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Morphometric analysis of *Fusarium* spp. isolates and relationship with pathogenic potential in banana Grande Naine (*Musa* sp. Cavendish) in Côte d'Ivoire

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Abstract*: Fusarium* is one of the best-known plant pathogenic fungi, particularly in bananas. This study was conducted to determine the variability of *Fusarium* isolates and their potential impact on banana quality in Côte d'Ivoire. Apparently healthy bananas were collected from the seven production localities and used to isolate the associated fungi. Morphological characterization of the fungi included macroscopic (appearance, coloration and mycelial growth) and microscopic (presence or absence of septa, shape, size and conidial concentration) cultural characteristics. The pathogenicity of the isolates was assessed by the absence or presence of rotting symptoms on the bananas. The results showed that the coloration of the *Fusarium* isolates varied from white to yellow. Some isolates were cottony and thick, while others were flaky and carpeted. The mean macroconidia dimensions were 19.11-29.52 × 2.69-4.64 µm. The average number of septa in macroconidia ranged from 3-5 septa. Macroconidia were fusiform with pointed ends; microconidia were oval with one or two pointed ends. Among the morphometric characteristics of *Fusarium* isolates, the number and size of macroconidia was the most important discriminating traits for differentiating isolates. In terms of pathogenicity, all isolates caused a symptom except the one isolated in the Dabou area, which did not cause any symptoms. The incubation period varied from 10 to 16 days depending on the isolate.

1. Introduction

Banana (*Musa accuminata* L.) is one of the most widely traded fruits in the world and plays a significant role in the economies and diets of many tropical and inter-tropical countries. It ranks 4th in the world after rice, wheat and maize in terms of global yield (Lassoudière, 2007). As well as playing a significant role in food security, bananas are a cash crop and a

source of employment and income for local populations (Arias *et al*., 2003). In Côte d'Ivoire, the banana sector is one of the mainstays of the agricultural economy. With a cultivated area of 11,918 ha (FAO, 2022) and production of 531,382.44 tons in 2022 (FAO, 2022), Côte d'Ivoire ranks 2nd behind Cameroon in Africa and 13th in the world. Banana dessert industry in Côte d'Ivoire is based on a limited number of cultivars belonging to the Cavendish sub-group, and the varieties marketed in Côte d'Ivoire are 'Grande naine', 'Poyo' and 'Williams' (Kouassi, 2001; Kouame and Kanpigni, 2022). It accounts for 8% of agricultural GDP and provides 15,000 direct jobs and 30,000 indirect jobs (Chauvin *et al.*, 2025).

However, annual banana production and quality are severely reduced by pest and disease attacks. Losses caused by pests and diseases can reach 100%, affecting all organs of banana plant, from roots to flowers (Ploetz *et al*., 2003). In addition to field diseases, post-harvest fungal diseases are another major threat, especially for dessert bananas intended for export. These are crown rot and anthracnose, which cause significant damage and economic losses due to the deterioration of bananas during storage and transport (Nath *et al*., 2014; Kra *et al*., 2018).

Among the fungi associated with these post-harvest diseases, the genus *Fusarium* is among the most common and most damaging to fruit (Nelson *et al*., 1981). The *Fusarium* genus is a cosmopolitan fungus that can be transported by soil, air or plant debris. On bananas, this fungus is responsible for rotting (Ploetz, 2006). At least six species of *Fusarium* have been described as responsible for or associated with banana rots throughout the world. These are *Fusarium camptoceras*, *Fusarium concentricum*, *Fusarium proliferatum*, *Fusarium semitectum* and *Fusarium subglutinans* (Ploetz *et al*., 2003; Leslie and Summerell, 2006). This diversity of *Fusarium* species in bananas makes it difficult to identify the precise agent responsible for rotting (Ploetz, 2006). As a result, the pesticides used to control the disease are ineffective and targeted control strategies have failed. With a view to ensuring agricultural sustainability and boosting the competitiveness of banana exports, this study was conducted with the aim of understanding the variability that exists among species belonging to the *Fusarium* genus. It focuses on their involvement in the development of post-harvest diseases in bananas in Côte d'Ivoire in order to contribute to improving the quality of bananas for export.

2. Materials and Methods

Collection site

Banana dessert samples were collected from seven production areas in Côte d'Ivoire (Fig. 1): Abengourou (6°43' N,-3°29' W), Aboisso (5°55'N, -4°12'W), Agboville (5°55'N, -4°12'W), Azaguié (5°55'N, -4°12'W), Dabou (5°19' N, -4°22'W), Grand-Bassam (5°12'N, -3°44'W); and Tiassalé (5°53'N, -4°49'W). The sample collection was done every 6 months during one year

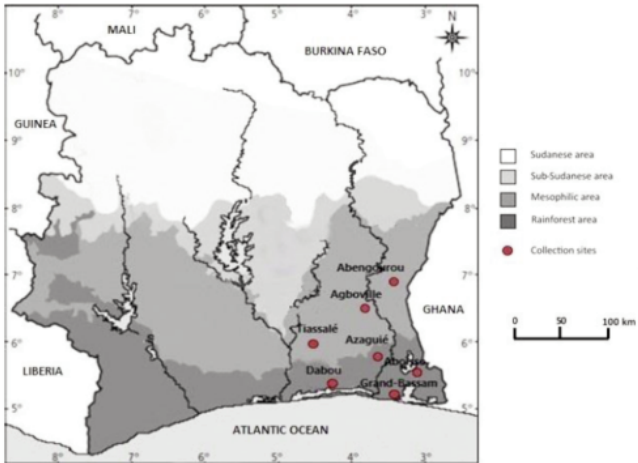

Fig. 1 - Map of banana sample collection sites in Côte d'Ivoire.

Plant material

The material consisted of ripe and apparently healthy bananas of the Grande Naine variety from the Cavendish subgroup. In each production stations, 65 banana fingers was collected each 6 months for isolation. A total of 2,080 banana fingers 18 weeks old were collected from all seven banana-producing localities in Côte d'Ivoire. For the pathogenicity test, 81 mature banana fingers were collected in the Dabou area. A total of 2161 banana fingers were used for the study.

Sampling of *banana*

Samples of 18-week-old bananas were collected at random from 16 production stations in seven production areas in Côte d'Ivoire. Three boxes (100 bananas/box) were taken from pallets of bananas ready for export at each production station. The bananas were incubated for 21 days at room temperature (27±1°C) until symptoms developed at the Plant Health Unit laboratory at Nangui Abrogoua University.

Isolation of fungal strains

Bananas showing symptoms of post-harvest diseases after 21 days of storage were used for the isolation of fungi. The surface of the bananas was disinfected with 1% diluted sodium hypochlorite for 5 minutes. Explant pieces measuring approximately 5 mm, taken from the edge of each symptom, were seeded on agar in Petri dishes (Meddah *et al*., 2010). The Petri dishes were incubated at laboratory temperature (27 ± 1°C) until fungal colonies developed. The colonies developed from each explant were transferred to Potato Dextrose Agar (PDA) medium and purified by single spore culture according to the method adapted from Choi *et al*. (1999).

Morphological characterization of fungal strains

Evaluation of mycelial growth. Colony diameter of isolated fungi was measured daily along two perpendicular axes drawn on the back of each Petri dish, and the mean of the two values was recorded. For each isolate, three plates were used, and the experiment was repeated three times. The mycelial diameter was calculated daily using the modified Dohou formula (Dohou *et al.*, 2004):

$$\mathrm{di} = \frac{\mathrm{d1+d2}}{2}$$

where di is colony diameter of strain I, d1 is colony diameter of strain along axis 1 and d2 = colony diameter of strain along axis 2.

The mean growth diameter was then calculated for the three Petri dishes using the following formula:

$$D = \frac{1}{\mathrm{n}} \sum(\mathrm{di})$$

where *D* is mean diameter of the colony of strain I, di = diameter of the colony of strain I and n = 3

Macroscopic and microscopic description of fungal strains. Cultural characteristics, namely side and reverse coloration, mycelium aspect and isolate growth pattern, were observed on PDA medium. These parameters were evaluated on seven-day-old isolates.

Microscopic observation of isolates was performed after 15 days of incubation on PDA medium. Three plates were used for each isolate, and preparations were made and observed.

For each isolate, three boxes were used and mounts were prepared and observed between a slide and cover slip under an optical microscope fitted with a micrometer at 400× magnification (Optika, Italy). The conidia shape (macroconidia and microconidia) was described, and the dimensions and number of septa of the macroconidia were evaluated after observing 90 conidia per isolate.

Evaluation of fungal strain sporulation. The number of spores produced was assessed by measuring the spore concentration of 15-day-old *Fusarium* isolates. Three 6 mm diameter mycelium pellets were taken from the colonies and placed in 10 ml of distilled water. The solution was gently shaken for 30 seconds to separate the conidia from the conidiospores. The different conidial suspensions were obtained after being filtered through sterile Whatman paper.

The number of conidia in the solutions was determined after counts were made in 1 µl of spore suspension using a Malassez slide. Ten rectangles were considered. Three spore solutions were prepared per isolate and 10 counts were performed per spore solution. The average number of conidia per millilitre of solution was calculated using the formula developed by Duncan and Torrence (1992):

$$N = \frac{\sum(\mathrm{ni})}{\mathrm{a\,x\,V}} \mathrm{\,x\,Fd}$$

where N is mean number of conidia, ni is conidia number per rectangle i, a is number of rectangles considered, V is volume of a small rectangle (L×W×H = 0.01 mm) and Fd is dilution factor

Assessment of the pathogenicity of fungal strains

Production of fungi inoculum. Fusarium conidia suspension was obtained from 15-day-old cultures. Three mycelium pellets were taken and placed in 10 ml of sterile distilled water. The suspension obtained was filtered through sterile filter paper to separate the conidia and mycelial fragments. The spore solutions were adjusted to a final concentration of 10^6 conidia/ml with distilled water.

Soft inoculation of banana fruits. Bunch of apparently healthy bananas, ready to be packaged at the station, were collected at random on the day of the experiment. These bananas were cut to obtain several detached fingers. The surface of the crowns was refreshed with a sterile scalpel. The fruits were soaked in a 2% diluted sodium hypochlorite (NaClO) solution for 5 min. The fruits were then dried on sterile tissue paper under a laminar flow hood. The soft inoculation technique was used to evaluate the path-

ogenicity of the eight *Fusarium* isolates.

Sterile compresses were soaked in 50 µl of spore suspension from each isolate and placed on the crown, epicarp and distal end of each fruit in order to assess the sensitive part of the banana.

The inocula were kept on the fruit using sterile parafilm. The bananas were then incubated at room temperature (28±1°C). The pathogenicity of the *Fusarium* isolates was studied and demonstrated by the development of symptoms and the incubation time of the disease. Three bananas were used per isolate tested, and the experiment was repeated three times. Control bananas were inoculated with sterile distilled water and placed under the same conditions as the test bananas (Fig. 2).

Statistical analyses

The data collected during this study were analyzed using Statistica software (version 7.1). A one-factor analysis of variance was performed to compare the average colony diameters on day 5 and the average number of partitions in the macroconidia of *Fusarium* isolates.

A two-factor analysis of variance was used to compare the average sizes of macroconidia and

Fig. 2 - Control and test bananas: Left= Control bananas inoculated with distilled water; Right= Test bananas inoculated with the spore suspension of the fungal

microconidia according to *Fusarium* isolates, as well as the average spore concentrations of macroconidia and microconidia from different *Fusarium* isolates.

Significant results at the 5% threshold were separated with least significant difference (LSD) test.

3. Results

Macroscopic characteristics of Fusarium isolates

Culture of isolates on PDA medium showed diversity in color, aspect and mode of mycelial growth. Three morphological groups were observed (Table 1).

Isolates F1 from the Abengourou area, F3 from

Table 1 - Cultural characteristics of the morphological groups of the eight *Fusarium* isolates

Morphological groups	Collection areas	Isolates	Coloration (front)	Coloration (reverse)	Colony aspect	Growth pattern
Creamy white colour (front and reverse)	Abengourou Abidjan Aboisso Dabou Grand- Tiassalé	F1 F3 F4 F6 F7 F8			carpet-like and cottony	diffuse
Ivory colour (front) Light yellow colour (reverse)	Abengourou	F2			dense and cottony	concentric circles
Light yellow colour (front and reverse)	Azaguié	F5			carpet-like and cottony	diffuse

(F 1) Isolate 1 from Abengourou; (F 2) Isolate 2 from Abengourou; (F 3) Isolate from Abidjan; (F 4) Isolate from Aboisso; (F 5) Isolate from Azaguié; (F 6) Isolate from Dabou; (F 7) Isolate from Grand-Bassam; (F 8) Isolate from Tiassalé.

Abidjan, F4 from Aboisso, F6 from Dabou, F7 from Grand-Bassam and F8 from Tiassale had white mycelium on the top and bottom of the Petri dish. The aspect of their mycelium was flaky and carpet-like, with a diffuse growth pattern. Isolate F2 from Abengourou had yellow-colored mycelium on the front. On the back, the mycelium was yellow in the centre and white at the margin. The mycelium was cottony and thick with concentric rings. Isolate F5 from Azaguié had yellow aerial mycelium and a pale yellow back. The mycelium was flaky and carpet-like. Isolate F5 from Azaguie had yellow aerial mycelium and a pale yellow underside. The mycelium was flaky and carpet-like in aspect. The growth pattern was diffuse.

Mycelial growth of Fusarium isolates

The average diameters of *Fusarium* isolates varied over time on PDA medium. Statistical analysis revealed a significant difference between the average colony diameters (F = 10.120 and P < 0.001). The mycelial growth curves of *Fusarium* isolates showed an initial adaptation period from day 1 to day 2, during which weak growth in colony diameter was observed for all isolates (from 0.85 to 1.84 cm). Then, a phase of rapid radial expansion from day 2 to day 4, during which the diameter of the colonies of isolates F1, F2, F3, F5, F6, F7 and F8 showed rapid growth (from 1.2 to 5 cm), except for isolate F4, which showed slow growth (from 0.86 to 1.64 cm). Finally a plateau phase from day 4 to day 9, during which the diameter of the colonies of isolates F1, F2, F3, F5, F6, F7 and F8 reached a plateau of around 5 to 5.5 cm, except for isolate F4, which grew slowly from 1.62 to 5 cm, reaching a plateau at the end of day 8 (Fig. 3).

Microscopic characteristics of Fusarium isolates

Two types of conidia were observed among the *Fusarium* isolates. Some conidia, called macroconidia, had partitions and were elongated, spindle-shaped, with both ends pointed. Other conidia, called microconidia, had no septa and were hyaline with different shapes (Table 2).

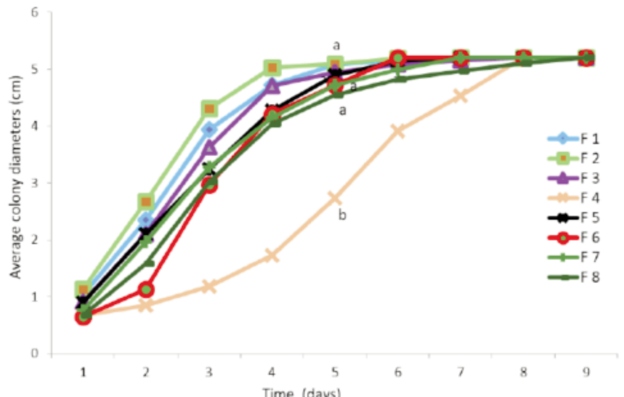

Fig. 3 - Evolution of the average diameters of *Fusarium* isolates over time: (F 1) Isolate 1 from Abengourou; (F 2) Isolate 2 from Abengourou; (F 3) Isolate from Abidjan; (F 4) Isolate from Aboisso; (F 5) Isolate from Azaguié; (F 6) Isolate from Dabou; (F 7) Isolate from Grand-Bassam; (F 8) Isolate from Tiassalé. Values assigned the same letter are identical according to Fisher's LSD test at the α= 5% threshold.

Table 2 - Different shapes of macroconidia and microconidia of *Fusarium* isolates

Fusarium isolates	Macroconidia	Microconidia
F 1 , F 3, F 4, F 5, F 6, F 7, F 8	Fusiform (two pointed ends)	Oval (two rounded ends)
F 2	Fusiform (two pointed ends)	Oval (one rounded end and one pointed end)

(F 1) Isolate 1 from Abengourou; (F 2) Isolate 2 from Abengourou; (F 3) Isolate from Abidjan; (F 4) Isolate from Aboisso; (F 5) Isolate from Azaguié; (F 6) Isolate from Dabou; (F 7) Isolate from Grand-Bassam; (F 8) Isolate from Tiassalé.

All isolates had fusiform macroconidia with both ends pointed. Isolates F 1 from Abengourou, F3 from Abidjan, F4 from Aboisso, F5 from Azaguié, F6 from Dabou, F7 from Grand-Bassam and F8 from Tiassalé had oval-shaped microconidia with rounded ends.

Variability in the morphometric dimensions of macroconidia in Fusarium isolates

Diversity was observed in the average morphometric dimensions (length and width) of macroconidia depending on the *Fusarium* isolates (Fig. 4). Statistical analyses showed a significant difference ($F = 39.75$ and $P < 0.001$). The average length of macroconidia in the eight *Fusarium* isolates ranged from 19.11 µm to 29.52 µm. The average width of macroconidia in the eight *Fusarium* isolates ranged from 2.69 µm to 4.64 µm.

The F1 isolate from Abengourou and the F5 isolate from Azaguié had the longest macroconidia. The F3 isolate from Abidjan and the F6 isolate from Dabou had the smallest macroconidia. The F5 isolate from Azaguié and the F1 isolate from Abengourou had the widest macroconidia. The F4 isolate from Aboisso, the F6 isolate from Dabou and the F7 isolate from Grand-Bassam had the narrowest macroconidia.

Statistical analysis showed an interaction between the length and width of the macroconidia. Strains F1 and F5 had the longest and widest macroconidia. Isolates F3, F4 and F6 had shorter and narrower macroconidia. Morphometric dimensions of macroconidia (µm)

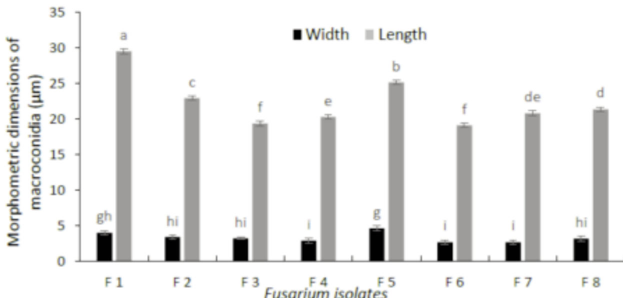

Fig. 4 - Variations in the average morphometric dimensions of *Fusarium* isolate macroconidia according to different collection areas G×400: (F 1) Isolate 1 from Abengourou; (F 2) Isolate 2 from Abengourou; (F 3) Isolate from Abidjan; (F 4) Isolate from Aboisso; (F 5) Isolate from Azaguié; (F 6) Isolate from Dabou; (F 7) Isolate from Grand-Bassam; (F 8) Isolate from Tiassalé. Values assigned the same letter are identical according to Fisher's LSD test at the α= 5% threshold.

Variability in the morphometric dimensions of microconidia in Fusarium isolates

Diversity was observed in the average morphometric dimensions (length and width) of microconidia depending on the *Fusarium* isolates (Fig. 5). Statistical analyses showed a highly significant difference ($F = 39.86$ and $P < 0.001$). The average length of microconidia in *Fusarium* isolates ranged from 6.11 µm to 10.53 µm. The average width of microconidia in the eight *Fusarium* isolates ranged from 2.5 µm to 3.00 µm. The F7 isolate from Grand-Bassam and the F3 isolate from Abidjan had the longest macroconidia. The F2 isolate from Abengourou and the F6 isolate from Dabou had the smallest microconidia. Isolate F5 from Azaguié had the widest microconidia. Isolates F2 from Abengourou, F3 from Abidjan, F4 from Aboisso and F6 from Dabou had the narrowest microconidia.

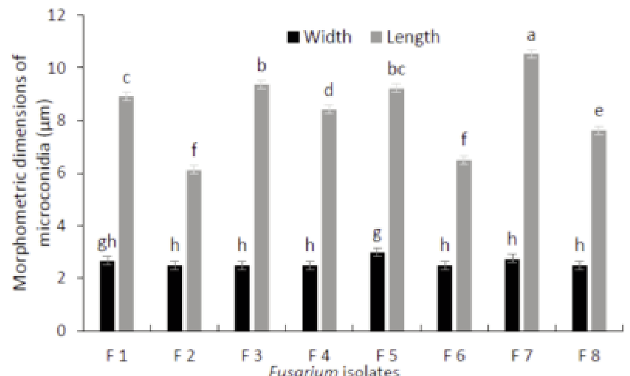

Fig. 5 - Variations in the average morphometric dimensions of *Fusarium* isolate macriconidia according to different collection areas G×400: (F 1) Isolate 1 from Abengourou; (F 2) Isolate 2 from Abengourou; (F 3) Isolate from Abidjan; (F 4) Isolate from Aboisso; (F 5) Isolate from Azaguié; (F 6) Isolate from Dabou; (F 7) Isolate from Grand-Bassam; (F 8) Isolate from Tiassalé.

Groups of macroconidia with a homogeneous number of septa

The number of septa in the macroconidia was ranged from 3 to 5. Statistical analysis showed a highly significant difference between the number of septa in *Fusarium* isolates depending on the collection area ($F = 12.55$ and $P < 0.001$). The two isolates from Abengourou and the one from Tiassalé had the highest number of partitions (4-5 septa), while the isolate from the Azaguié area had the lowest number of partitions (3-4 septa). The other isolates had an intermediate number of partitions between 3 and 4 septa (Fig. 6).

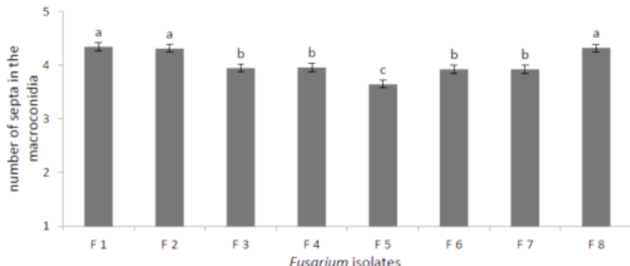

Fig. 6 - Average number of septa in macroconidia of *Fusarium* isolates in collection areas G×400: (F 1) Isolate 1 from Abengourou; (F 2) Isolate 2 from Abengourou; (F 3) Isolate from Abidjan; (F 4) Isolate from Aboisso; (F 5) Isolate from Azaguié; (F 6) Isolate from Dabou; (F 7) Isolate from Grand-Bassam; (F 8) Isolate from Tiassalé. Values assigned the same letter are identical according to Fisher's LSD test at the α= 5% threshold.

Groups of isolates with homogeneous conidia concentration

The average concentration of macroconidia was 3.5×10^5 conidia/ml, while that of microconidia was 3.1×10^5 conidia/ml (Fig. 7). The macroconidia concentration of *Fusarium* isolates ranged from 1.7×10^5 to 6.3×10^5 conidia/ml. The microconidia concentration ranged from 3.4×10^5 to 9.9×10^5 conidia/ml (Fig. 7).

The highest concentration of conidia (macroconidia and microconidia) was 7.10^5 conidia/ml. In contrast, the lowest concentration of conidia was 114.10^3 conidia/ml. Statistical analysis showed a highly significant difference ($F = 260.213$ and $P < 0.001$). Statistical analysis showed an interaction between the average concentrations of conidia and *Fusarium* isolates ($F = 212.439$ and $P < 0.001$).

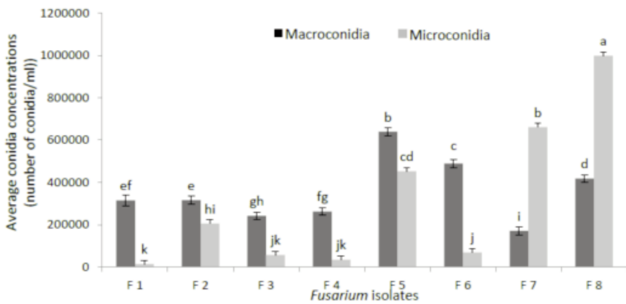

Fig. 7 - Variations in average spore concentrations in macroconidia and microconidia of *Fusarium* isolates in different collection areas: (F 1) Isolate 1 from Abengourou; (F 2) Isolate 2 from Abengourou; (F 3) Isolate from Abidjan; (F 4) Isolate from Aboisso; (F 5) Isolate from Azaguié; (F 6) Isolate from Dabou; (F 7) Isolate from Grand-Bassam; (F 8) Isolate from Tiassalé. Values assigned the same letter are identical according to Fisher's LSD test at the α= 5% threshold.

The group composed of isolates from Abengourou, Abidjan, Azaguié, Aboisso and Dabou had more macroconidia than microconidia. The group composed of isolates from the Tiassalé and Grand-Bassam areas had more microconidia than macroconidia. Two patterns emerged in each of the two groups: in the first group, some isolates (Abengourou and Azaguié) produced more macroconidia than others (Abidjan, Aboisso and Dabou); in the second group, some isolates (Tiassalé) produced more microconidia than others (Grand-Bassam).

Correlation between the morphometric parameters of Fusarium isolates

Principal component analysis revealed the existence of two dimensions (dim1 and dim2) with respective inertia rates of 25.5% and 17.4% (Fig. 8). The variables macroconidia length (ML), macroconidia width (MW) and septa number (NS) are the variables that strongly influence (20 to 25%) the formation of the dim1 axis. The variable microconidia width (mW) contributes moderately (15%) to the formation of the dim1 axis. On the other hand, the variables macroconidia concentration (CM), microconidia concentration (Cm) and microconidia length (mL) strongly influence the formation of both axes. There is a

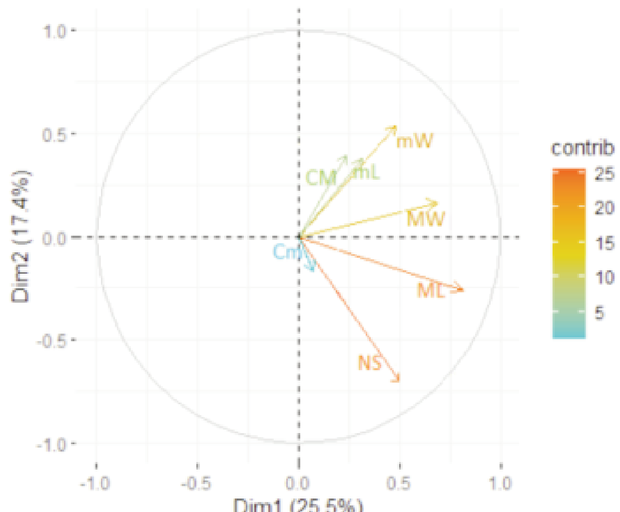

Fig. 8 - Correlation between the morphometric parameters of *Fusarium* isolates infecting bananas: (ML) Macroconidia length; (MW) Macroconidia width; (mW) Microconidia width; (Ml) Microconidia length; (NS) Septa number; (CM) Concentration of macroconidia, (Cm) Concentration of microconidia; (Dim 1) Dimension 1; (Dim 2) Dimension 2; (Contrib) Contribution.

very strong positive correlation between the ML, mW and NS variables. Similarly, the correlation between the mL and MW variables is strongly positive. However, there is no correlation between the variables CM and Cm. Thus, the morphometric dimensions and number of macroconidia are the most discriminating variables. The morphometric dimensions of microconidia are less discriminating.

Pathogenicity of Fusarium isolates

Symptoms observed. Soft inoculation of bananas with *Fusarium* isolates showed only one type of symptom depending on the part of the banana inoculated and the strain (Fig. 9). The symptom was characterised by soft brown rot of varying extent on the surface of the fruit. Considering the strain inoculated, all isolates caused soft rot, except for the Dabou strain, which caused no symptoms. The control bananas showed no symptoms. As for the inoculated part of the banana, the isolates from Abengourou, Abidjan, Aboisso, Azaguié and Grand-Bassam all caused symptoms at the crown of the infected bananas. The Tiassalé isolate caused symptoms at the distal end, and the Aboisso isolate caused symptoms on the crown and distal end of the inoculated bananas. However, no symptoms were observed on the epicarp, regardless of the strain inoculated.

Fig. 9 - Variations in average spore concentrations in macroconidia and microconidia of *Fusarium* isolates in different collection areas: (F 1) Isolate 1 from Abengourou; (F 2) Isolate 2 from Abengourou; (F 3) Isolate from Abidjan; (F 4) Isolate from Aboisso; (F 5) Isolate from Azaguié; (F 6) Isolate from Dabou; (F 7) Isolate from Grand-Bassam; (F 8) Isolate from Tiassalé. Values assigned the same letter are identical according to Fisher's LSD test at the α= 5% threshold.

Incubation period. The time to symptom expression varied from 10 to 16 days depending on the isolates and inoculation sites (Table 3). The first symptom appeared 10 days after inoculation, caused by the Abidjan strain at the crown. The Aboisso strain induced the symptom 14 days after inoculation at the crown and 2 days later at the distal end. The F1 isolate induced the symptom 14 days after inoculation at the crown and 2 days later at the distal end. The F2 isolate induced the symptom 14 days after inoculation at the crown and 2 days later at the distal end. The F3 isolate induced the symptom 14 days after inoculation at the crown and 2 days later at the distal end.

The F4 isolate induced the symptom 14 The Aboisso strain induced the symptom 14 days after inoculation at the crown and at the distal end 2 days later. The Abengourou F1 isolate induced symptoms on the 12th day and the F2 isolate caused symptoms on the 13th day after inoculation. The Grand-Bassam and Tiassalé isolates induced symptoms 13 days after inoculation at the crown and distal end, respectively. The Azaguié strain caused symptoms 16 days after inoculation. The control fruits and those inoculated with the Dabou strain showed no symptoms during the incubation period.

Table 3 - Incubation time and duration of symptom appearance

Fusarium isolates	Incubation period (days)
F 3	10
F 1	12
F 2	13
F 7	13
F 8	13
F 4	14
F 5	16

(F 1) Isolate 1 from Abengourou; (F 2) Isolate 2 from Abengourou; (F 3) Isolate from Abidjan; (F 4) Isolate from Aboisso; (F 5) Isolate from Azaguié; (F 6) Isolate from Dabou; (F 7) Isolate from Grand-Bassam; (F 8) Isolate from Tiassalé.

4. Discussion and Conclusions

Macroscopic characterization of *Fusarium* isolates revealed variability in color and appearance depending on their origin. Three types of coloration were observed: white, ivory and pale yellow, and two types of aspect (cotton-like and downy).

This difference in cultural characteristics could be linked to the presence of different species within this population. However, this should be confirmed by further molecular analysis. Nevertheless, during their work on bananas in Morocco, Meddah *et al.* (2010) identified several species of *Fusarium* with different colors and appearances. With regard to the mycelial growth of *Fusarium* spp., the latency phase could correspond to an adaptation phase, during which the fungus establishes its mycelium growth elements by mitosis, leading to mycelium elongation and allowing the fungus to grow. Ruiz-Roldán *et al*. (2010), in their study on germination, sporulation and hyphal fusion in *Fusarium oxysporum*, showed that these different processes were carried out through mitosis. The exponential phase corresponds to the phase of active cell division and rapid vegetative growth of *Fusarium* isolates. This result would suggest that *Fusarium* isolates make optimal use of the energy resources available in the nutrient medium. The plateau phase indicates that the fungus has begun its reproductive or conservation phase due to a nutrient depletion in the environment or limited space in the Petri dish. To avoid death, the fungus undergoes conservation. In all *Fusarium* spp. isolates, it was observed approximatively three periods, except for isolate F4, which was characterized by slower mycelium growth. This could reflect lower virulence in this isolate, unlike the other isolates.

The present study highlighted two types of conidia: macroconidia (spores with septa) and microconidia (spores without septa), which are specific to fungi of the *Fusarium* genus (Heit, 2015). Morphometric variability in macroconidia and microconidia was observed between *Fusarium* isolates. Some isolates had large, broad conidia, while others, such as isolate F6 from Dabou, had the smallest conidia. This diversity in conidia size could reflect genetic diversity or ecological adaptation of these species.

In terms of spore concentrations, the variability observed between the numbers of macroconidia and microconidia may be related to the fact that some isolates produced more macroconidia than microconidia, unlike other isolates in which there were more microconidia than macroconidia.

The macroconidia were fusiform and the microconidia were oval with one or two rounded ends. Balali and Iranpoor in 2006 also observed variability in the shape of *Fusarium* species. According to these authors, this difference is due to genetic variability between *Fusarium* species. Furthermore, the strong positive correlation between macroconidia size and the number of septa suggests that *Fusarium* isolates with the longest macroconidia also have the widest and most septate macroconidia.

The *Fusarium* isolates tested developed soft rot symptoms on inoculated bananas, except for the Dabou isolate. These same symptoms were observed by Odame (2010) and Zakaria *et al.* (2012) after inoculating bananas with *Fusarium* isolates. These results also show that bananas are a host for this pathogen. The results obtained suggest that the *Fusarium* isolates that induced symptoms on bananas are pathogenic to bananas. The absence of symptoms in the presence of the Dabou isolate could be due to the fact that this isolate has smaller conidia than the other seven isolates, as demonstrated in this study. Several authors have demonstrated the potential role of fungal spore size in pathogenicity (Li *et al*., 2011). In fact, large spores don't need to expand further before the germination tube is produced, which happens quite quickly, allowing for rapid invasion of the host. Small spores, on the other hand, undergo a very long phase of volume increase, which delays the formation of the germ tube and thus slows down the infection or blocks it if conditions become unfavorable. Furthermore, of the three parts inoculated with the isolates, only the crown and the distal end of the bananas proved to be susceptible. Symptoms began to develop 10 days after inoculation of the fruit when they began to ripen. This late onset of symptoms could be related to the ripening of the fruit. Lassois *et al.* (2009) showed that the development of rot was linked to the physiological state of bananas after harvest. Coates and Jonhson (1997) stated that during the ripening of fruit and vegetables, respiration and water loss increase, chlorophyll decreases, aromas are secreted and the fruit loses rigidity. These conditions favor the development of fungi that were in a dormant state before the fruit was harvested.

Our findings demonstrate that Banana post-harvest rot can be caused by several isolates of

Fusarium. These isolates a very different in morphologic characters that affects their pathogenicity. These findings may contribute to the development of more effective strategies for the management of banana post-harvest diseases, thereby improving fruit quality.

References

ARIAS P., DANKERS C., LIU P., PILKAUSKAS P., 2003 - *The world banana economy 1985-2002.* - FAO, Food and Agriculture Organisation of the United Nations, Rome, Italy, pp. 102.

BALALI G.R., IRANPOOR M., 2006 - *Identification and genetic variation of* Fusarium *species in Isfahan, Iran, using pectic zymogram technique*. - Iran J. Sci. Technol. A, 30: 91-102.

CHAUVIN E., JONCHERAY M., VALETTE H., BONNASSIEUX A., NOUR C.-H.B., 2025 - *La banane de Côte d'Ivoire: Les recompositions d'une filière agro-industrielle mondialisée*. - EchoGéo, 73: 1-28.

CHOI Y.W., HYDE K.D., HO W.H., 1999 - *Single spore isolation of fungi.* - Fungal Diversity, 3: 29-38.

COATES L., JOHNSON G., 1997 - *Postharvest diseases of fruit and vegetables*, 533-548. - In: BROWN J., and H. OGLE (eds.) *Plant pathogens, plant diseases*. Botany Department University of New England, Cocos Islands, Keeling, Australia.

DOHOU N., YAMANI K., BADOC A., DOUIRA A., 2004 - *Activité antifongique d'extraits de* Thymelea lythroides *sur trois Champignons du Riz*. - Bull. Soc. Pharm., Bordeaux, France, 143: 31-38.

DUNCAN C., TORRENCE L., 1992 - *Techniques for rapid detection of plant pathology.* - Blackwell Scientific Publication, Oxford, UK, pp. 234.

FAO, 2022 - *FAOSTAT*. - FAO, Food and Agriculture Organization of the United Nations, https://www.fao.org/faostat/

HEIT S., 2015 - *Identification de* Fusarium *et détection des mycotoxines associées par MALDI-TOF*. - Thèse de doctorat en pharmacie, Université de Laurraine, Nancy Cedex, France, pp. 128.

KOUAME L.K., KANPIGNI K.A.B., 2022 - Analyse sanitaire et phytosanitaire des filières fruitières en Côte d'Ivoire. Cas de la mangue, l'ananas et la banane. - HortiFresch, pp. 76.

KOUASSI K.S., 2001 - *Les secteurs banane (AAA) et banane plantain (AAB) en Côte d'Ivoire: Analyse bibliographique et prospective*. - CNRA Eds., Abidjan, Côte d'Ivoire, pp. 35.

KRA K.D., MUKETOU M.A., TOUALY M.N.Y., KOUAKOU Y.Y.F., ATTA D.H., 2018 - *Comparative effectiveness of three systemic fungicides on the fungi responsible for the cavendish subgroup grande naine banana post-harvest diseases in Côte d'Ivoire*. - Int. J. Adv. Res., 6(3): 347-353.

LASSOIS L., BUSOGORO J.P., JIJAKLI H., 2009 - *La banane: De son origine à sa commercialisation*. - Biotechnol. Agro. Soc. Environ., pp. 575-586.

LASSOUDIÈRE A., 2007 - *Le bananier et sa culture.* - Quae Edition, Versailles, France, pp. 383.

LESLIE J.F., SUMMERELL B.A., 2006 - *The* Fusarium *laboratory manual*. - Blackwell, Ames, IA, USA, pp. 288.

LI C.H., CERVANTES M., SPRINGER D.J., BOEKHOUT T., RUIZ-VAZQUEZ R.M., TORRES-MARTINEZ S.R., HEITMAN J., LEE S.C., 2011 - *Sporangiospore size dimorphism is linked to virulence* of Mucor circinelloides. - PLoS Pathog. 7(6): e1002086.

MEDDAH N., OUAZZANI T.A., BENKIRANE R., DOUIRA A., 2010 - *Mycoflore associée au bananier (*Musa acuminata *L.), variété Grande naine, cultivé sous serre dans la région du Gharb (Maroc).* - Bull. Inst. Sci., Rabat, Sect. Sci. Vie., 32(1): 1-11.

NATH K., SOLANKY K.U., BALA M., KUMAWAT G.L., 2014 - *Post-harvest deterioration of banana fruits and its control using Fungicides*. - Int. J. Plant Prot., 7: 345-348.

NELSON P.E., TOUSSOUN T.A., COOK R.J., 1981 - Fusarium: *Diseases, biology and taxonomy*. University Park, Pennsylvania State University Press, PA, USA, pp. 446-452.

ODAME A.E., 2010 - *Occurence and pathogenicity of crown rot disease organisms in major banana producing areas in Ashanti region*. - Thesis, University of Ghana, Ghana, pp. 96.

PLOETZ R.C., 2006 - Fusarium-*induced diseases of tropical, perennial crops*. - Phytopathol., 96: 648-652.

PLOETZ R.C., THOMAS J. E., SLABAUGH W.R., 2003 - *Diseases of banana and plantain*, pp. 73-134. - In: PLOETZ R.C. (ed.) *Diseases of tropical fruit crops*. CABI Publishing, Wallingford, UK, pp. 527.

RUIZ-ROLDÁN M.C., KÖHLI M., RONCERO M.I., PHILIPPSEN P., DI PIETRO A., ESPESO E.A., 2010 - *Nuclear dynamics during germination, conidiation, and hyphal fusion of Fusarium* oxysporum. Eukaryot Cell., 9(8): 1216-1224.

ZAKARIA L., WAN CHIK M., WAI HENG K., SALLE B., 2012 - Fusarium *species associated with fruit rot of Banana (*Musa *spp.), Papaya (*Carica papaya*) and Guava (*Psidium guajava*).* - Mal. J. Microbiol.*,* 8(2): 127-130.