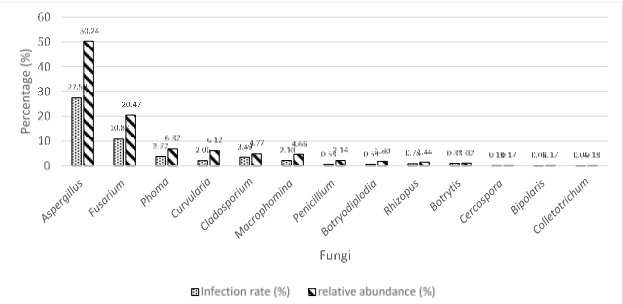


Fig. 2: Infection rate (%) and relative abundance of seed samples by the identified fungal genus.

Distribution of Frequencies of Identified Fungi based on Collection Places

The frequency results are displayed in Fig. 3. A total of 13 fungi were detected in 17 different locales. The genus Aspergillus has been detected in all locations, with rates varying from 12.5% to 100%. Later on, Fusarium was detected in 13 different places. A total of seven fungal genera have been found at Kari, Banfora 1, Farako-Bâ, Orodara. Then, six distinct genera were identified in the cities of Bobo Dioulasso 2, Kirbina, and Kongolékan. A total of five fungi genera were documented in the cities of Banfora 2 and 3, Niéneta, and Bobo Dioulasso 4. Furthermore, a total of four genera have been identified in the areas of Ouagadougou 1 and Bobo Dioulasso 3, while three genera have been found in the localities of Bobo Dioulasso 1 and Banfora 4. In conclusion, two distinct fungi species were identified in Ouagadougou 2, but only one species was found in Niangoloko.

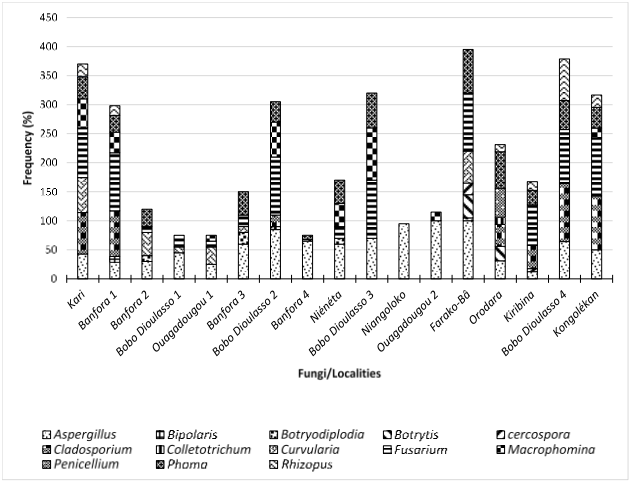


Fig. 3: Distribution of frequencies of identified Fungi based on collection places.

Morphological Description and Identification of Fungal Isolates

The findings of the morphological analysis of isolates are displayed in Table 4. Out of these findings, two (02) species of *Fusarium* spp. were identified. *Fusarium* spp. species have a white and sandy-white mycelium on the PDA medium, with pyriform, spindle-shaped conidia. Moreover, these data revealed the identification of two distinct species of *Curvularia*. The species *C. lunata* has a dark green mycelium on the PDA medium and often produces small conidia with three septa, generally in a curved shape. The conidia of *Curvularia* spp. are longer than those of the species *C. lunata*. The species *Macrophomina phaseolina* has a black mycelium with microsclerotia. The conidia are present within these microsclerotia. *Phoma* spp. exhibits a sluggish growth rate on the Potato Dextrose Agar (PDA) medium. The mycelium of this organism is dark brown to black in color and contains sclerotes, which serve as housing for the spores.

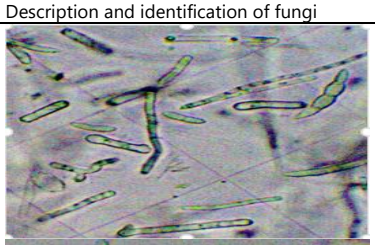
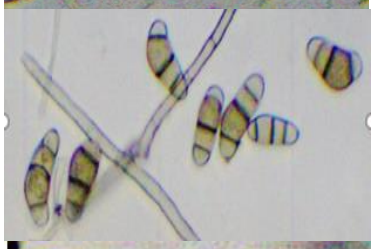
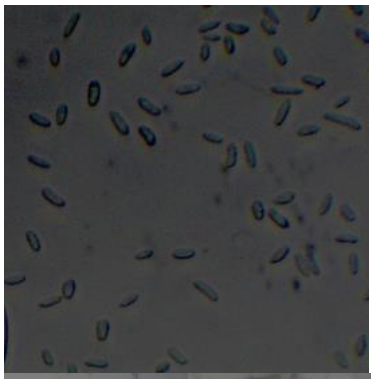
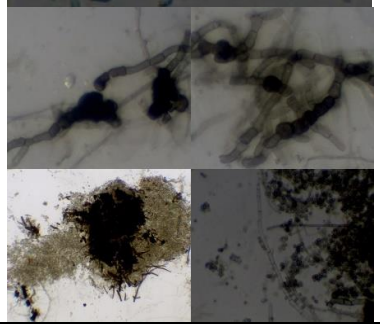
Pathogenic Potential of the Isolates

In general, the observation revealed that the inoculated seeds exhibited typical symptoms of rot, softening, and browning compared to the non-inoculated control (Fig. 4). The non-inoculated seeds exhibited only a few symptoms of the disease.

Pathogenicity of Isolates in the G197 Variety

The findings on the pathogenicity of the strains in the G197 variety are presented in Table 5. The strains have significantly different effects on the G197 variety ($p = 2{,}2.e^{-16}$) at a 5% significance level. *Curvularia* and *Macrophomina* strains exhibited high levels of aggression

Table 4: Morphological characterization of isolates

Isolates	Localities	Radial growth (cm/day)	Mycelium color	Description and identification of fungi	
FuE7	Bobo Dioulasso 2	0.96±0.01ghi	Greyish-white		0-3 septum macroconidies unicellular, globular or pyriform: *Fusarium* spp. (400x)
FuE10	Bobo Dioulasso 3	0.92±0.03ij	Greyish-white		
FuE4	Bobo Dioulasso 1	0.93±0.01ij	Greyish-white		
FuE13	Farako-Bâ	0.95±0.02hi	Greyish-white		
FuE1	Kari	0.89±0.01i	Pink-white		3-7 septates Hyaline macroconidias, straight or curved, fusiform: *Fusarium* spp. (400x)
FuE3	Banfora 2	0.88±0.01i	Pink-white		
FuE6	Banfora 3	0.88±0.01i	Pink-white		
FuE5	Ouagadougou 1	0.89±0.01i	Pink-white		
CuE1	Kari	1.04±0.02ef	black-green		3-septate conidies short: *Curvularia lunata* (Wakk) Boedijn (400x)
CuE10	Bobo Dioulasso 3	1.07±0.03e	black-green		
CuE3	Banfora 2	1.02±0.02e	black-green		
CuE5	Ouagadougou 1	1.00±0.01efgh	black-green		
CuE13	Farako-Bâ	1.06±0.01ef	black-green		
CuE4	Bobo Dioulasso 1	1.04±0.00ef	black-green		3-septates *Curvularia* sp. (400x)
CuE8	Banfora 4	0.98±0.01fghi	black-green		
CuE9	Niénéta	1.02±0.01efgh	black-green		
PhE6	Banfora 3	0.52±0.01k	Grey-brown		Unicellular *Phoma* spp. (400x)
PhE5	Ouagadougou 1	0.48±0.02k	Grey-brown		
PhE3	Banfora 2	0.51±0.01k	Grey-brown		
PhE7	Bobo Dioulasso 2	0.45±0.01k	Grey-brown		
PhE9	Nienata	0.50±0.01k	Grey-brown		
PhE10	Bobo Dioulasso 3	0.45±0.02k	Grey-brown		
PhE13	Farako-Bâ	0.45±0.02k	Grey-brown		
MpE5	Ouagadougou 1	1.98±0.05a	Grey-black		Oval ellipsoid, unicellular. *Macrophomina phaseolina* (Tassi) Goid (400x)
MpE7	Bobo Dioulasso 2	2.02±0.02a	Grey-black		
MpE10	Bobo Dioulasso 3	1.90±0.08bc	Grey-black		
MpE1	Kari	1.99±0.04ab	Grey-black		
MpE4	Bobo Dioulasso 1	1.87±0.01cd	Grey-black		
MpE9	Niéneta	1.83±0.02d	Grey-black		
MpE12	Ouagadougou 2	1.99±0.02a	Grey-black		

Legend: The codes for isolates are: FuE7 ; FuE10 ; FuE9 ; FuE13 ; FuE4 ; FuE1 ; FuE5 ; FuE6 ; FuE3 ; CuE4 ; CuE10 ; CuE1 ; CuE3 ; CuE5 ; CuE8 ; CuE9 ; CuE13 ; PhE6 ; PhE5 ; PhE3 ; PhE7 ; PhE9 ; PhE10 ; PhE13 ; MpE7 ; MpE5 ; MpE10 ; MpE1 ; MpE4 ; MpE9 ; MpE12, the first letter capitalized followed by the second letter in lowercase is the species name, and the third letter followed by a number is the sample and its number. The values (mean+SD) with the same letters in the same column are not significantly (P>0.05) different according to the Newman-Keuls (SNK) statistical test.

towards the G197 type. When considering individual strains, the *Curvularia lunata* strain from Bobo Dioulasso 3 obtained an average severity index of 74.16±5.15% and an average percentage of seed surface covered by mycelium (PSM) of 82.88±4.35%. These values are the highest among the indices. She was the most aggressive on the seeds, with a low average germination rate of 60% ±10%. The seeds exhibited softening and black spots on the inside. The rootlet was shorter than that of the untreated control. The *Macrophomina phaseolina* strain from

Table 5: Pathogenicity of isolates on the G197 variety

Isolats	Pathogenicity			Aggressiveness
	PSM (%)	TG (%)	IGM (%)	
FuE7	66.00±2.66gh	93.33±11.54abc	5617±0.92gh	TA
FuE10	71.77± 1.53defg	83.33±5.77bcde	61.63±1.40ef	TA
FuE1	60.44±2.58ij	73.33±5.77defg	52.54±2.80hi	TA
FuE3	51.55±0.50lm	90.00±0.00abcd	43.24±3.50l	MA
FuE4	59.11±3.67ijk	90.00±0.00abcd	50.92±2.77hij	TA
FuE6	50.00±2.88m	90.00±0.00abcd	42.23±0.92l	MA
FuE9	56.88±4.78jkl	83.33±5.77bcde	48.70±4.55ijk	MA
FuE13	54.77±3.79klm	93.33±5.77abc	46.47±4.25jkl	MA
FuE5	54.22±3.42klm	93.33±5.77abc	45.46±4.20kl	MA
CuE4	75.55±2.41bcde	63.33±5.77h	70.52±3.55ab	TA
CuE1	76.66±2.08bc	63.33±5.77fgh	70.32±1.21ab	TA
CuE10	82.88±4.35a	60.00±10.00gh	74.16±5.15a	TA
CuE3	76.22±1.71bcd	63.33±5.77fgh	67.69±3.11bcd	TA
CuE5	77.55±2.26ab	73.33±5.77defg	66.28±4.30bcde	TA
CuE8	74.22±2.50bcdef	80.00±10.00cde	64.46±1.94bcdef	TA
CuE9	72.55±0.83cde	66.66±5.77efgh	68.10±2.12bc	TA
CuE13	76.22±0.83bcd	63.33±5.77fgh	67.69±2.45bcd	TA
PhE6	43.44±1.53n	100±0.00a	36.37±1.81m	MA
PhE5	29.11±5.10o	100±0.00a	22.83±3.89n	NA
PhE3	33.88±0.96o	100±0.00a	27.07±0.35n	MA
PhE7	29.00±0.66o	100±0.00a	22.63±0.35n	NA
PhE9	32.55±1.83o	100±0.00a	25.66±1.26n	MA
PhE10	32.88±1.71o	100±0.00a	26.47±1.40n	MA
PhE13	34.22±1.17o	100±0.00a	27.68±1.26n	MA
MpE5	75.77±3.59bcde	66.66±5.77gh	64.46±1.75bcde	TA
MpE7	66.11±5.09gh	76.66±11.54cdef	63.25±0.35gh	TA
MpE10	68.66±1.76fgh	90.00±0.00bcd	62.84±2.29cdef	TA
MpE1	69.88±1.38defg	80.00±0.00cde	60.62±0.00efg	TA
MpE4	70.22±0.84cdefg	80.00±0.00cde	59.99±0.04efg	TA
MpE9	63.11±1.34hi	83.33±5.77cde	53.95±1.60hi	TA
MpE12	69.55±1.07efg	80.00±0.00cde	59.61±0.7fg	TA
TNT	0.00±0.00p	100±0.00a	0.00±0.00o	
Pr(>F)	< 2.2e-16***	< 2.2e-16***	< 2.2e-16***	
Signifiance	HS	HS	HS	

Legend: Pr: Likelihood that has been observed; **HS:** Highly Significant; **PSM:** Percentage of seed surface covering with mycelium; **TG**: Rate of seed germination; **IGM:** Indicator of disease severity; TA: Highly aggressive, MA: Moderately aggressive, NA: Non-aggressive**.** The isolates are identified by their respective codes as shown in Table 4. The sample and its number are indicated by the third letter after a Fig. Values (mean+SD) followed by the same letter in the same column not significantly (P>0.05) different according to the Newman-Keuls (SNK) statistical test.

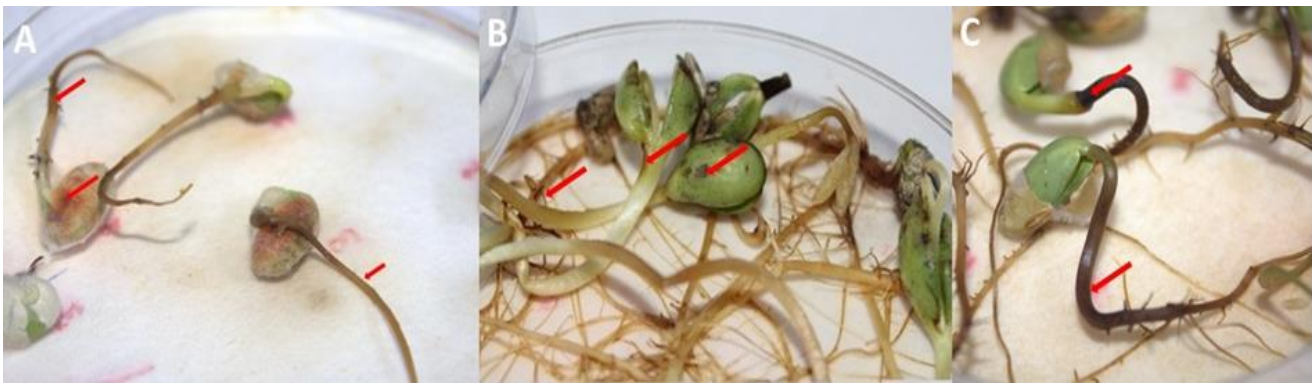


Fig. 4: Symptoms of the isolates on the seeds. (A)The seed germinates with browning of the germination tube and the presence of whitish mycelium, followed by a pinkish browning on the seed coat due to *Fusarium*. (B) Browning, rotting inside and outside of the seeds, and reduction in the length of the radicles due to *Curvularia*. (C) Seed germination with browning and softening on the seed germination tube and necrosis on the seed coat caused by *Phoma*.

Ouagadougou 2 obtained the highest average severity index of 64.46±1.75% and the highest average PSM (percentage of seed surface covering mycelium) of 75.77±3.59% among strains of the same species, with a low average germination rate of 66.66±5.77%. The seeds inoculated with these strains exhibited pronounced microsclerotia on the surface, and black rot was observed inside the seeds. The strains of the Fusarium genus from Bobo Dioulasso 1, 2, 3, and Kari were highly aggressive, whereas the other strains were moderately aggressive. The germination rate of the seeds subjected to the effect of these strains decreased by 83.33±5.77% compared to the untreated control. The seeds have been softened on the surface and browned on the inside. The lowest average severity indices and PSM values were obtained with *Phoma* sp. strains. They were moderately aggressive except for the Bobo Dioulasso 2 and Ouagadougou strains, which were non-aggressive. The highest values for the index and PSM were found in the Banfora strain, with an average index of 36.37±1.81% and an average PSM of 43.44±1.53%. The germination rate was 100%, similar to the untreated control.

Table 6: Pathogenicity of isolates on the G196 variety

Isolates	Pathogenicity			Aggressiveness
	PSM (%)	TG (%)	IGM (%)	
FuE7	65.11±1.67e	86.66±5.77abcd	55.57±2.12g	TA
FuE10	73.44±1.53bcd	63.33±5.7defg	65.27±0.92bcd	TA
FuE1	62.77±3.89ef	86.66±5.77abcd	54.36±2.73g	TA
FuE3	51.33±1.76h	90.00±11.54abc	43.24±2.12hi	MA
FuE4	58.44±4.16fg	90.00±5.77abc	53.95±1.60h	TA
FuE6	50.33±2.18h	96.66±5.77ab	41.02±2.12i	MA
FuE9	56.44±2.71h	90.00±0.00abc	46.68±2.64h	MA
FuE13	55.11±7.19h	86.66±5.77abcd	46.47±6.07h	MA
FuE5	56.44±7.12h	96.66±5.77ab	47.69±7.72h	MA
CuE4	79.11±1.95ab	63.33±5.77g	71.94±0.70ab	TA
CuE1	77.33±0.88ab	73.33±5.77defg	69.11±0.60abc	TA
CuE10	82.33±0.57a	40.00±0.00h	77.15±2.12a	TA
CuE3	77.00±2.30ab	76.66±11.54cdef	67.29±2.18abcd	TA
CuE5	76.77±2.14ab	66.66±5.77fg	66.68±1.26abcd	TA
CuE8	74.33±0.00bc	80.00±10.00cdef	65.47±0.00bcde	TA
CuE9	77.33±0.00ab	70.00±0.00efg	67.90±0.00abc	TA
CuE13	78.22±0.50ab	70.00±0.00efg	68.50±0.60abc	TA
BtE6	40.88±2.91i	100±0.00a	33.34±3.05i	MA
PhE5	30.77±4.07i	100±0.00a	24.65±2.45k	NA
PhE3	33.00±1.33i	100±0.00a	25.66±3.33k	MA
PhE7	29.44±1.92i	100±0.00a	23.23±0.92k	NA
PhE9	31.88±2.00i	100±0.00a	26.47±1.40k	NA
PhE10	33.32±1.01i	100±0.00a	26.87±0.70k	MA
PhE13	35.55±2.41i	100±0.00a	28.69±1.94k	MA
MpE5	74.77±3.00abc	60.00±0.00efg	69.11±3.11cde	TA
MpE7	68.00±1.20cde	76.66±5.77cdef	60.62±2.18defg	TA
MpE10	73.33±2.66bcd	83.33±5.77bcde	64.26±3.37cdef	TA
MpE1	67.77±3.46cde	90.00±0.00abc	59.41±2.18efg	TA
MpE4	67.55±2.91cde	83.33±5.77bcde	57.99±2.45fg	TA
MpE9	66.44±4.78de	80.00±10.00cdef	56.58±3.89g	TA
MpE12	66.22±3.00de	80.00±10.00cdef	60.01±0.00efg	TA
TNT	0.00±0.00k	100±0.00a	0.00±0.00l	
Pr(>F)	< 2.2e-16***	< 2.2e-16***	< 2.2e-16***	
Meaning	HS	HS	HS	

Legend: Pr: observed probability. **HS**: highly significant, **PSM**: percentage of surface covered by mycelium, **TG**: germination rate **IGM**: Index of Disease Severity, **TA**: Highly aggressive, **MA**: Moderately aggressive, **NA**: Non-aggressive. The isolates are identified by their respective codes as shown in Table 4. Values (mean+SD) followed by the same letter in the same column not significantly (P>0.05) different according to the Newman-Keuls (SNK) statistical test.

Pathogenicity of Isolates on the G196 Variety

The results of the impact of strains on the G196 variety are presented in Table 6. A highly significant difference in the effects of the strains is observed on the G196 variety (p = 2,2. e^{-16}) at a threshold of 5%. All strains of *Curvularia* and *Macrophomina* were highly aggressive. The *Curvularia lunata* strain from Bobo Dioulasso 3 obtained the highest average severity index of 77.15±2.12% and the highest average PSM (percentage of symptomatic plants) of 82.33±0.57%, with the lowest germination rate of 40%. In addition, *Macrophomina phaseolina* from Ouagadougou obtained an average severity index of 69.11±3.11% and an average disease severity percentage of 74.77±3.00%. It was the most aggressive strain among its species, with a germination rate of 60±0% compared to 100% for the untreated control. Furthermore, *Fusarium* sp. from Bobo Dioulasso 1, 2, 3, Kari was highly aggressive, whereas the other strains were moderately aggressive. The strain *Fusarium* sp. from Bobo Dioulasso 3 obtained an average severity index of 65.27±0.92% and an average PSM (Pathogenicity-Related Secondary Metabolites) of 73.44±1.53%, the highest indices among strains of its species. The germination rate of the seeds exposed to the effect of this strain decreased to 63.33±5.77%, compared to the untreated control, which had a rate of 100%. The results demonstrated that the species *Phoma* spp. achieved the lowest IGM and PSM levels. All of its strains were somewhat aggressive, except for the strains from Bobo Dioulasso 2 and Ouagadougou. The highest average values for IGM and PSM for this species were found in the Banfora 3 strain, with 33.34±3.05% for IGM and 40.88±2.91% for PSM. The germination rate was 100%, similar to the untreated control. It should be noted that the same strains of *Curvularia lunata*, *Macrophomina phaseolina*, *Fusarium* spp., and *Phoma* spp. were aggressive on both varieties. The symptoms observed were identical to those described in paragraph 3.1.3.1, but with a more pronounced severity and a lower germination rate in the G196 variety compared to the G197 variety.

Correlation between Seed Germination and the Percentage of Seed Surface Covered by Mycelium

Fig. 5 and 6 depict a scatter plot illustrating the variability in seed germination under the influence of isolates. The points are distributed on both sides of the trend curves, which explains the strong relationship between germination and the percentage of surface covered by mycelium. The higher the gravity, the less the germination decreased. When the trend curves are polynomial, the determination coefficients R^2 = 0.70 and 0.77 tend towards 1, indicating that the fit is more or less perfect.

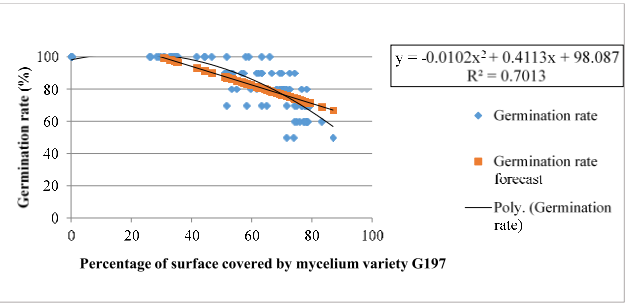


Fig. 5: The polynomial regression curve of soybean germination in the G197 variety under the effect of isolates.

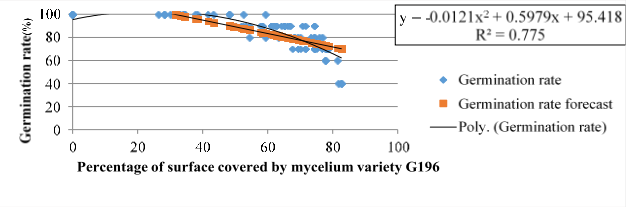


Fig. 6: The polynomial regression curve of soybean germination in the G196 variety under the effect of isolates.

DISCUSSION

The presence of fungi in soybean seeds can result in a reduction in seed quality while also serving as the main source of infection for many soybean illnesses. Identifying these fungi that are linked to seeds is a crucial step that could aid in managing them. This study demonstrated that soybean seeds in Burkina Faso are plagued by a diverse array of fungi. 13 fungus genera that are linked to soybean

seeds have been identified. These results confirm those obtained by Bado (2012), who identified 14 species of pathogenic fungi on soybean seeds from six districts in Burkina. The most prevalent genera found in the analyzed samples were *Aspergillus* (27.24%; 50.24%), *Fusarium* (10.88%; 20.47%), *Phoma* (3.72%; 8.82%), *Cladosporium* (3.48%; 4.77%), *Macrophomina* (2.3%; 4.66%), and *Curvularia* (2.05%; 6.12%). According to recent reports by the International Seed Testing Association (ISTA) in 2021, seeds serve as a vector for over 200 plant infections (Denancé and Grimault, 2022). In addition, Shade et al. (2017) show that seeds not only carry the genetic heritage of plants, but they are also involved in the transfer of fungal pathogens associated with them. On one hand, Hartman et al. (2015) found that most seed-associated fungi have the ability to infect and colonize seeds, often leading to seedling blight, pod rot, and seed decay. Their damage significantly affects germination, reduces plant vigor, yield, and the quality of soybean seeds. On the other hand, Agarwal and Sinclair (1997) demonstrated that contaminated seeds can serve as a source for both local and long-distance dispersal of pathogens, hence contributing to the spread of diseases. The population of Fusarium exhibited a high infection rate (10.88%) and a high relative abundance (20.47%). This result is consistent with the work of Bonzi (2005), who observed the presence of this fungus in all maize-growing regions of Burkina Faso, with incidence rates ranging from 1.5 to 99%. In addition, favorable environmental factors such as high humidity and temperature, combined with insect activity, can create conditions conducive to the fungal infection of seeds. (Cardwell et al., 2000; Roth et al., 2020). The population of *Fusarium* was observed to be more abundant in 13 localities, in accordance with the findings of Chang et al. (2020), who emphasized that *Fusarium* is the most frequent and abundant among the seed-transmitted fungi in intercropped soybean cultivation in China.

Furthermore, multiple investigations conducted in China have revealed the association of various *Fusarium* species with seed rot, root rot, and pod rot in soybeans, which significantly impacts the quality and quantity of seeds (Barros et al., 2014; Chang et al., 2015; Chang et al., 2020; Naeem et al., 2019). *Fusarium* species are also associated with a number of plant diseases, including vascular wilt, root rot, and stem rot (Pitt & Hocking, 2009). This study enabled the isolation of nine strains of *Fusarium*, eight strains of *Curvularia*, seven strains of *Macrophomina*, and seven strains of *Phoma*. Regarding the species, six of them have been identified based on their morphological characteristics, confirmed using the Common Laboratory Seed Health Testing Methods key by Mathur et Kongsdal (2003). The presence of *Fusarium* sp., *Curvularia lunata*, *Curvularia* sp., *Macrophomina phaseolina*, and *Phoma* spp. has been identified in all five provinces of Burkina Faso. Furthermore, the pathogenicity of soybean seed-associated strains has been tested on the seeds. It is worth noting that all tested strains infected the seeds at varying levels of severity. *Curvularia lunata* exhibited higher aggressiveness and a low germination rate, followed by *Curvularia* sp., *Macrophomina phaseolina*, *Fusarium* spp., and *Phoma* spp. The findings of this study demonstrated that species of *Fusarium*, *Curvularia*, and *Macrophomina* significantly inhibited soybean seed germination, and the pathogenicity of the species varied depending on the geographical origin of the strains and the soybean variety. The other fungi are not reported as pathogenic; rather, those were reported as storage fungi on soybeans (Anwar et al., 1995; Gupta et al., 1993). The studies conducted by Shovan et al. (2008), Naeem et al. (2019), Chang et al. (2020) and Roth et al. (2020) have indicated that *Fusarium* species are identified as pathogenic agents responsible for the brown rot of soybean seeds and roots. In addition, Jacobs et al. (2018) and Wang et al. (2019) reported the presence of *F. brasiliense* and *F. cuneirostrum* in Michigan, infecting both soybean and dry bean. Furthermore, in a study on the conidial generation of *Macrophomina phaseolina* by several soybean isolates, Hartman et al. (2015) showed that soybean charcoal rot is associated with the pathogen *Macrophomina phaseolina*.

The research conducted by An and Kim (2023) has confirmed that *M. phaseolina* is responsible for the charcoal rot of soybean seeds, roots, crowns, and stems, as observed in their study on pathogenicity testing methods. Previous studies (Naeem et al., 2019; Chang et al., 2020; An and Kim, 2023; Hosseini et al., 2023) have also shown that *Fusarium* and *Macrophomina* cause a decrease in seed germination and seedling emergence by inducing wilting and seed rot, findings that align with those observed in the current study. These species have caused the deterioration of soybean seeds and radicles, resulting in a decrease in root length and proliferation. The pathogenicity of isolates can also vary considerably from one strain to another within the same species (Arias et al., 2013). Furthermore, the findings of this study are consistent with those of Gupta et al. (2017), who identified the species *Curvularia lunata* as the most predominant and pathogenic among the seeds in the Dalbergia region of India. The results of this study also confirm that *Curvularia lunata* is the most pathogenic fungus associated with soybean seeds, causing surface softening, black rot inside and outside the seeds, as well as a reduction in root length and emergence. These species have caused seed rot, soybean root decay, and reduced root length and proliferation. Finally, the relationship between germination and the percentage of surface covered by mycelium showed that the seed germination rate decreased as the severity of seed rot increased due to the strains for both varieties. This explains the dependence of soybean seed germination on the aggressiveness of the strains.

Conclusion

This study has demonstrated that soybean seeds are commonly colonized by various genera of fungi. The *Fusarium*, *Curvularia*, *Macrophomina*, and *Phoma* genera have been found to be major pathogens affecting soybean seeds. The identification based on morphological characteristics yielded two species of *Fusarium* spp.; two species of *Curvularia*, *lunata* and *Curvularia* sp.; the

species *Macrophomina phaseolina;* and the species *Phoma* spp., which were associated with soybean seeds. These fungal agents were found to be pathogens on seeds, with noticeable variations in the level of aggressiveness among different strains, affecting both seed germination and the emergence of seedlings. The transmission of these diseases from soybean plant seeds has emerged as a significant problem that hampers soybean production and disrupts seed displacement. Nevertheless, future research needs to focus on elucidating the molecular characteristics, virulence mechanisms, and severity of these species in soybean plants. Furthermore, it is imperative to investigate techniques for controlling these viruses.

Author's Contribution: Teendbwaoga Merlène Prisca OUEDRAOGO: Conceptualization, methodology, software, formal analysis, data curation, writing—original, draft preparation. Abalo Itolou KASSANKOGNO: Conceptualization, writing—review and editing, supervision. Elise SANON: supervision, writing—review and editing. Bonwendson Clément NIKIEMA: methodology. Hawa SOHORO: methodology. Seydou BARRO: methodology, software, formal analysis, writing—original. Aïdatou KAFANDO: formal analysis. Issa WONNI: supervision, writing—review and editing.

Acknowledgment: The authors would like to thank the phytopathology and mycology laboratories of INERA Farako-Bâ, Bobo Dioulasso 398 (Burkina Faso), the phytopathology and mycology tropical laboratory of the University Joseph-KI ZERBO, and the Project d'Appui à l'Enseignement Supérieur (PAES) funded by the World Bank.

Declaration of Competing Interests: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Conflicts of Interest: The authors of this paper declare no conflict of interest.

REFERENCES

Agarwal, V. K., & Sinclair, J. B. (1997). *Principles of Seed Pathology* (2nd ed.). CRC Press. https://doi.org/10.1201/9781482275650

Akem, C. (1992). Maladies du soja: Biologie, identification et lutte: guide de recherche de Ilita No. 40. *Programme de la formation, International Institute of Tropical Agriculture*, 37.

An, S. H., & Kim, H. T. (2023). Establishment of Pathogenicity Test Method for *Macrophomina phaseolina* Causing Soybean Charcoal Rot. *Research in Plant Disease*, *29*(1), 1-10. https://doi.org/10.5423/RPD.2023.29.1.1

ANAM-BF. (2022). *Etat du climat de l'année 2022 au Burkina Faso*. Agence Nationale de la Météorologie (ANAM-BF). p. 3. https://www.meteoburkina.bf/documents/7/Etat_climat2022.pdf

Anwar, S. A., Abbas, S. F., Gill, M. M., Rauf, C. A., Mahmood, S., & Bhutta, A. R. (1995). Seed-borne fungi of soybean and their effect on seed germination. *Pakistan Journal of Phytopathology*, *7*(2), 184-190. https://doi.org/10.5555/19961006433

Arias, M. M. D., Leandro, L. F., & Munkvold, G. P. (2013). Aggressiveness of *Fusarium* Species and Impact of Root Infection on Growth and Yield of Soybeans. *Phytopathology®*, *103*(8), 822-832. https://doi.org/10.1094/PHYTO-08-12-0207-R

Bado, M. (2012). *Contribution à l'étude du flétrissement des plants de soja au Burkina Faso*. Rapport de fin de cycle. Centre Agricole Polyvalent de Matourkou (CAP-M). p. 81.

Barros, G., Alaniz Zanon, M., Chiotta, M., Reynoso, M., Scandiani, M., & Chulze, S. (2014). Pathogenicity of phylogenetic species in the *Fusarium graminearum* complex on soybean seedlings in Argentina. *European Journal of Plant Pathology*, *138*, 215-222. https://doi.org/10.1007/s10658-013-0332-2

Boka, A., Bouet, A., Tiendrebeogo, A., Kassankogno, A. I., Ouedraogo, I., Nda, G. N. E., Denezon, O. D., & Adiko, A. (2018). Pathogenic Variability of *Bipolaris oryzae* Causing Leaf Spot Disease of Rice in West Africa. *International Journal of Phytopathology*, *7*(3), 103-110. https://doi.org/10.33687/phytopath.007.03.2643

Bonzi, S. (2005). *Efficacité des extraits aqueux de plantes dans la lutte contre les champignons transmis par les semences de maïs (Zea mays L.): Cas particulier de Bipolaris maydis (Nisikado et Miyaké) Shoen., agent de l' helminthosporiose*. Mémoire de fin de cycle. https://beep.ird.fr/collect/upb/index/assoc/IDR-2007-BON-EFF/IDR-2007-BON-EFF.pdf

CAE, (2001). *Etude pour la promotion des filieres agro-industrielles*. Document de Synthèse. Centre Agro-Entreprise (CAE/ CHEMONICS). p. 166.

Cardwell, K. F., Kling, J. G., Maziya-Dixon, B., & Bosque-Pérez, N. A. (2000). Interactions Between *Fusarium verticillioides*, *Aspergillus flavus*, and Insect Infestation in Four Maize Genotypes in Lowland Africa. *Phytopathology®*, *90*(3), 276-284. https://doi.org/10.1094/PHYTO.2000.90.3.276

Chang, K. F., Hwang, S. F., Conner, R. L., Ahmed, H. U., Zhou, Q., Turnbull, G. D., Strelkov, S. E., McLaren, D. L., & Gossen, B. D. (2015). First report of *Fusarium proliferatum* causing root rot in soybean (*Glycine max* L.) in Canada. *Crop Protection*, *67*, 52-58. https://doi.org/10.1016/j.cropro.2014.09.020

Chang, X., Li, H., Naeem, M., Wu, X., Yong, T., Song, C., Liu, T., Chen, W., & Yang, W. (2020). Diversity of the Seedborne Fungi and Pathogenicity of *Fusarium* Species Associated with Intercropped Soybean. *Pathogens*, *9*(7), Article 7. https://doi.org/10.3390/pathogens9070531

Dabat, M. H., Li, X., & Lançon, F. (2001). Marché international du soja: Des flux en profonde recomposition. *OCL. Oléagineux Corps gras Lipides*, *8*(3), 191-198. https://doi.org/10.1051/ocl.2001.0191

Denancé, N., & Grimault, V. (2022). Seed pathway for pest dissemination: The ISTA Reference Pest List, a bibliographic resource in non-vegetable crops. *EPPO Bulletin*, *52*(2), 434-445. https://doi.org/10.1111/epp.12834

DSSE/DGESS/MARAH, (2024). *Rapport sur les résultats définitifs de l'enquête permanente agricole (EPA) de la campagne agricole 2023/2024*. Rapport définitifs EPA 2023-2024. Direction des statistiques Sectorielles et de l'évaluation; Direction générale des études et des statistiques sectorielles; Ministère de l'agriculture, des ressources animales et halieutiques. p. 41. file:///C:/Users/HP/OneDrive/Documents/Prisca%20th%C3%A8se/Dossier%20BARRY/Document%20revue%20soja/Rapport-Resultats-def-EPA2023_2024_VF.pdf

Gilbert, G. (2011). *Bilan des maladies du soya identifiées au Laboratoire de diagnostic en phytoprotection pour la période 2006-2010*. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation, Direction de la phytoprotection, Laboratoire de diagnostic en phytoprotection, MAPAQ. p. 3. https://www.agrireseau.net/references/13/Bilan%20maladie%20soya%202006-2010.pdf

Gupta, I. J., Schmithenner, A. F., & Mcdonald, M. (1993). Effect of storage fungi on seed vigour of soybean. *Seed Science and Technology*, *21*, 581-591. https://www.cabidigitallibrary.org/doi/full/10.5555/19942304140

Gupta, S., Dubey, A., & Singh, T. (2017). *Curvularia lunata* as, a dominant seed-borne pathogen in Dalbergia sissoo Roxb: Its location in seed and its phytopathological effects. *African Journal of Plant Science*, *11*(6), 203-208. https://doi.org/10.5897/AJPS2017.1529

Hartman, G. L., Rupe, J. C., Sikora, E. J., Domier, L. L., Davis, J. A., & Steffey, K. L. (2015). *Compendium of soybean diseases and pests* (Fifth edition). APS Press, The American Phytopathological Society.

Hosseini, B., Voegele, R. T., & Link, T. I. (2023). Diagnosis of Soybean Diseases Caused by Fungal and Oomycete Pathogens: Existing Methods and New Developments. *Journal of Fungi*, *9*(5), Article 5. https://doi.org/10.3390/jof9050587

INSD, (2023). *Annuaire statistique 2022 de la région du Centre, des Hauts-Bassins, des Cascades*. Rapport de statistique. Institut national de la statistique et de la démographie (INSD). p. 242. https://www.insd.bf/fr/statistiques/autres-statitiques/annuaires-statistiques-regionaux

Jacobs, J. L., Oudman, K., Sang, H., & Chilvers, M. I. (2018). First Report of *Fusarium brasiliense* Causing Root Rot of Dry Bean in the United States. *Plant Disease*, *102*(10), 2035. https://doi.org/10.1094/PDIS-02-18-0332-PDN

MARAH/DGESS/EPA, (2021). *Résultats definitifs de la campagne agropastorale 2020/2021, de la situation alimentaire et nutritionnelle du pays et perspectives*. Rapport general. Ministère de l'Agriculture et des Aménagements hydro-Agricoles, Direction générale des études et des statistiques sectorielles. p. 121.

Mathur, S. B., & Kongsdal, O. (2003). *Common Laboratory Seed Health Testing Methods for Detecting Fungi*. International Seed Testing Association.

Meda, B. H. (2023). *Carte de la zone d'étude*. Base Nationale de Données Topographiques (BNDT). Institut Géographique du Burkina Faso.

Naeem, M., Li, H., Yan, L., Raza, M., Gong, G., Chen, H., Yang, C., Zhang, M., Shang, J., Liu, T.-G., Chen, W., Abbas, M., Irshad, G., Khaskheli, M., Yang, W., & Chang, X. L. (2019). Characterization and Pathogenicity of *Fusarium* Species Associated with Soybean Pods in Maize/Soybean Strip Intercropping. *Pathogens*, *8*, 117. https://doi.org/10.3390/pathogens8040245

OECD/FAO, (2022). *Perspectives agricoles de l'OCDE et de la FAO 2022-2031* (Éditions OCDE). Organisation for Economic Co-operation and Development. https://www.oecd-ilibrary.org/agriculture-and-food/perspectives-agricoles-de-l-ocde-et-de-la-fao-2022-2031_63c6c63f-fr

Picasso, C., Asimi, S., & Dhéry, M. (1984). *Résultats de la recherche et application au développement*. *39*.

Pitt, J. I., & Hocking, A. D. (2009). *Fungi and Food Spoilage* (Third edition). Springer Science & Business Media.

Rojas, J. A., Jacobs, J. L., Napieralski, S., Karaj, B., Bradley, C. A., Chase, T., Esker, P. D., Giesler, L. J., Jardine, D. J., Malvick, D. K., Markell, S. G., Nelson, B. D., Robertson, A. E., Rupe, J. C., Smith, D. L., Sweets, L. E., Tenuta, A. U., Wise, K. A., & Chilvers, M. I. (2017). Oomycete Species Associated with Soybean Seedlings in North America-Part II: Diversity and Ecology in Relation to Environmental and Edaphic Factors. *Phytopathology*, *107*(3), 293-304. https://doi.org/10.1094/PHYTO-04-16-0176-R

Roth, M. G., Webster, R. W., Mueller, D. S., Chilvers, M. I., Faske, T. R., Mathew, F. M., Bradley, C. A., Damicone, J. P., Kabbage, M., & Smith, D. L. (2020). Integrated Management of Important Soybean Pathogens of the United States in Changing Climate. *Journal of Integrated Pest Management*, *11*(1), 17. https://doi.org/10.1093/jipm/pmaa013

Shade, A., Jacques, M.-A., & Barret, M. (2017). Ecological patterns of seed microbiome diversity, transmission, and assembly. *Current Opinion in Microbiology*, *37*, 15-22. https://doi.org/10.1016/j.mib.2017.03.010

Shovan, L., Sultana, N., Begum, J., & Pervez, Z. (2008). Prevalence of fungi associated with soybean seeds and pathogenicity tests of the major seed-borne pathogens. *International Journal Sustainable*, *3*(4), 24-33.

SIATOL, (2016). *Etude d'impact à 360° sur Siatol (Burkina Faso)*. SIATOL. p. 65. https://ferdi.fr/dl/df-k7QBbmiCHyUceyS3in1oaBR5/publication-siatol-evaluation-d-impact-a-360.pdf

USDA-FAS, (2024). *Oilseeds: World Markets and Trade*. Foreign Agricultural Service. p. 39. https://fas.usda.gov/sites/default/files/2024-08/oilseeds.pdf

Wang, M. M., Chen, Q., Diao, Y. Z., Duan, W. J., & Cai, L. (2019). *Fusarium incarnatum-equiseti* complex from China. *Persoonia: Molecular Phylogeny and Evolution of Fungi*, *43*, 70. https://doi.org/10.3767/persoonia.2019.43.03