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MORPHOLOGICAL CHARACTERIZATION OF PATHOGENIC FUNGI CAUSING MOLD ON MAIZE GRAINS IN ABIDJAN MARKETS (CÔTE D'IVOIRE)

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ABSTRACT

Maize (*Zea mays* L.), an herbaceous plant of Poaceae family, is the staple food of many people in developing countries. However, this product, as all crops, suffers from several biotic constraints during post-harvest storage. Among these constraints, molds caused by phytopathogenic fungi are the most important. The present study aimed to contribute to food security by characterizing fungal pathogens in stored maize grains. A survey was carried out in 10 communes of the Autonomous District of Abidjan, followed by sampling of maize grains stored. Samples were labelled and then taken to the laboratory for analysis. Fungal isolation was carried out on PDA (Potato Dextrose Agar) medium. Morphological characterization of the different fungal genera obtained was carried out after isolation. Results showed that maize grain wholesale trade is mainly held by men (72%) and that 85% of those traders are educated. Six (6) fungal genera were morphologically identified. These are *Aspergillus, Fusarium, Rhizopus, Pythium, Botryodiplodia* and *Trichoderma*. Among these fungal genera, *Aspergillus* was the most isolated with a rate of 60.65%, followed by *Fusarium* (30.28%). *Aspergillus* and *Fusarium* fungal species are toxigenic and can produce mycotoxins under the right conditions. They require special attention in order to propose effective and sustainable solutions to their control.

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INTRODUCTION

Maize (*Zea mays* L.) is an annual herbaceous plant of Poaceae family. With millet, sorghum and rice, it represents the staple food of many people in West Africa, especially in Sahelian regions (Neethirajan *et al.*, 2007; Bawa, 2021; N'Da *et al.*, 2022). These four cereals represent over 50% of food consumption in developing countries (N'Da *et al.*, 2022) and therefore occupy a key role in diet due to their high-energy value (Charcosset and Gallais, 2009). They are rich in starch, protein and minerals, and are low-cost to produce. However, maize consumption is marginal in industrialized countries, where its use is oriented towards processing industries and animal feed (Dedi and Diomande, 2017).

In Côte d'Ivoire, maize is a key staple crop, used in many northern diets and in livestock feeding. Maize is grown through all the country's agro-ecological zones, with a high concentration in northern Côte d'Ivoire, which accounts for 60% of national production (N'Da *et al.*, 2022). In volumes, maize is the second largest cereal crop in Côte d'Ivoire after rice, with annual production estimated at over 1.3 million tonnes in 2021 (FAO, 2023). Maize growing is now a major source of income for northern populations. Agriculture is largely the economic backbone of Côte d'Ivoire, with 2/3 of the working population employed and accounting for 34% of total gross domestic product (GDP) and 66% of revenue from exports (Dedi and Diomande, 2017). Maize is consumed in various forms: fresh cobs braised or boiled, dried seeds fried, meal used to make tô (N'Da *et al.*, 2022). As such, maize plays a key role in the food security of the Ivory Coast's population. However, maize, like other crops, is affected by many abiotic and biotic constraints. Biotic constraints due to fungi, bacteria and viruses cause significant in-field yield losses of up to 80% if untreated (Dedi and Diomande, 2017). According to Dedi and Diomande (2017), poor post-harvest storage of this cereal could lead to the development of molds such as *Aspergillus, Penicillium, Fusarium, Gibberella*, and *Cladosporium*, which will reduce seed quality due to the mycotoxins produced. Indeed, presence of mycotoxins in seeds that can produce toxic secondary metabolites represents a significant health risk for humans and livestock that consume them (Dedi and Diomande, 2017). Mycotoxins are known to be carcinogenic, immunosuppressive, estrogenic, and teratogenic (Baddi *et al.*, 2021). They can also cause huge economic losses to agriculture and agri-food industry (Ouali *et al.*, 2023; Ouili *et al.*, 2022).

The most powerful and toxic aflatoxins include aflatoxin B1, a highly carcinogenic toxin produced by the fungus *Aspergillus flavus*. It has been associated with liver cancer, stunted growth of children and reduced immunity (Dieme *et al.*, 2016). Considering these sanitary problems and economic losses caused by mycotoxins, particular research attention is focused on them worldwide (Dieme *et al.*, 2016; Baddi *et al.*, 2021; Ouili *et al.*, 2022; Ouali *et al.*, 2023). Therefore, identifying pathogens responsible for the deterioration of the marketable and nutritional quality of maize grains is crucial to ensure consumer health. This study was therefore initiated to contribute to food security by characterizing fungal pathogens of maize grains in storage.

MATERIALS AND METHODS

Study Area

This study was carried out in the Autonomous District of Abidjan, located in the south of Côte d'Ivoire. Covering an area of 2119 km2, Autonomous District of Abidjan is bounded to the north by the Sikensi and Agboville departments, to the south by Altantic Ocean, on the west by Dabou and Jacqueville departments, and on the east by Alépé and Grand-Bassam departments (Yapi and Zirihi, 2015; Diomande *et al.*, 2022). Geographical coordinates of this district are 5°20′11′′ Northern latitude and 4°01′36′′ Western longitude (Yapi and Zirihi, 2015). The study was carried out in ten (10) communes (Abobo, Adjamé, Anyama, Attécoubé, Cocody, Koumassi, Marcory, Port-Bouët, Treichville and Yopougon) out of the 13 in the autonomous district of Abidjan (Figure 1). Data were collected in the markets of these communes. These communes were selected for their importance in economic market activities, and for the high presence of cereals, which are a staple food for many people in Côte d'Ivoire. Experiments were carried out at the Plant Pathology Laboratory of the Plant Physiology and Pathology Teaching and Research Unit of the Faculty of Biosciences, Université Félix HOUPHOUËT-BOIGNY, Cocody, Abidjan, Côte d'Ivoire.

Plant Material

Maize grain used in this study was collected from stocks stored at markets in the 10 communes of the Autonomous District of Abidjan (Abobo, Adjamé, Anyama, Attécoubé, Cocody, Koumassi, Marcory, Port-Bouët, Treichville and Yopougon). These grains were apparently healthy or moldy.

Technical Equipment

Technical materials used are mainly glassware, some laboratory equipment and small materials. These equipment was used for fungi isolation and various analyses These comprise 90 mm-diameter Petri dishes, gloves, polyethylene bags, forceps, needles, an oven, an autoclave, a 10-2 precision balance, a laminar flow hood and permanent markers.

Market Prospection and Sampling in Autonomous District of Abidjan Market Prospection in Autonomous District of Abidjan

In order to collect data on markets in the Autonomous District of Abidjan, a survey was carried out from August 10 to September 15, 2022 and replicated from January 2 to February 4, 2023. Before starting surveys, three criteria were used to define the sample of traders to be interviewed: be a grain wholesaler in one of the communes selected for the study, have maize in their store's grain stocks, and be available to answer the questions. Based on these criteria, 50 traders were selected from the various markets in the selected communes, with 5 traders per commune. For survey operations, several data collection techniques were used: individual formal interviews using a well-structured questionnaire on a survey sheet, individual informal interviews or free discussions, and direct observation of store stocks to determine infrastructure and production methods for maize grain. Questionnaires covered general information (date, communes, etc.), trader characteristics (name, gender, education and occupation), trader knowledge (maize origin, type and storage, causes of fungal disease damage, methods of fungal disease control in stock), and means of maize storage (bagged or bulk). An identification key was used to enable traders to identify fungal diseases on maize grains in stock. Data collected during surveys were used to create an Excel database.

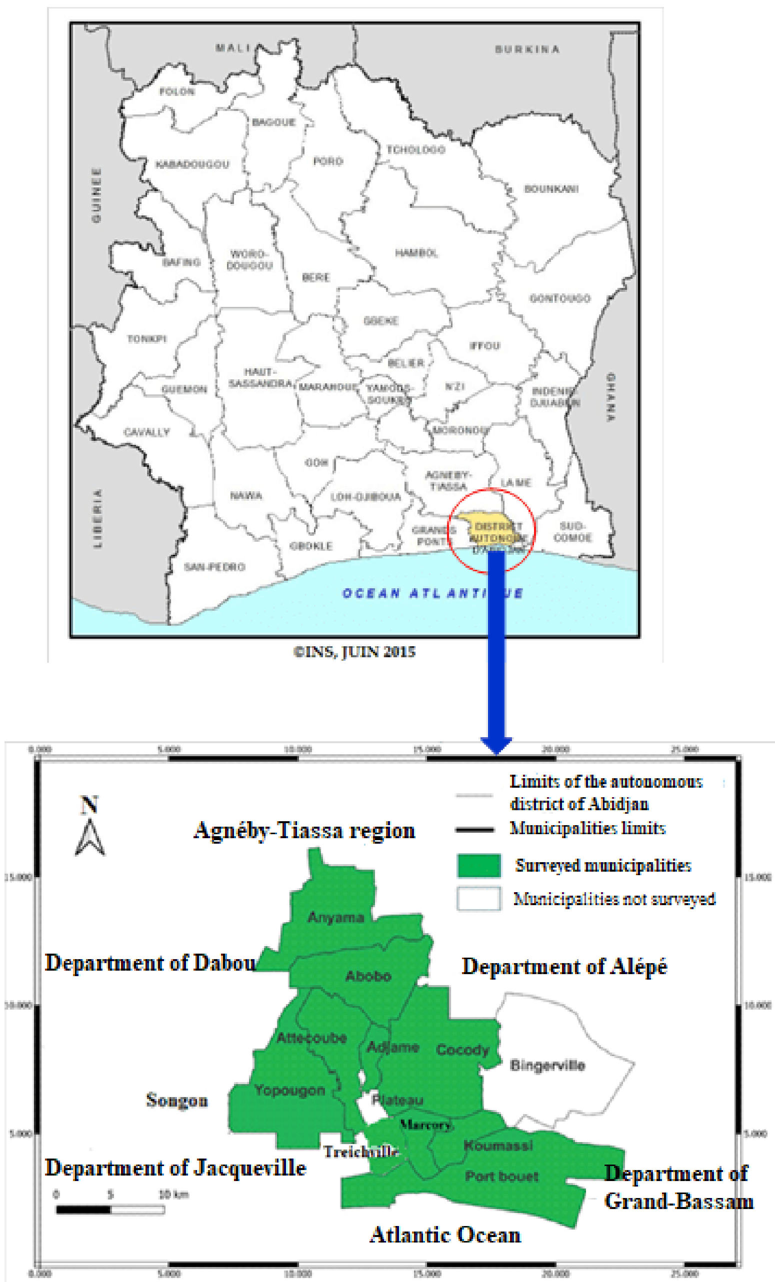


Figure 1. Map of study area.

Sampling

Traders were selected at random at each market studied in the Autonomous District of Abidjan. Maize grains infested with pathogenic fungi and/or apparently healthy were collected (500 g) using sterile gloves and packed in labeled polyethylene plastic bags. A total of 100 maize grain samples were collected from markets in the 10 communes visited, representing 10 samples per commune. Following collection, labeled maize samples were packed in transparent plastic bags and transported to the laboratory for various mycological analyses.

Characterization of Post-Harvest Fungi in Stored Maize Grains

Medium preparation

Synthetic growth medium Potato Dextrose Agar (PDA) was used to isolate molds from maize grains. This medium is recommended for isolation and enumeration of molds and yeasts in food products (Botton et al., 1990). It was prepared by adding 20 g of mashed potatoes, 20 g of D-glucose and 20 g of agar in an Erlenmeyer flask. This mixture was adjusted to 1 L with distilled water, then autoclaved at 121°C under a pressure of 1 bar for 30 minutes. The mixture was then cooled to 45°C in a laminar flow hood, and antibiotics (350 µl lactic acid, 250 mg.l-1 ampicillin and 10 mg.l-1 rifampicin) were added to combat bacteria. The whole mixture was homogenized under magnetic stirring, then distributed into 90 mm diameter Petri dishes at a rate of 20 ml per dish.

Isolation of fungal flora from maize grains in storage

Two methods were used to isolate mycoflora from maize grains samples (the maize grains disinfection method and the maize grains non-disinfection method).

Method of disinfecting maize grains

The grains from each maize sample were disinfected with sodium hypochlorite (4%) for 5 min, followed by 3 rinses with sterile distilled water, each lasting 3 min. After three rinses with sterile distilled water, maize grains were dried on sterile blotting paper in a laminar flow hood and then seeded (Ghiasian *et al.*, 2004). Under aseptic conditions, the disinfected and dried maize grains were placed directly, using sterile forceps, in Petri dishes containing frozen PDA medium at a rate of 5 grains per Petri dish and in Petri dishes containing sterilized filter paper disks soaked in 3 ml of distilled water (also at a rate of 3 maize grains per Petri dish). Petri dishes containing these explants were incubated at 25 ± 2°C for 72 h. After this time, a colony developed near the maize grains and is then purified. Three replicates were performed for each sample.

Method for non-disinfecting stored maize grains

A second batch of non-disinfected maize grains was also placed directly with sterile forceps into Petri dishes containing PDA culture medium and sterilized filter paper discs soaked in 3 ml distilled water. Five maize grains were seeded per Petri dish. Three replicates were performed for each sample.

Purification of fungal pathogens from stored maize grains

Various colonies developed in incubated maize grains were purified by subculturing individual colonies on medium PDA under laminar flow hood. Mycelial disks were collected from each developed fungus growth front and placed in Petri dishes center. Several purifications were carried out to obtain pure strains (a single fungus) by transferring mycelium from fungi to new Petri dishes containing the same PDA medium.

Identification of fungi

Identification of fungi was started two weeks after first transplants following methods of Botton *et al.* (1990) and Barnett and Hunter (1972). Identified and unidentified fungi were then described.

Macroscopic identification of fungi

Macroscopic identification of the various fungal isolates was based on the study of cultural characteristics. Characteristics studied include pigmentation (color) of the upper and lower surfaces of colonies, growth rate, colony margins and mycelial appearance, considering morphotypes (Botton *et al.*, 1990).

Microscopic identification of fungi

Microscopic identification of fungus isolates was based mainly on morphological analysis of mycelium (absence or presence of partitions, color and pattern of ramification) and spores: shape, color, texture of walls, grouping into chains (Botton *et al.*, 1990). Each isolate was surface-sampled on PDA culture medium using a platinum loop, and placed on a glass slide with two drops of methylene blue cotton added. Then this slide was carefully heated with a Bunsen burner to facilitate reaction. Finally, the slide was covered with a coverslip. Several observations were made successively at different magnifications using optical microscopy until immersion (Botton *et al.*, 1990).

Data Analysis

Survey data were treated and analyzed using Sphinx Plus version 5 software. Data obtained from open discussions and direct observations were analyzed according to responses. Data entry and graphs were generated using Excel software, version 2021.

RESULTS

Demographic and Socioeconomic Characteristics of Traders

Surveys were carried out on a sample of 50 traders of maize grains in various markets in 10 communes surveyed in the Autonomous District of Abidjan (Côte d'Ivoire). Results in Table 1 show demographic and socio-economic characteristics of traders surveyed. Analysis of results in this table reveals that the market for wholesale maize grains is a male-dominated activity in the markets of Abidjan's communes. In fact, 72% of the traders surveyed were men, compared with 28% women (Table 1). In general, the level of education of those surveyed is high. The proportion of uneducated traders is much lower (15%) than that of educated traders (85% for all levels). For the 85% of traders with education, 58% had secondary education, 19% primary education and 8% higher education (Table 1). Most of maize grain wholesalers surveyed in the markets of the 10 communes of the Autonomous District of Abidjan were Ivorian (60%), with 30% being non-Ivorian (Table 1).

Table 1. Demographic and socioeconomic characteristics of traders.

Variables		Total	Percentage (%)
Sexe	Men's	36	72,00
	Women's	14	28,00
Level of education	Primary	9	18,00
	Secondary	29	58,00
	Superior	4	8,00
	Out of school	8	16,00
Nationality	Ivorian	30	60,00
	No Ivorian	19	38,00
	Unknown	1	2,00

Diversity of Commercialized Maize Ecotypes and Packaging Methods

In various markets of the 10 communes in the Autonomous District of Abidjan where the survey was carried out, three ecotypes of maize grains were sold: white maize, yellow maize and red maize. Red maize was the least common (1%), while the other two represented 99% with 49% and 50% respectively for white and yellow maize (Table 2). During surveys, all traders interviewed indicated that the maize grains sold came mainly from Côte d'Ivoire's agricultural regions, such as the centre-north and west, but in different proportions (Table 3). Thus, 40.45% of traders obtain their maize grains from localities in the north of Côte d'Ivoire. In contrast, 33.71% of maize grain traders reported that they obtained their supplies in central Côte d'Ivoire, compared with 24.71% in western Côte d'Ivoire. With regard to the packaging of maize grain, 94% of traders use jute bags and often plastic bags, while 6% prefer bulk packaging, based on storing their maize in baskets or on the ground (Table 2).

Damages Causes of Stored Maize Grains in Market

Surveys in markets across the 10 communes of the Autonomous District of Abidjan identified many common problems (Table 2). Main causes of maize grains in stock are breakage (47%), followed by mildew (37%), and finally color change and powdering (8%). Regarding causes of maize grain spoilage, 95% of retailers surveyed recognized the main causes of maize spoilage (Table 2). For these traders, spoilage of maize grains in stock is generally due to insects and fungi (55% and 41% respectively). However, they also reported losses due to rodents (8%) on various markets (Table 2). According to them, all these pests affect maize grain marketability and nutritional quality.

Traders' Methods to Control Maize Pests

Survey results for wholesale maize grains traders showed that 67% of them did not use any control methods against pests responsible for maize grain quality degradation in stock (Table 2). According to these traders, when maize begins to deteriorate, they send it to the semolina mill. The other 33% of traders indicated that they used methods to control pests that caused maize grain quality deterioration (Table 2). Out of the 33% of traders reporting methods of pest control for maize grains in stock, 92% used chemical methods of pest control (Table 2). However, they had refused to specify the commercial name of products used or active ingredients contained in those products. Other retailers (8%) used mechanical methods to control pests such as rodents and insects by killing them (Table 2). Biological control has not been used by market traders in the 10 communes surveyed to control pests on maize grains stocks.

Table 2. Main characteristics assessed during the survey.

Variables		Rate (%)	Total rate (%)
Colour of maize ecotypes sold on markets	Yellow	49	100
	White	50	
	Red	1	
Methods for conditioning maize grains	Bags	94	100
	Bulk	6	
Knowledge of grain deterioration causes	Yes	95	100
	No	5	
Different types of damage on maize grains	Mould	37	100
	Breaks	47	
	Colour change	8	
	Powders	8	
Main causes of maize grains spoilage	Insects	55	100
	Mould	41	
	Rodents	4	
Using of methods to control maize grain pests	Yes	33	100
	No	67	
Different types of control methods used against maize pests	Chemicals	92	100
	Mechanicals	8	
	Biologicals	0	

Table 3. Origin of maize sold on markets in the 10 communes.

Regions	City of origin	Proportion (%)	Total proportions (%)
North	Tengréla	13,48	40,45
	Ferkessédougou	5,62	
	Ouangolodougou	12,36	
	Dabakala	5,62	
	Korhogo	3,37	
Center	Oumé	8,99	33,71
	Sinfra	6,74	
	Divo	14,61	
	Daoukro	3,37	
West	Daloa	19,10	24,71
	Man	4,49	
	Issia	1,12	
Unknown	Inconnue	1,12	1,12

Identification of Fungi Genera Isolated from Stored Maize Grains

After 7 days' incubation at 25°C, fungal growth around maize grains was observed in all samples from the 10 commune markets, with variations in isolate percentage (Table 4). A total of 165 isolates were purified using two methods of isolation (disinfected and non-disinfected seeds). Combined macroscopic and microscopic analysis of purified colonies identified six fungal genera: *Aspergillus*, *Fusarium*, *Botryodiplodia*, *Pythium*, *Rhizopus* and *Trichoderma*. Of these six fungal genera, 13 species were identified. These include 6 species of the genus *Apergillus* (*Apergillus flavus*, *Aspergillus niger*, *Apergillus* sp.1, *Apergillus* sp.2, *Apergillus* sp. 3, *Apergillus* sp. 4), 3 species of the genus *Fusarium* (*Fusarium oxysporum*, *Fusarium* sp.1, *Fusarium* sp. 2), 1 species of the *Botryodiplodia* genus (*Botryodiplodia* sp.), 1 specie of *Pythium* genus (*Pythium* sp.), 1 specie of *Rhizopus* genus (*Rhizopus* sp.) and 1 specie of *Trichoderma* genus (*Trichoderma* sp.).

Table 4. Isolation rate according to sample origin.

Municipalities	Isolation rate (%)
Attécoubé	3,42
Anyama	8,46
Cocody	11,33
Adjamé	24,13
Yopougon	8,27
Koumassi	9,01
Port-Bouët	2,81
Treichville	9,75
Abobo	10,71
Marcory	12,11

Isolation Rates of Fungi Genera Responsible for Maize Grains Losses

Isolation rates of fungal genera responsible for maize grains damages on markets in the communes of the Autonomous District of Abidjan are illustrated in Figure 2. Isolation rates varied from one fungal genus to another, and within the same fungal genus from species to species ($p < 0.05$). This rate varied from 1.09% to 60.65% for fungal genera. Fungal genus *Aspergillus* had the highest isolation rate (60.65%), and genus *Rhizopus* was the least isolated (1.09%) in maize grains samples (Figure 2). Isolation rates for fungal species of *Aspergillus* genus ranged from 4% to 23.35%. The highest isolation rate was observed with *Aspergillus flavus* (23.35%) and the lowest with *Aspergillus* sp. 2 (4%). In *Fusarium* genus, isolation rates ranged from 6.85% to 12.03%. Highest isolation rates were obtained with *Fusarium oxysporum* (12.03%) and *Fusarium* sp.1 (11.40%), and lowest with *Fusarium* sp.2 (6.85%). Fungi were most isolated in maize samples from the commune of Adjamé (24.13%). In contrast, samples from the communes of Port-Bouët and Attécoubé had the lowest fungal isolation rates, at 2.81% and 3.42% respectively (Table 4).

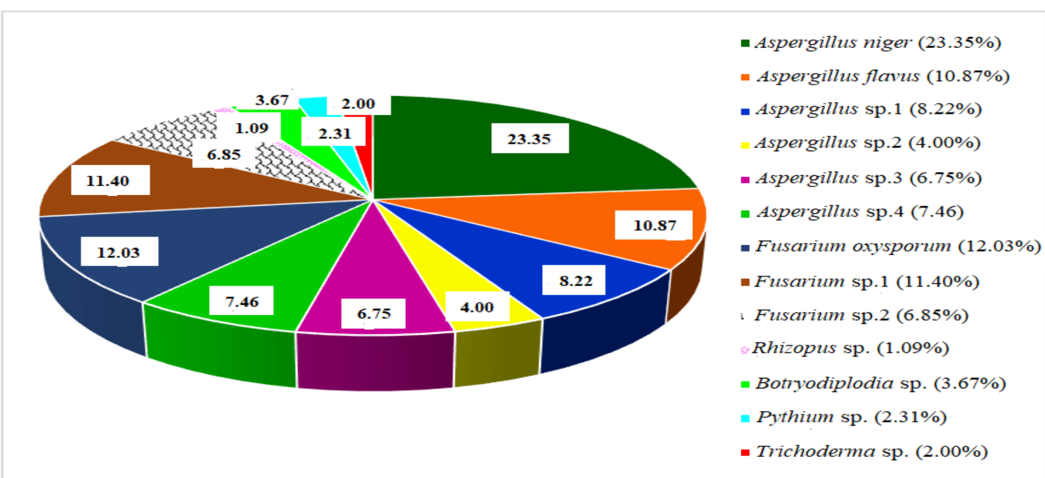


Figure 2. Isolation rate of fungal genera responsible for maize grains damage.

Morphological Diversity of Fungal Genera Responsible for Stored Maize Grains Damage

Morphological characteristics of the different fungal genera responsible for maize grains deterioration in storage using two weeks (14 days) strains aged are described above.

Description of *Aspergillus* Isolates

Aspergillus niger

On the upper surface, colony is granular and black with a colorless underside. The thallus is powdery. Microscopic observation shows a smooth, hyaline, long conidiophore with globular conidia (Figure 3A).

Aspergillus flavus

The thallus of the fungus is yellowish to white on the upper surface of Petri dish and unpigmented on the underside. Microscopically, mycelium is septate and conidia are clear, approximately colored or blackish. They are globose and ovoid (Figure 3B).

***Aspergillus* sp. 1**

The thallus of the fungus is fluffy white and powdery green in color, turning dark green as it ages with a colorless underside. Microscopically, a smooth, colorless conidiophore is observed with conidia and a vesicle (Figure 3 C).

***Aspergillus sp.* 2**

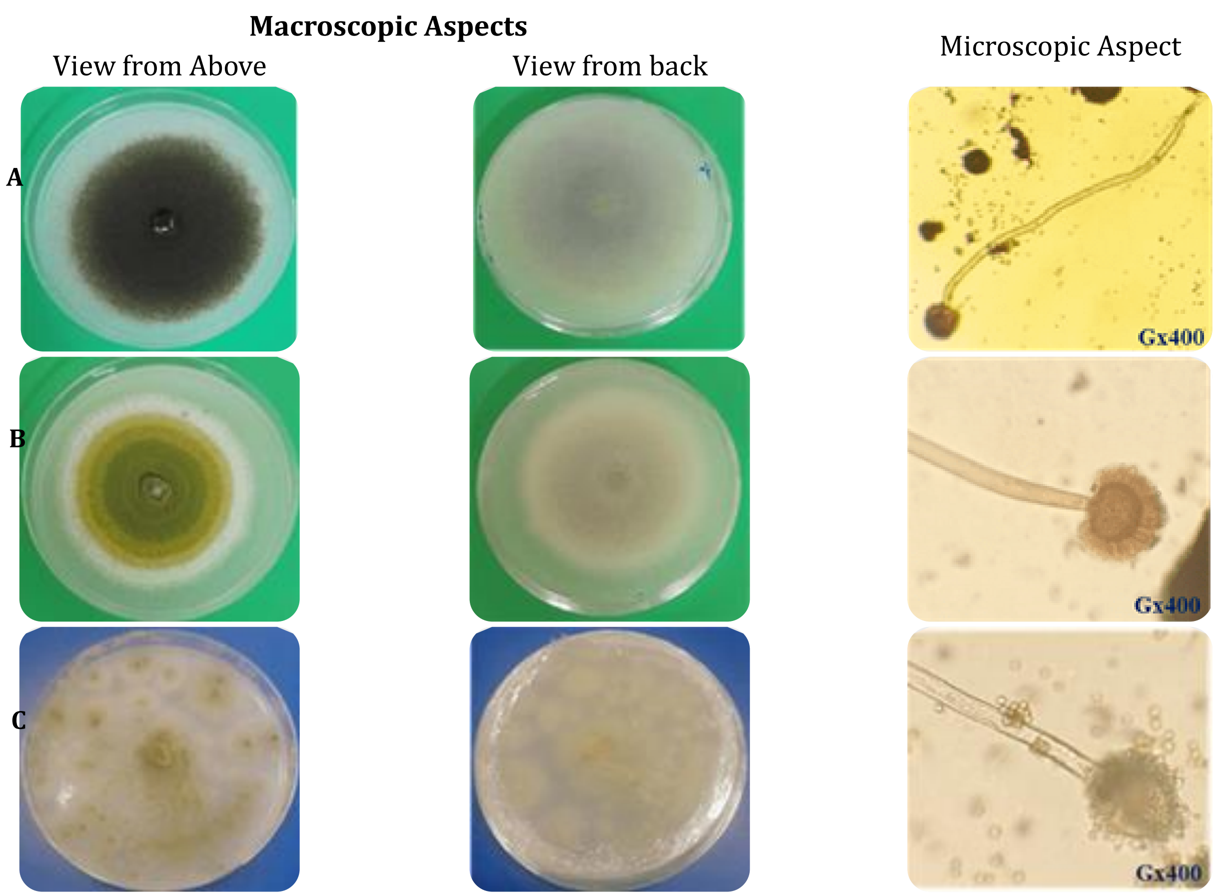
An abundant dark green powdery colony with a dark brown underside is observed. Smooth, colorless conidiophores with a spherical vesicle were observed under a microscope (Figure 3 D).

***Aspergillus* sp. 3**

On the upper surface, a green powdery colony can be seen growing in a circle. The underside is colorless and darkens with age. Microscopic examination revealed smooth, colorless conidiophores and small, dark conidia (Figure 3E).

***Aspergillus* sp. 4**

A light green, powdery colony is observed. The thallus is powdery, and the underside of this strain is unpigmented. Microscopic examination revealed an *Aspergillus* head with a smooth, colorless conidiophore (Figure 3F).



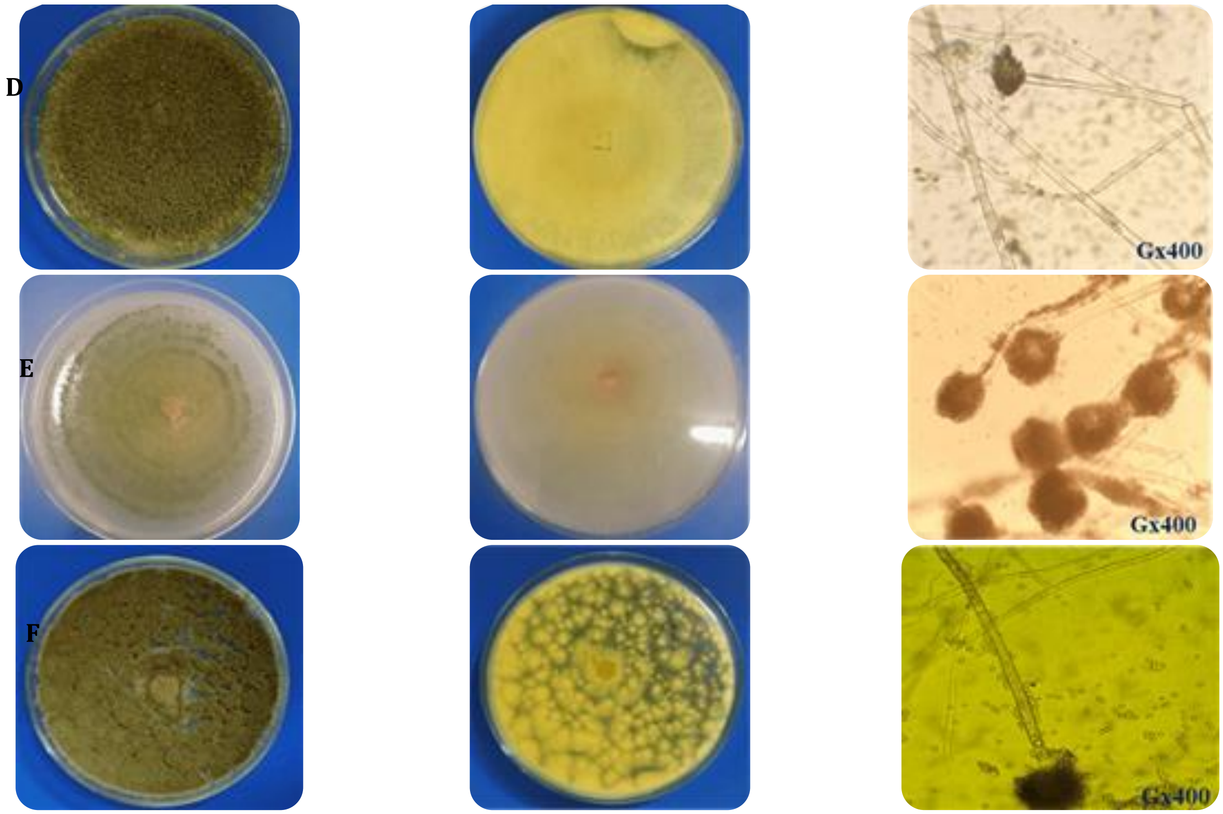


Figure 3. Macroscopic and microscopic aspects of isolates of the genus *Aspergillus;* A: *Aspergillus niger*; B: *Aspergillus flavus*; C: *Aspergillus* sp.1; D: *Aspergillus* sp.2; E: *Aspergillus* sp.3 and F: *Aspergillus* sp.4

Description of *Fusarium* Isolates

Fusarium oxysporum

Thallus of this fungus is white with a fluffy to flaky colony, white at first, then becoming pinkish to purple with age, with a darker mauve or purple underside. Macroconidia and microconidia can be observed under a microscope. The conidiophores are short and branched (Figure 4A).

***Fusarium* sp. 1**

Fungus appears dark pink with a dark purple underside. Abundant macroconidia and microconidia were observed under a microscope (Figure 4B).

***Fusarium* sp. 2**

The thallus of the fungus is downy with a pink coloration, and the underside is unpigmented. Microscopically, the conidiophores are simple with numerous ovoid conidia (Figure 4C).

Description of *Rhizopus*, *Pythium*, *Botryodiplodia*, and *Trichoderma* Isolates

***Botryodiplodia* sp.**

Fungus thallus is dark brown at the front and black at the reverse. Its cultural appearance is cottony, doubled and raised. Microscopic observation shows large, oval conidia with rounded ends, enclosed by a central envelope with septate spores (Figure 5A).

***Pythium* sp.**

A white, cottony colony with a white underside and very rapid growth. Microscopy revealed a round sporangium with a thin wall (Figure 5B).

***Rhizopus* sp.**

Colonies are very fast-growing and extensive, with a cottony thallus. Colonies are white at first, turning gray and darkening with age. Microscopic examination showed brown sporangiophores at the tips of the sporangia (Figure 5C).

***Trichoderma* sp.**

The appearance of the thallus is woolly white at first, and then greenish tufts appear with age, either isolated or arranged in concentric rings on the culture medium. The reverse side is yellow brown. Branched, smooth-walled mycelia can be observed under a microscope (Figure 5D).

DISCUSSION

Maize is a staple food for many people around the world.

However, during storage, materials are subjected to various biotic constraints, including mold caused by fungi. The overall aim of this study was therefore to contribute to food security by characterizing fungal pathogens of maize grains in storage. Results from this study shows that 72% of the wholesalers of maize grains in the markets of the 10 communes in the Autonomous District of Abidjan are men. Only 28% of women are engaged in this commercial activity. This result is in contrast to the findings of Miassi *et al.* (2018), who reported in their study in southern Benin that maize marketing was a predominantly female activity. Indeed, they found that 78% of the traders surveyed were women. This difference could be explained by the study, which focused only on maize wholesalers, whereas Miassi *et al.* (2018) surveyed wholesalers, semi-wholesalers and retailers. Wholesalers represent the first actors in the commercial chain after growers. The difference could also be explained by the fact that wholesale maize marketing is an activity that requires intense muscular effort, explaining the high frequency of men in our study. However, Aké (2016) showed in his study on the development factors of commercial activities on the markets of Abidjan that the proportion of women engaged in trade was estimated at 60% and that of men at 40%.

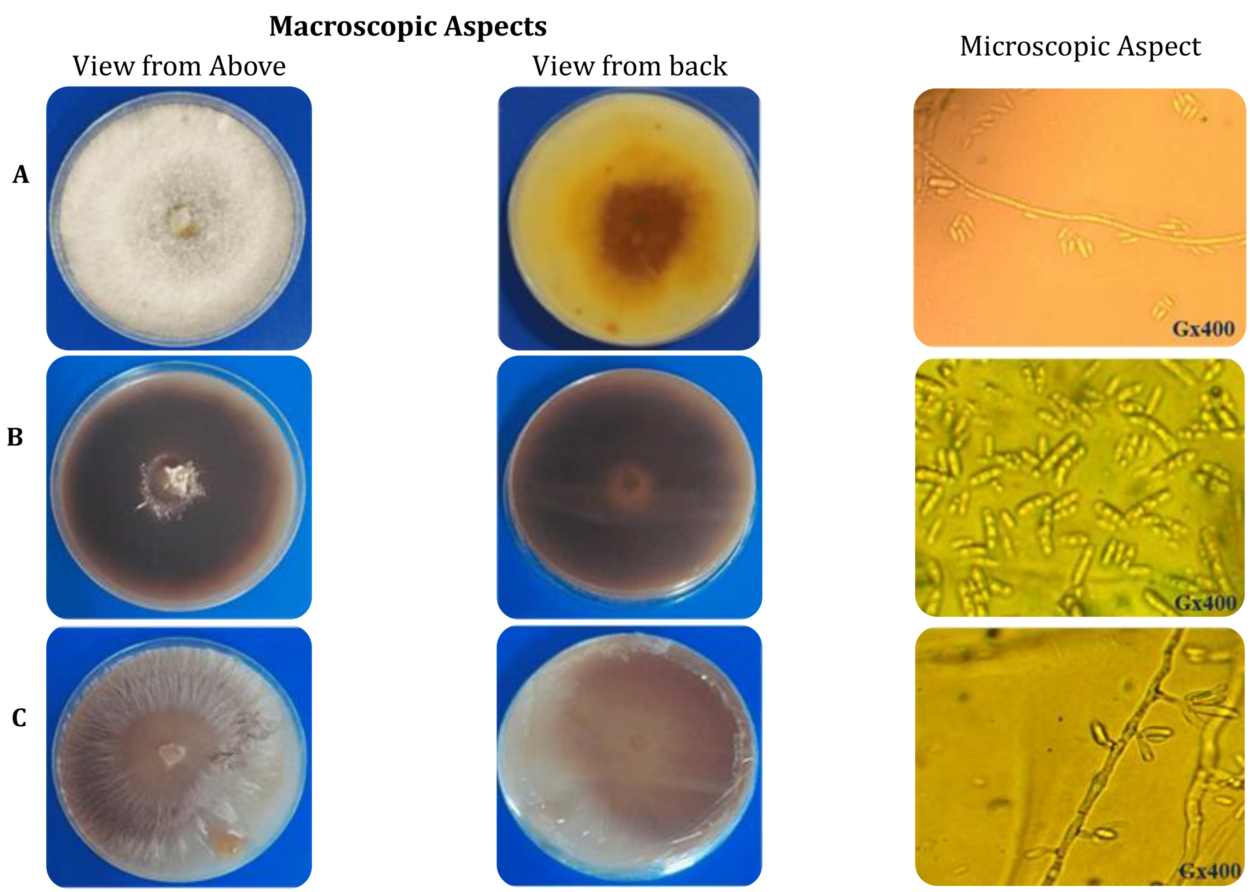


Figure 4. Macroscopic and microscopic aspects of isolates of the genus *Fusarium;* A: *Fusarium oxysporum*, B: *Fusarium* sp.1 and C: *Fusarium* sp.2.

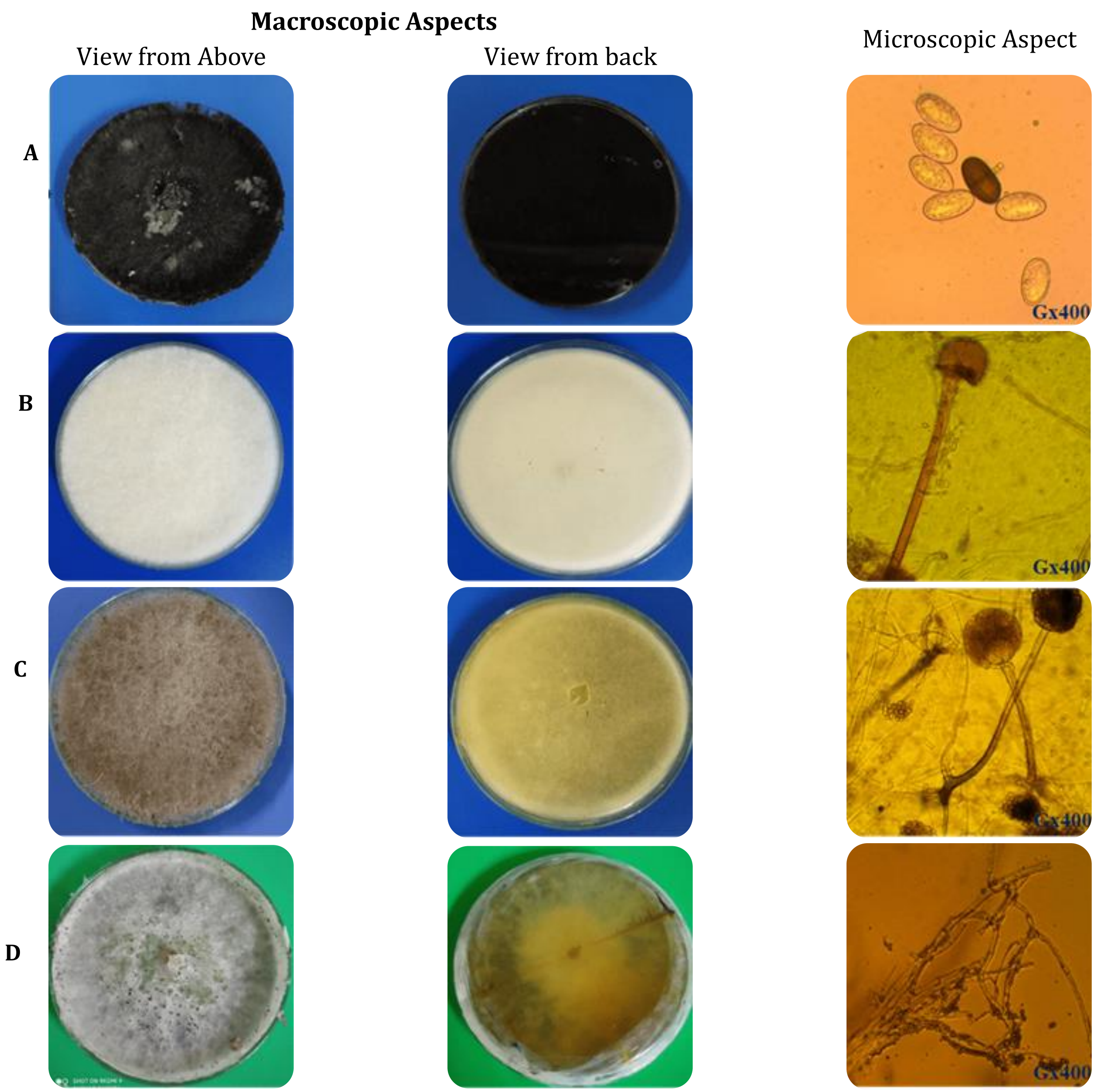


Figure 5. Macroscopic and microscopic aspects of isolates of other fungal genera; A: *Botryodiplodia* sp., B: *Pythium* sp., C: *Rhizopus* sp. and D: *Trichoderma* sp.

Traders of different markets in the 10 communes of Abidjan district surveyed have various levels of education. Indeed, 58% of those surveyed had secondary education, 18% had primary education, and 8% had higher education. This gives a school enrolment rate of 84%, compared with 16% who had not attended school. This result disagrees with that of Miassi *et al.* (2018), who found that 70% of maize traders in Benin are not educated. Similarly, Aké (2016) showed that commercial activity in general on the markets of the Autonomous District of Abidjan is characterized by a low level of education of its actors and does not require obtaining a diploma. However, it should be noted that the level of education is an important and very favorable asset for the introduction of innovations among traders.

Regarding maize ecotypes selling on markets in 10 communes of the Autonomous District in Abidjan, 3 ecotypes were identified (White, Yellow and Red) with different rates. White is the most widely available ecotype (50%), followed by yellow (49%). Red ecotypes were rarely found (1%) among the retailers surveyed. This difference in ecotypes could be explained by the sources of supply for maize traders, which are not the same growing areas. Indeed, 40.45% of maize stocks found on the markets come from the north of Côte d'Ivoire, 33.71% from the center, 24.71% from the west and 1.12% from an unknown source.

Insects (55%), mold (41%) and rodents (4%) are the main causes of deterioration of maize grains in stock. To control these pests of maize grains, 33% of traders use control methods versus 67% who do not. According to Johnson *et al.* (2012), insects are the main problem for rice and maize storage in agricultural areas, and the *Sitophilus* genus is the most important pest. The different damages associated with mold attacks include depreciation of maize quality by changing its taste and color, and the possibility of transmitting toxins, such as aflatoxins, dangerous to human health (Bourais and Amine, 2006; Montet, 2022).

Sanitary analysis of samples collected from various markets identified six fungal genera: *Aspergillus*, *Fusarium*, *Botryodiplodia*, *Pythium*, *Rhizopus* and *Trichoderma*. Isolation percentages varied from one fungal genus to another. Aspergillus genus was the most commonly found in all maize samples. These results are in line with those of Reddy *et al.* (2004), who also reported that the genus Aspergillus was one of the most common fungi in cereal and poultry feed samples. According to Hajjaji *et al.* (2006) and Jedidi *et al.* (2018), this pathogen is very common in stored cereals in Africa. The *Fusarium* genus is the second largest number of species isolated. This result is in line with those of Compaoré *et al.* (2021) and Gaston *et al.* (2023) who reported that the genus *Fusarium* is one of the fungi frequently found in maize seeds in Burkina Faso. The abundance of *Aspergillus* and *Fusarium* genera in stored maize seed can be directly linked to storage conditions in traders' warehouses and humidity in storage areas. During the survey, we found that most of the traders we met did not respect maize conditioning standards in their warehouses, and that most of these storage areas were humid or ventilated. The two genera *Aspergillus* and *Fusarium* are known to be very harmful fungi for human and animal health, due to their mycotoxins (Compaoré *et al.*, 2021).

In the genus *Aspergillus*, two species have been morphologically identified: *A. flavus* and *A. niger*. However, according to Klich (2007), *A. flavus* is an opportunistic crop pathogen with a cosmopolitan distribution. It is best known for its colonization of cereals, legumes and nuts. *A. flavus* is considered particularly harmful to seeds, as it produces several types of aflatoxin Compaoré *et al.* (2021). However, *Aspergillus niger* is a fungus commonly found in onion seeds, reducing seed germination (Dabire *et al.*, 2021). According to Tabuc (2007), *Fusarium* is a field contaminant that affects agricultural products both before and during harvest. *Fusarium* is a microscopic fungus responsible for infection of both plants and certain animal foods. Fungal species of these two genera (*Aspergillus* and *Fusarium*) require special attention in order to propose effective, appropriate and sustainable control solutions that are affordable for farmers and traders.

CONCLUSION

This study characterized wholesale maize grain traders on the 10 commune markets of Autonomous District of Abidjan in order to identify the main causes of maize damage stored in stores, and to isolate and identify the fungal pathogens responsible for this damage. The maize grain wholesale trade is mainly carried out by men on the markets of the Autonomous District of Abidjan. Traders have a higher level of education than others. The wholesale maize grain trade is mostly owned by Ivorians. Maize grains in stock are affected by a number of factors, including insects and fungi. Six fungal genera were isolated from maize grains samples and identified morphologically. These were *Aspergillus*, *Fusarium*, *Botryodiplodia*, *Pythium*, *Rhizopus* and *Trichoderma*. *Aspergillus* and *Fusarium* were the most isolated fungal genera. Both pathogens are toxigenic and can produce mycotoxins under the right conditions, so particular attention must therefore be given to them.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

TS proposed the research topic, devised the methodology, and wrote the manuscript. AAH Field data collection and pathogen isolation; CB supervision of the work and correction of the manuscript; ABLA statistical analysis of the data collected; BB identification of fungal pathogens; YG data entry and correction of the manuscript; and KD supervision of the work, provision of working materials, and correction of the manuscript.

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