

MYCELIA GROWTH OF *Colletotrichum truncatum* AND *Fusarium verticillioides* ON PEPPER (*Capsicum chinense*) FRUITS IN DIFFERENT MEDIA AND THEIR IMPACT ON THE NUTRITIONAL COMPOSITION OF INFECTED FRUITS

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ABSTRACT

*This study examined the effects of various growth conditions on the mycelial development of two fungal Pathogens and evaluated the nutritional makeup of the resulting infected pepper fruits. The study investigated the complex relationships between the nutritional makeup of the host plant and fungus growth. Using a variety of growth media (potato dextrose agar, carrot dextrose agar, cornmeal agar, oatmeal agar, cauliflower dextrose agar, and Sabouraud synthetic nutrient), the growth dynamics of two separate fungal pathogens (*Colletotrichum truncatum* and *Fusarium verticillioides*) were investigated. Various growth media had various effects on mycelia growth. For *F. verticillioides*, oatmeal, and cornmeal agar showed the maximum mycelia growth (90 cm) after 7 days in culture, while for *C. truncatum*, oatmeal agar and cauliflower dextrose agar produced the same results. In addition, an analysis of the nutritional makeup of pepper fruits infected with the two pathogens showed changes in proximate compositions, vitamins, minerals, and phytochemicals. Inoculated pepper fruits exhibited lower levels of ash, carbs, fat and protein, and higher levels of fiber and moisture. While healthy pepper fruits recorded higher 6.48%, 1.50%, 2.70% and 0.47% of alkaloids, tannin, flavonoid, and saponin respectively, fruits infected with *C. truncatum* and *F. verticillioides* recorded 1.8 and 1.60% alkaloids, 0.81 and 0.50% tannin, 0.59 and 0.40% flavonoid, and 0.26 and 0.36% saponin, respectively. Similar patterns were observed for vitamin and mineral contents. By providing insights that could affect agricultural practices and the management of plant diseases, this comparative study advances our understanding of the complex interactions among fungal pathogens, growth media, and nutritional value of infected plant hosts.*

Key words: fungi, *C. truncatum*, *F. verticillioides*, pepper fruit, nutritional composition

INTRODUCTION

Pepper is a staple spice in kitchens globally, enjoying widespread popularity across various cuisines. In 2022, Pepper was the world's 548th most-traded product, with a total trade of \$ 5.13 billion (Nair, 2022). In addition to having a wide range of uses, from food additions to medicinal purposes, they are highly significant socio-economically (Muhamad *et al.*, 2023). They comprise a range of essential nutritional elements such as vitamin A, C, E, b-carotene, folic acid, microelements, phenolic compounds, protein, sugars, vitamins, and several bioactive compounds (Jaiswal *et al.*, 2021). Due to their economic importance and vulnerability of pepper plants to a range of fungal infections (Vallejo-Gutiérrez *et al.*, 2019), the crop was chosen as the host organism in this study. Fungal infections have a profound effect on pepper fruit nutritional quality, which affects both growers and consumers (Majid *et al.*, 2017). In contemporary agricultural systems, the dynamic interplay between fungal diseases and their host plants remains a critical component in determining

crop yield and quality (Obani and Ikotun, 2021). Plant diseases have the potential to significantly threaten the world's food supply through both isolated and combined infections. They also swiftly evade countermeasures like synthetic pesticides and the cultivation of resistant plants (Prusky and Sionov, 2021). Peppers are susceptible to infections by *Colletotrichum truncatum* which typically causes anthracnose that can affect the plant at any stage of development and causes severe yield losses (Zakaria, 2021). *Fusarium verticillioides* also remains a major threat in vegetable production as it has the ability to survive under extreme weather conditions and as well produce airborne spores that makes it to occur widely in the environment (Omotayo and Babalola, 2023).

Fungi, owing to their versatility and resilience, exhibit diverse growth patterns influenced by an array of environmental factors. Investigating how growth media modulate the interaction between fungal pathogens and pepper plants can provide valuable insights into the mechanisms underlying pathogen-host interactions and unveil some potential

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avenues for enhancing crop resilience. Research has shown that in comparison to conventional media like Potato Dextrose Agar (PDA), the use of rice and starch medium can greatly increase fungal growth (Hazim *et al.*, 2022). In addition, fungi are endemic in tropical settings, yet vulnerable to changes in land cover, heat, and drought in arid tropical locations (Hazim *et al.*, 2022). The development patterns of fungi, such as polar growth, cell division, and cell fusion, are influenced by external chemo-attractants and the local activation of core cell polarity regulators (Clark-Cotton *et al.*, 2022). In a similar vein, it was shown that the mycelium aspect and pigment synthesis of certain fungal species differed depending on the culture media (Kumakech and Opio, 2023). In general, the choice of culture media can greatly influence the growth and development of fungal pathogens, underscoring the need to understand each species' specific requirements for optimal cultivation (Chauhan *et al.*, 2017). The choice of growth medium is crucial because it affects the general conditions and nutrient environment that promote fungal growth (Navarrete-Perea *et al.*, 2021). Research has been done on the growth media's ability to promote fungal development and create antagonistic relationships with plant diseases. The most successful but also most costly type of growth media is PDA media (Ningsih *et al.*, 2023).

This work aims to enhance our understanding of the intricate linkages that regulate plant-fungus interactions by conducting a comparative examination of the nutritional composition and mycelial growth of infected pepper fruits. The findings of this study could have a practical impact on improving farming methods, creating focused disease control plans, and enabling sustainable pepper production in the face of fungal disease outbreaks. This study investigates how growing media affects the development of two distinct fungal pathogen mycelia and how this affects the nutritional composition of the fungus-affected pepper fruits.

MATERIALS AND METHODS

Fungal Strain Collection,

Isolation, and Identification

Fruits showing symptomatic sunken lesions dotted with black circular patches, and those with internal rots were randomly collected from five different communities (Nguru, Lejja, Nru, Ede-Obala, and Ibagwa-Ani) that are predominantly pepper farmers during the 2021 to 2022 rainy seasons. These communities are separated from each other by more than 5 km in Nsukka Local Government Area of Enugu State, Nigeria. The average annual temperature during the collection period was 24-27 °C, with maximum temperatures of 34 and 30 °C in 2021 and 2022, respectively. Relative humidity in 2021 ranged from 30-77%, while average relative humidity was less than 70% in 2022. In 2021, the rainy seasons spanned from May to October, with

precipitation peaks from August to October. The collections were made in August in the two years studied. The mean rainfall amount for the years studied were 219 and 264 mm, respectively for 2021 and 2022. In each location, three farms were visited and in each farm three diseased plant samples were collected, making it a total of nine samples in each location and 45 diseased fruit samples in all the locations. In these pepper fields, the fungal organisms infecting the plants have not been established. To obtain the fungal isolates, small tissue fragments from the lesion margins were disinfected in 1% NaClO for 2 min., washed three times with sterile water, and placed on potato dextrose agar (PDA) amended with streptomycin sulphate (Biosynth Ltd) at 100 µg m⁻¹. After 4 days at 25 °C, colony margins were transferred to fresh PDA plates and pure cultures were then grown on PDA and inoculated at 25 °C under 12 h photoperiod of light and 12 h of darkness which facilitated sporulation. The sporulating hyphae were identified under microscope and cultured on PDA plates and incubated at 25 ± 20 °C for a week to obtain pure single colonies following the single spore technique. Pure cultures were then stored at 4 °C on PDA slants for future experiments. The cultural and morphological characteristics of all the isolates were identified.

Virulence Test

The ability to cause infection on pepper was determined. Pepper plants were grown in 81 pots containing autoclaved potting mix and placed in a greenhouse section of the Department of Crop Science, University of Nigeria, Nsukka (25 °C and 85% relative humidity with supplemental light). The fungal strain of *F. verticillioides* was cultivated in the dark at 25 °C for 7 days, and the colony surfaces were gently scraped with a glass spreader. During anthesis of already planted pepper plants, the conidial suspension of *F. verticillioides*, which was adjusted to a concentration of 1.0×10^6 conidia mL⁻¹ sterile water and 0.01% polysorbate 80 using a hemocytometer, were inoculated on the styles and stigmas of 54 pepper plants with a sterilize needle. The remaining 27 plants served as control. Four weeks after fruiting, all fruits of both the inoculated and control plants were harvested. The inoculated fruits were crushed to check for the presence of Fusarium symptoms and the diameter of the rot was taken. On the uninfected pepper fruits, the virulence of *C. truncatum* were accessed. Mycelia plugs were placed on the surface of the fruits over an artificial wound that facilitated the penetration of the fungus into the plant tissue. The inoculated fruits were placed on a moistened filter paper and incubated in a growth chamber at 25 °C and 85% relative humidity with a 12-h photo period. After seven days, the lesion diameter was measured. The 27 pepper fruits were replicated three times, and this experiment was repeated twice.

Analysis of *F. verticillioides* and *C. truncatum* Growth in Different Media

The nutrient media studies were carried out in the Plant Pathology Laboratory at the University of Nigeria, Nsukka. Six media were tested to determine their effect on the growth rate and sporulation of pathogens. The media include potato dextrose agar (PDA), carrot dextrose agar (CDA), Sabouraud agar (SBA), oatmeal agar (OMA), cornmeal agar (CMA), and cauliflower dextrose agar (CDA). This experiment was laid out as a simple Completely randomized design (CRD) with six treatments, replicated three times.

Preparation of potato dextrose agar

Before media preparation, 70 mL ethanol and 30 mL of water were mixed thoroughly to clean and sterilize the environment aseptically. A 300 g of potato was washed to remove dirt, peeled and diced and was boiled for 15 min. in 1.5 litres of distilled water. The extract was collected through a muslin cloth and made up to 1.5 litres with distilled water and boiled. Upon boiling, 20 g of dextrose was added to the pot, followed by 20 g of agar as the water boiled. It was continuously stirred to prevent it from caking. After 5 min., the mixture was brought down and poured into a conical flask, and sealed to prevent the nutrient agar from escaping in the form of steam and prevent contamination before it was taken for autoclaving. The agar mixture was poured into uncontaminated Petri dishes.

Carrot dextrose agar

Three hundred (300) g of carrot was washed to remove dirt, peeled and diced and was boiled for 15 min. in 1.5 litres of distilled water. The extract was collected through a muslin cloth and made up to 1.5 litres with distilled water and boiled. Upon boiling, 20 g of dextrose was added to the pot, followed by 20 g of agar as the water boiled. It was continuously stirred to prevent it from caking. After 5 min., the mixture was brought down and poured into a conical flask and sealed to prevent the nutrient agar from escaping in the form of steam and prevent contamination before it was taken for autoclaving. The agar mixture was poured into uncontaminated Petri dishes.

Oatmeal agar

The oat was cooked for about 15- 30 min. Once cooked, cheesecloth was used to sieve out the water. The oat water was poured into a flask and topped up to 1500 mL with distilled water. The sieved water was poured into a flask and distilled water was added to make it up to 1500 mL, the water was poured back into the pot and boiled. Upon boiling, 20 g of dextrose was added to the pot, followed by 20 g of agar as the water boiled. It was continuously stirred to prevent it from caking. After 5 min., the mixture was brought down and poured into a conical flask sealing the

mouth to prevent the nutrient agar from escaping in the form of steam and prevent contamination before it was taken for autoclaving. The agar mixture was poured into uncontaminated Petri dishes.

Corn meal agar and Sabouraud dextrose agar

Seventeen (17) g of cornmeal was suspended in 1 litre of distilled water. It was brought to a boil to dissolve completely. One percent (1%) peptone was added and sterilized by autoclaving at 121 °C for 15 min. For the Sabouraud dextrose agar, 65 g of Sabouraud dextrose agar was suspended in 1000 mL of distilled water. It was heated to boiling to dissolve the medium completely. This was further sterilized by autoclaving at 121 °C for 15 min.

Cauliflower dextrose agar

Three hundred (300) g of curds of cauliflower was washed and diced and was boiled for 15 min. in 1.5 litres of distilled water. The extract was collected through a muslin cloth and made up to 1.5 litres with distilled water and boiled. Upon boiling, 20 g of dextrose was added to the pot, followed by 20 g of agar as the water boiled. It was continuously stirred to prevent it from caking. After 5 min., the mixture was brought down and poured into a conical flask sealing the mouth to prevent the nutrient agar from escaping in the form of steam and prevent contamination before it was taken for autoclaving. The agar mixture was poured into uncontaminated Petri dishes.

Assessment of the Effect of Fungal Pathogens (*F. verticillioides* and *C. truncatum*) on Nutritional Contents of Pepper Fruits

Uncontaminated peppers (40 fruits divided by two), which were harvested from the uninoculated (control) plants, were surface-sterilized and inoculated with the isolated organisms differently. Mycelia plug (5 mm in diameter) from a 7-day-old PDA culture of each isolate (20 in number for each isolate) were placed on the surface of the fruits over an artificial wound for easy penetration of the pathogen, kept moist with a piece of moistened absorbent cotton and incubated in a growth chamber at 25 °C under 12-h photoperiod and 85% relative humidity. After 7 days, the nutrient contents of infected and uninfected pepper fruits were determined.

Moisture content, total ash, crude protein, crude fiber, and crude fat (proximate composition) of the samples were determined according to AOAC (2016). Utilizable carbohydrate content was calculated by difference (Manzi *et al.*, 2004). Phytochemical contents (tannin, flavonoid, and saponin) were determined by the methods of Silva *et al.* (2017), Singh and Kumar (2017), and Gul *et al.* (2017). Vitamin content (A, E, and C) was determined by the methods of Agostini-Costa *et al.* (2017) while mineral contents (Mg, Ca, Fe, Zn, P, Na, K) were determined by the methods of Khan *et al.* (2019).

Data Analysis

Raw data collected in this study were analyzed using the GenStat statistical package (12th edition) and treatment means were separated using Fishers' least significant difference (F-LSD) at 5% probability level. GraphPad Prism 5th edition was used for charts and graphs.

RESULTS

Morphological Characterization of the Two Fungal Organisms

Out of the 45 infected samples, 18 isolates were identified as *Fusarium* spp., while twenty-seven were identified as *Colletotrichum* spp. through microscopic examination of morphological and

cultural characteristics. The isolates grown exhibited predominant phenotypic observations that matched the essential characteristics of *C. truncatum* and *F. verticillioides* already described by Jayawardena *et al.* (2015), Diaz *et al.* (2017), and Leslie and Summerell (2006). *Colletotrichum* isolates all produced similar white to grey colonies (Figure 1a) in culture after 7 days of incubation at 28 °C. The aseptate conidia were predominantly fusiform (Figure 1b) with both ends tapered to a point, 2.10-2.80 µm in width and 21.70-22.10 µm in length (Table 1). Based on the morphological characteristics, twenty-seven isolates were identified as *C. truncatum*. Cultures of *F. verticillioides* have white mycelia at first (Figure 2), but they turn pink to violet as they age.

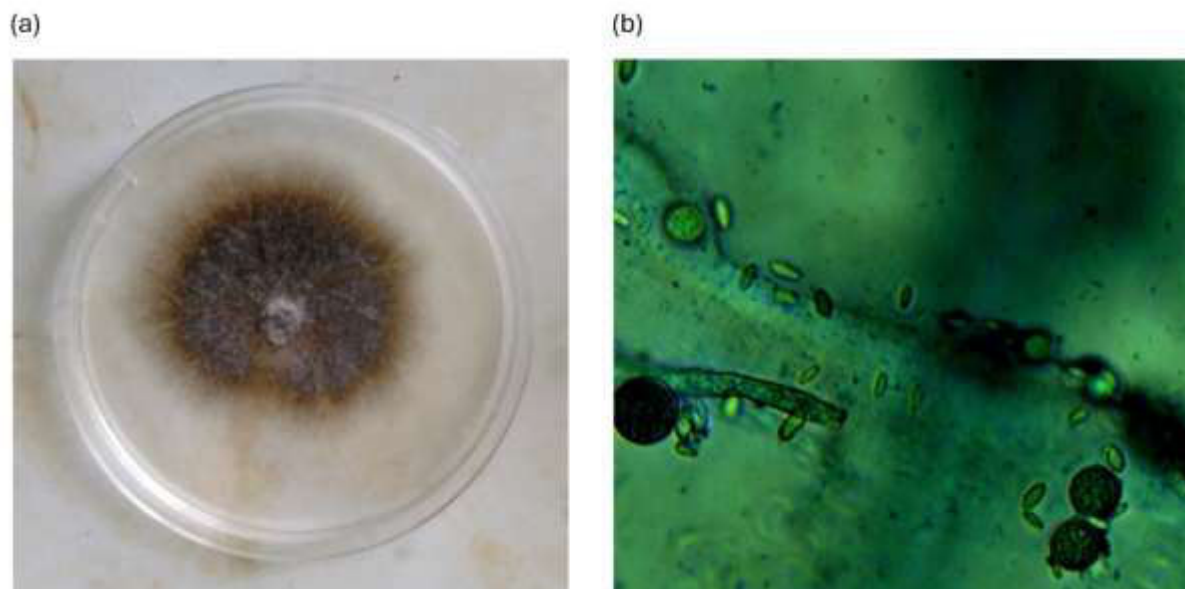


Figure 1: Colony (a) and conidia (b) of *C. truncatum* 385mm

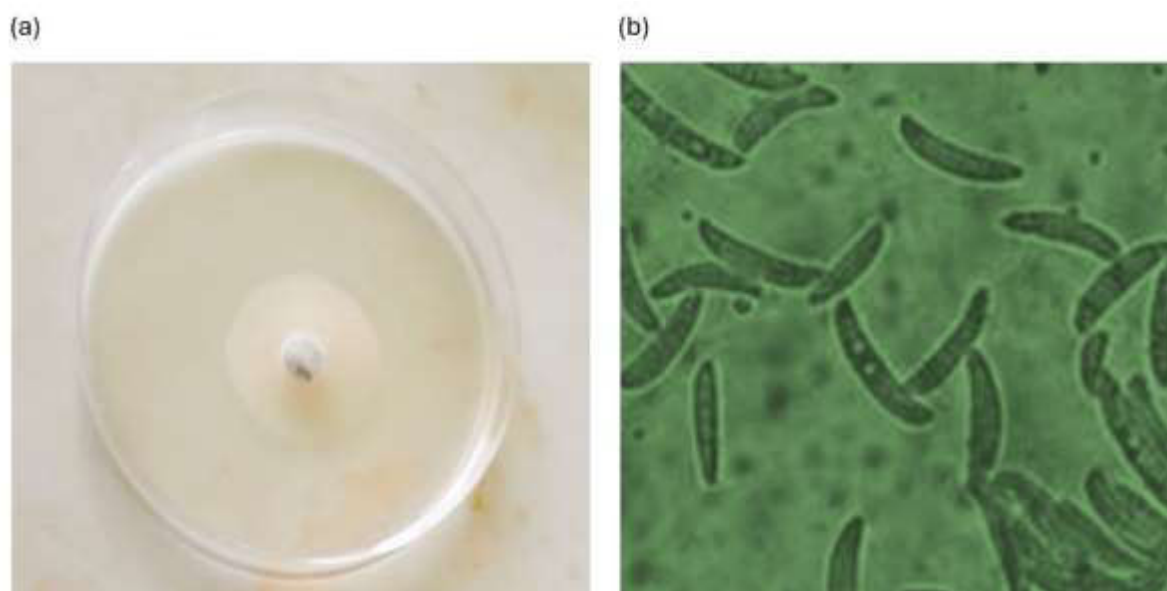


Figure 2: Colony (a) and conidia (b) of *F. verticillioides* 385mm

Table 1: Morphological characteristics of *Colletotrichum truncatum* and *Fusarium verticillioides*

Species	Strain	Colony colour	Colony texture	Conidial length (µm)	Conidial width (µm)
<i>C. truncatum</i>	Ng ₁ F	white	Cottony	22.30	2.20
<i>C. truncatum</i>	Ng ₂ F	white	Cottony	22.52	2.15
<i>C. truncatum</i>	Ng ₃ F	white	Cottony	21.70	2.00
<i>C. truncatum</i>	Ng ₄ F	whitish grey	Cottony	23.30	2.58
<i>C. truncatum</i>	Ng ₅ F	whitish grey	Cottony	22.80	2.60
<i>C. truncatum</i>	Ng ₆ F	whitish grey	Cottony	23.10	2.62
<i>C. truncatum</i>	Ng ₇ F	whitish brown	Fluffy Cotton	21.90	2.72
<i>C. truncatum</i>	Ng ₈ F	whitish brown	Fluffy Cotton	22.20	2.69
<i>C. truncatum</i>	Ng ₉ F	whitish brown	Fluffy Cotton	22.60	2.80
<i>F. verticillioides</i>	11L ₁	whitish pink	Powdery	40.00	2.40
<i>F. verticillioides</i>	11L ₂	whitish pink	Powdery	40.20	2.35
<i>F. verticillioides</i>	11L ₃	whitish pink	Powdery	39.50	2.40
<i>F. verticillioides</i>	11L ₄	Creamy pink	Powdery	40.65	2.32
<i>F. verticillioides</i>	11L ₅	Creamy pink	Powdery	40.25	2.30
<i>F. verticillioides</i>	11L ₆	Creamy pink	Powdery	40.52	2.40
<i>F. verticillioides</i>	11L ₇	whitish pink	Powdery	38.90	2.35
<i>F. verticillioides</i>	11L ₈	whitish pink	Powdery	38.75	2.40
<i>F. verticillioides</i>	11L ₉	whitish pink	Powdery	39.00	2.42
<i>C. truncatum</i>	Nr ₁	whitish brown	Fluffy Cotton	22.50	2.80
<i>C. truncatum</i>	Nr ₂	whitish brown	Fluffy Cotton	24.35	2.40
<i>C. truncatum</i>	Nr ₃	whitish brown	Fluffy Cotton	22.70	2.35
<i>C. truncatum</i>	Nr ₄	whitish brown	Fluffy Cotton	23.00	2.40
<i>C. truncatum</i>	Nr ₅	whitish brown	Fluffy Cotton	23.90	2.58
<i>C. truncatum</i>	Nr ₆	whitish brown	Fluffy Cotton	23.00	2.60
<i>C. truncatum</i>	Nr ₇	whitish brown	Fluffy Cotton	24.50	2.62
<i>C. truncatum</i>	Nr ₈	whitish brown	Fluffy Cotton	24.20	2.72
<i>C. truncatum</i>	Nr ₉	whitish brown	Fluffy Cotton	25.10	2.40
<i>F. verticillioides</i>	EO ₁	whitish pink	Powdery	41.20	2.35
<i>F. verticillioides</i>	EO ₂	whitish pink	Powdery	40.75	2.40
<i>F. verticillioides</i>	EO ₃	whitish pink	Powdery	40.90	2.40
<i>F. verticillioides</i>	EO ₄	whitish pink	Powdery	40.50	2.35
<i>F. verticillioides</i>	EO ₅	whitish pink	Powdery	41.20	2.40
<i>F. verticillioides</i>	EO ₆	whitish pink	Powdery	40.25	2.42
<i>F. verticillioides</i>	EO ₇	whitish pink	Powdery	40.62	2.35
<i>F. verticillioides</i>	EO ₈	whitish pink	Powdery	41.43	2.40
<i>F. verticillioides</i>	EO ₉	whitish pink	Powdery	41.66	2.58
<i>C. truncatum</i>	I ₁	whitish grey	Cottony	23.30	2.58
<i>C. truncatum</i>	I ₂	whitish grey	Cottony	22.80	2.60
<i>C. truncatum</i>	I ₃	whitish grey	Cottony	23.10	2.62
<i>C. truncatum</i>	I ₄	grey	Cottony	24.20	2.72
<i>C. truncatum</i>	I ₅	grey	Cottony	24.50	2.62
<i>C. truncatum</i>	I ₆	grey	Cottony	24.70	2.72
<i>C. truncatum</i>	I ₇	whitish grey	Cottony	23.30	2.40
<i>C. truncatum</i>	I ₈	whitish grey	Cottony	22.80	2.50
<i>C. truncatum</i>	I ₉	whitish grey	Cottony	23.10	2.52

Ng - Nguru, 11L - Lejja, Nr - Nru, EO - Ede-Oballa, I - Ibagwa-Ani.

Isolates from Ng, Nr and I are infected with *C. truncatum*, while isolates from 11L and EO were infected with *F. verticillioides*.

Virulence

The fruits inoculated with *C. truncatum* showed lesions with a mean diameter of 14 mm (Figure 3a). Similarly, pepper fruits inoculated with *F. verticillioides* revealed rots inside the fruits (Figure 3b). These

symptoms were observed in samples collected from Lejja and Ede Oballa. The pathogens were reisolated to confirm Koch's postulates and to confirm the similarity of cultural/microscopic morphology with those of the inoculated *Fusarium* and *Colletotrichum* isolates.

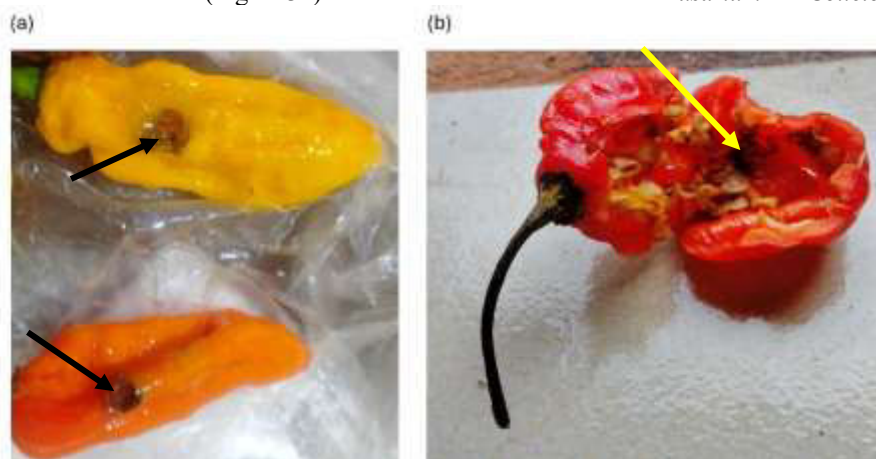


Figure 3: Signs of virulence in fruits inoculated with (a) *C. truncatum* and (b) *F. verticillioides* at 7 days post-inoculation

Effect of Different Growth Media on the Growth of *F. verticillioides* and *C. truncatum*

This experiment was carried out to note the variations in the response of *C. truncatum* and *F. verticillioides* concerning their mycelia growth on six different nutrient media. One of the pathogens (*C. truncatum*) measured significantly ($p \leq 0.05$), maximum growth (80.50 cm) 7 days after inoculation on cauliflower dextrose agar followed by oatmeal agar (79.00 cm), Sabouraud (77.00 cm), potato dextrose agar (75.00 cm), carrot dextrose agar (66.83 cm) and corn meal agar (47.50 cm) (Figure 4). *F. verticillioides* also showed a significant ($p \leq 0.05$) variation concerning growth media utilized 8 days after inoculation (Figure 4). While corn meal agar and oatmeal agar had the highest growth at 85.00 cm each, cauliflower dextrose agar recorded 74.00 cm followed by PDA, carrot, and Sabouraud (66.00, 65.00, and 55.00 cm, respectively).

Effect of the Fungal Pathogens on the Nutritional Content of the Pepper Fruits

The effect of fungal pathogens on the nutritional composition of pepper fruits is a critical aspect to explore as it directly impacts both the quality and safety of the produce. These two fungal pathogens (*C. truncatum* and *F. verticillioides*) influenced significantly ($p \leq 0.05$) the levels of phytochemicals present in pepper fruits. Pepper fruits that were infected with *C. truncatum* and *F. verticillioides* recorded, respectively 1.80% and 1.60% alkaloids, 0.81% and 0.50% tannin, 0.59% and 0.40% flavonoid, and 0.26% and 0.36% saponin (Table 2). Uninfected control pepper fruits recorded higher phytochemical contents of 6.48%, 1.50%, 2.70% and 0.47% for alkaloids, tannin, flavonoid, and saponin, respectively.

Infection of pepper fruits significantly ($p \leq 0.05$) affected the proximate composition of the fruits (Table 3). The infected fruits with *C. truncatum* and

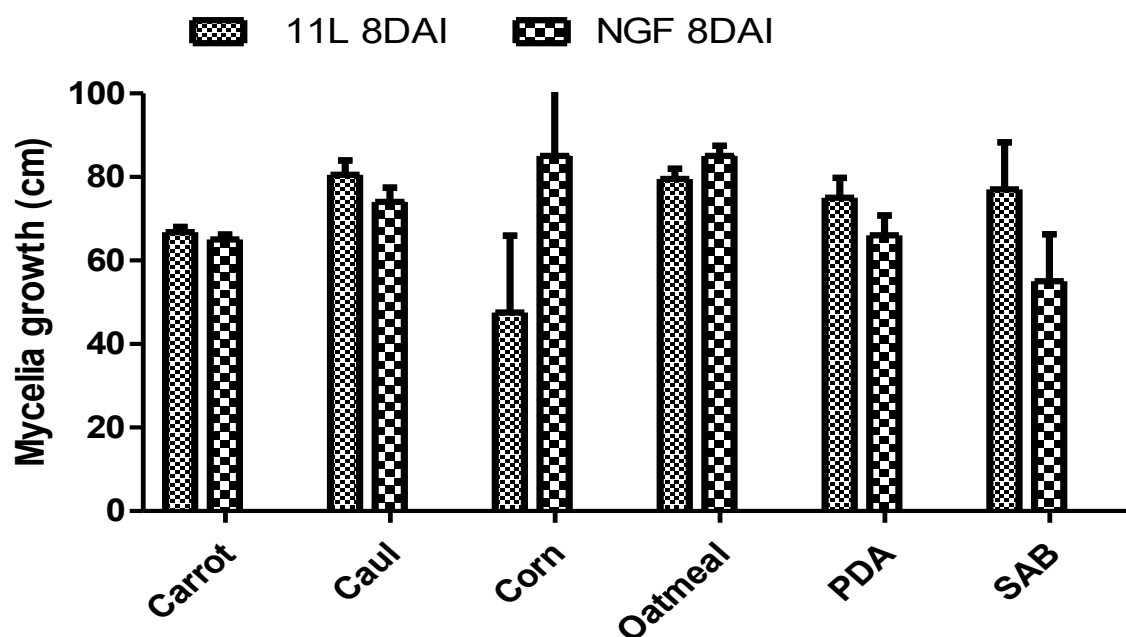


Figure 4: Effect of media on the mycelia growth of *C. truncatum* (11L) and *F. verticillioides* (NGF) at eight days after inoculation (8 DAI). Carrot: Carrot dextrose agar; Caul: Cauliflower dextrose agar; Corn: Cornmeal dextrose agar; Oatmeal: Oatmeal dextrose agar; PDA: Potato dextrose agar; SAB: Sabouraud synthetic nutrient.

Table 2: Effect of the inoculated organisms on some phytochemical content of pepper (%)

	Alkaloids	Tannin	Flavonoid	Saponin
Control	6.48 ^a	1.50 ^a	2.70 ^a	0.47
<i>C. truncatum</i>	1.85 ^b	0.81 ^b	0.59 ^b	0.26
<i>F. verticillioides</i>	1.60 ^b	0.50 ^c	0.40 ^b	0.32
CV%	17.6	10.7	47.4	28.6
F-LSD ($p \leq 0.05$)	1.165	0.199	1.165	NS

F-LSD - Fishers least significant difference, NS - non-significant

Table 3: Effect of the inoculated organisms on the proximate composition of pepper (%)

	Moisture	Ash	Crude fiber	Fat	Protein	Carbohydrates
Control	62.70 ^c	1.56 ^{ab}	1.80 ^b	1.44 ^a	3.13 ^a	24.20 ^a
<i>C. truncatum</i>	74.50 ^a	1.47 ^b	4.94 ^a	0.16 ^c	0.38 ^b	18.58 ^b
<i>F. verticillioides</i>	69.94 ^b	1.75 ^a	3.67 ^a	0.48 ^b	1.46 ^b	23.26 ^a
% CV	1.4	6.3	23.6	8.4	35.0	4.5
F-LSD ($p \leq 0.05$)	1.998	0.199	1.635	0.117	1.159	1.998

F-LSD - Fishers least significant difference

F. verticillioides had a higher moisture content (74.50% and 69.94%, respectively) as compared to the uninfected pepper which had 62% moisture content. The trend is the same for crude fiber content where the infected fruits recorded 4.94 and 3.67 % respectively and 1.80% for the uninfected.

There is a slight difference between the ash content of the infected fruits. Pepper infected with *F. verticillioides* recorded higher ash content (1.75%) followed by the uninfected, which recorded 1.56%, while the pepper infected with *C. truncatum* had the least ash content (1.47%). The crude fat content, protein, and carbohydrate contents of uninfected pepper were 1.44, 3.13, and 24.20%, respectively. The fruits infected with *C. truncatum* had lesser fat (0.16%), protein (0.38%), and carbohydrates (18.58%) when compared to those infected with *F. verticillioides* which recorded 0.48, 1.46, and 23.26% for fat, protein, and carbohydrates, respectively.

Infection by *C. truncatum* and *F. verticillioides* significantly ($p \leq 0.05$) influenced the vitamins A, C, and E contents of pepper fruits (Table 4). The uninfected fruits had 6.78, 84.21, and 5.66 mg 100-g⁻¹ of vitamins A, C, and E, respectively, whereas the fruit infected with *C. truncatum* recorded 3.26, 42.63, and 2.40 mg 100-g⁻¹ of vitamins A, C, and E, respectively. The fruits infected with *F. verticillioides* had 2.78, 51.27, and 1.66 mg 100-g⁻¹ of vitamins A, C, and E, respectively.

The inoculation of *C. truncatum* and *F. verticillioides* significantly ($p \leq 0.05$) influenced the mineral content of the fruits (Table 5). Pepper fruits infected with *C. truncatum* had a lower Ca (1.70 mg 100-g⁻¹), Mg (4.81 mg 100-g⁻¹), Na (0.26 mg 100-g⁻¹), K (25.16 mg 100-g⁻¹) and Zn (0.11 mg 100-g⁻¹) contents as compared to the fruits infected with *F. verticillioides*, which recorded 2.12, 6.32, 1.21, 27.92, and 1.92 mg 100-g⁻¹ of Ca, Mg, Na, K, and Zn respectively. Phosphorus content of fruit infected with *C. truncatum* (7.68 mg 100-g⁻¹) was slightly above the fruit infected with *F. verticillioides* (5.79 mg 100-g⁻¹). The uninfected pepper recorded 8.39, 12.64, 2.50, 15.68, 34.24, and 0.59 mg 100-g⁻¹ of Ca, Mg, Na, P, K, and Zn respectively. The Zn content was not significant between infected and uninfected fruits.

Table 4: Effect of inoculated organisms on vitamin contents of pepper fruits

	Vitamin A (mg 100-g ⁻¹)	Vitamin C (mg 100-g ⁻¹)	Vitamin E (mg 100-g ⁻¹)
Control	6.78 ^a	84.21 ^a	5.66 ^a
<i>C. truncatum</i>	3.26 ^b	42.63 ^b	2.40 ^b
<i>F. verticillioides</i>	2.78 ^b	51.27 ^c	1.66 ^b
% CV	23.4	1.7	30.9
F-LSD ($p \leq 0.05$)	1.998	1.998	1.998

F-LSD - Fishers least significant difference

Table 5: Effect of the inoculated organisms on some mineral contents of pepper (mg 100-g⁻¹)

	Ca	Mg	Na	P	K	Fe	Zn
Control	8.39 ^a	12.64 ^a	2.50 ^a	15.68 ^a	34.24 ^a	1.25	0.59 ^b
<i>C. truncatum</i>	1.70 ^b	4.81 ^b	0.26 ^b	7.68 ^b	25.16 ^c	1.92	0.11 ^c
<i>F. verticillioides</i>	2.12 ^b	6.32 ^b	1.21 ^b	5.79 ^b	27.92 ^b	2.72	1.92 ^a
CV%	20.2	12.6	44.1	10.3	3.4	29.7	9.4
F-LSD ($p \leq 0.05$)	1.635	1.998	1.165	1.998	1.998	NS	0.164

F-LSD - Fishers least significant difference

DISCUSSION

The study revealed distinct growth patterns of *F. verticillioides* and *C. truncatum* across various growth media. Each fungal species responded differently to the composition and nutrient availability of the media, leading to differential growth rates and morphological characteristics.

The observed variations in mycelial growth of the two fungal pathogens across different growth media highlight the significance of environmental factors in shaping fungal development. The diversity in nutrient availability, pH levels, and other components of the growth media contribute to distinct patterns of mycelial expansion. The results shed light on the specific nutrient requirements of *F. verticillioides* and *C. truncatum* during in-vitro cultivation. Variations in growth performance across different media suggest varying nutritional preferences and metabolic capabilities of the fungi, which may be exploited for targeted interventions or control strategies. Understanding these variations provides insights into the specific nutritional requirements of each fungal species, aiding in the development of targeted interventions for disease control. One of the pathogens (*C. truncatum*) measured significant maximum growth 8 days post-inoculation on cauliflower dextrose agar, oatmeal agar, Sabouraud, and potato dextrose agar. Carrot dextrose agar and corn meal agar showed a slower growth of this organism (66.83 and 47.50 cm respectively). The second organism, *F. verticillioides* also showed a significant ($p \leq 0.05$) variation in growth media utilized 8 days after inoculation. Cauliflower dextrose agar, corn meal, oatmeal agar, and PDA had the highest mycelial growth, while carrot dextrose agar and Sabouraud were slower. The choice of growth medium influenced not only the growth rate but also the morphology and structural features of the fungal colonies. Differences in colony size, color, texture, and sporulation patterns observed on different media provide insights into the phenotypic plasticity and adaptive responses of *F. verticillioides* and *C. truncatum* to their environment. The growth medium can significantly influence the expression of virulence factors and pathogenicity traits in fungal pathogens. Understanding how different media conditions modulate fungal growth and development is crucial for deciphering the molecular mechanisms underlying pathogenesis and host-fungus interactions (Lee *et al.*, 2023).

The effect of different growth media on the in-vitro growth of *F. verticillioides* and *C. truncatum* highlights the intricate relationship between fungal physiology, nutrient availability, and environmental factors. These findings were in tandem with the findings of Mapuranga *et al.* (2022) where they examined the infection strategies and pathogenicity of biotrophic plant pathogens. These insights deepen our understanding of fungal biology and have practical implications for agricultural research and disease management efforts. The study sheds light on the intricate relationship between fungal pathogens and their host plants. The observed variations in mycelial growth and nutritional composition suggest a dynamic interplay between the fungi and the pepper plants' defense mechanisms. These findings were also in consonance with the findings of Adnan *et al.* (2019), Umadevi and Anandaraj (2019), and Fu *et al.* (2021). Understanding how different growth media influence these interactions provides crucial information for developing strategies that bolster plant resistance and mitigate the impact of fungal infections on crop yield and quality. Trivedi *et al.* (2021), Debnath *et al.* (2023), Wahab *et al.* (2023), and Ahmed *et al.* (2023) also confirm that growth media have practical implications for agricultural practices, emphasizing the importance of selecting appropriate growth media to manage fungal diseases effectively. Tailoring growth conditions to limit the proliferation of specific fungal pathogens can be a valuable strategy for minimizing crop losses. Additionally, Pandey *et al.* (2016) and He *et al.* (2016) showed the need for integrated disease management approaches that consider both environmental and host factors. This study contributes to the broader understanding of ecological dynamics in plant-fungus interactions. It highlights the adaptability of fungal pathogens to different environmental conditions and emphasizes the need for a holistic approach to studying these interactions. This knowledge can inform ecological models and contribute to a more comprehensive understanding of how fungi contribute to ecosystem dynamics (He *et al.*, 2016).

The comparative analysis of nutritional composition in infected pepper fruits reveals potential shifts in essential components, such as proximate, vitamins, minerals, and organic compounds. For carbohydrates in this study recorded 24.20, 18.00 and 23.26 % for the uninfected, infected with *C. truncatum* and *F. verticillioides*, respectively, whereas protein was 3.13, 0.38, and 1.46 for uninfected, infected with *C. truncatum*, and *F. verticilloide*. This is in tandem with the findings of Attiah *et al.* (2024), where he recorded a decline in carbohydrates and protein by 68.18 and 68.17% respectively. These findings agree with those of Liu *et al.* (2022) who opined that plant fungal infections can alter the microbial communities in pepper plants, impacting the proximate composition. They further showed that fungal pathogens like *Penicillium*, *Cladosporium*, and *Fusarium* influenced microbial diversity. Wang *et al.* (2019) also agreed that plant fungal infection by *Fusarium* species can lead to mycotoxin

accumulation in pepper tissues, potentially affecting the proximate composition of pepper fruit.

Fungal infections may lead to alterations in nutrient uptake and utilization by the host plant (Liu *et al.*, 2022; Rad *et al.*, 2022). These changes can impact the overall nutritional quality of the harvested fruits, with implications for both food security and economic considerations. Fungal pathogens can alter the levels of macronutrients such as carbohydrates, proteins, and fats in pepper fruits (Knez *et al.*, 2023; Li *et al.*, 2023). For instance, the infection may lead to a decrease in carbohydrate content due to the diversion of nutrients towards fungal growth. Fungal infections can affect the concentration of essential micronutrients like vitamins and minerals in pepper fruits. Some pathogens may deplete certain vitamins, such as vitamin C, through enzymatic degradation. Others might disrupt mineral uptake and translocation within the plant, leading to deficiencies in elements like calcium, magnesium, or iron. In the findings of Frimpong *et al.* (2019), *Aspergillus* invasion resulted in the reduction of the levels of essential nutrients like vitamins and minerals in pepper. The research by Ragasová *et al.* (2022) demonstrated that colonization of pepper roots by beneficial microorganisms, such as arbuscular mycorrhizal fungi (AMF) and *Azospirillum brasilense*, can influence the levels of nutrients in pepper plants. Overall, the interaction between microorganisms and pepper plants can significantly affect the nutrient composition of pepper fruit, emphasizing the importance of understanding and managing these relationships for optimal plant health and human nutrition. Fungal pathogens can influence the levels of phytochemicals present in pepper fruits (Hosni *et al.*, 2011). These bioactive compounds, including phenolics, flavonoids, and alkaloids, contribute to the plant's defense against pathogens and have potential health benefits for consumers (Roy *et al.*, 2022). However, their synthesis and accumulation may be altered in response to fungal infection, either increasing as part of the plant's defense response or decreasing due to metabolic disturbances. From this study, the bioactive compounds such as flavonoids and alkaloids of healthy and infected fruits differed significantly. Uninfected fruits recorded 6.48 and 2.70% for alkaloid and flavonoid, whereas the fruits infected with *C. truncatum* recorded 1.85 and 0.59% for alkaloid and flavonoids respectively. Meanwhile the fruits infected with *F. verticilloides* had 1.60 and 0.40% for alkaloids and flavonoids. These findings were in agreement with that of (Kumar *et al.*, 2021) as he reiterated that fungal infections affected the nutritional value of pepper fruits. Fungal pathogens can impact the antioxidant capacity of pepper fruits by altering the levels of antioxidants such as polyphenols and carotenoids (Mohammed *et al.*, 2022). Antioxidants play a crucial role in scavenging free radicals and preventing oxidative damage in plants and humans. Therefore, changes in antioxidant activity due to fungal infection can affect the shelf life and nutritional value of pepper fruits (Kumar *et al.*, 2021).

CONCLUSION

The comparative study of the effect of growth media on mycelia growth of two fungal pathogens provided insights into the complex dynamics between fungi and pepper plants. The choice of growth media was shown to exert a substantial impact on the development of pathogens, underscoring the importance of environmental factors in shaping fungal behaviour. Moreover, pathogenic infection was found to impact the nutritional composition of pepper fruits. This finding highlights the intricate relationship between fungal infections and nutritional quality of host fruits. Such insights have implications for both agricultural practices and food safety, emphasizing the need for a comprehensive understanding of the environmental conditions influencing these interactions. By recognizing the intricate interplay between growth media, fungal pathogens, and nutritional outcomes in pepper fruits, we pave the way for more informed strategies aimed at enhancing both crop yield and quality in the face of fungal challenges. Following the standard practice in mycology, oath meal agar can be recommended in further studies on these pathogens considered. Infected pepper fruits should be jettisoned by rural dwellers who think that they have complete nutrient on infected pepper.

REFERENCES

- Adnan M., Islam W., Shabbir A. *et al.* (2019). Plant defense against fungal pathogens by antagonistic fungi with *Trichoderma* in focus. *Microb. Pathogen.*, **129**, 7-18. <https://doi.org/10.1016/j.micpath.2019.01.042>
- Agostini-Costa T.S., Gomes I.S., Melo L.A.M.P., Reifschneider F.J.B. and Ribeiro C.S.C. (2017). Carotenoid and total vitamin C content of peppers from selected Brazilian cultivars. *J. Food Compos. Anal.*, **57**, 73-79. <https://doi.org/10.1016/j.jfca.2016.12.020>
- Ahmed N., Zhang B., Bozdar B. *et al.* (2023). The power of magnesium: unlocking the potential for increased yield, quality, and stress tolerance of horticultural crops. *Front. Plant Sci.*, **14**, 1285512. <https://doi.org/10.3389/fpls.2023.1285512>
- AOAC (2016) Official Methods of Analysis 20th edn. Association of Official Analytical Chemists (AOAC), International, Rockville, MD
- Attia M.S., Salem M.S. and Abdelaziz A.M. (2024). Endophytic fungi *Aspergillus* spp. reduces fusarial wilt disease severity, enhance growth, metabolism and stimulate the plant defense system in pepper plants. *Biomass Conversion and Biorefinery*, 1-11. <https://doi.org/10.1007/s13399-022-03607-6>
- Chauhan S., More A., Uikay R., Malviya P. and Moghe A. (2017). Brain tumor detection and classification in MRI images using image and data mining. In: 2017 International Conference on *Recent Innovations in Signal Processing and Embedded Systems (RISE)* (pp. 223-231), IEEE. <https://doi.org/10.1109/RISE.2017.8378158>
- Clark-Cotton M.R., Jacobs K.C. and Lew D.J. (2022). Chemotropism and cell-cell fusion in fungi. *Microbiol. Molecular Biol. Reviews*, **86** (1), e00165-21. <https://doi.org/10.1128/2FMMBR.00165-21>
- Debnath S., Elgorban, A.M., Bahkali, A.H. *et al.* (2023). Exploring the efficacy of 1-amino-cyclopropane-1-carboxylic acid (ACCA) as a natural compound in strengthening maize resistance against biotic and abiotic stressors: an empirical computational study. *Front. Microbiol.*, **14**, 1232086. <https://doi.org/10.3389/fmicb.2023.1232086>
- Dias M.D., Dias-Neto J.J., Santos M.D. *et al.* (2019). Current status of soybean anthracnose associated with *Colletotrichum truncatum* in Brazil and Argentina. *Plants* (Basel), **8** (11), 459. <https://doi.org/10.3390/plants8110459>
- Frimpong G.K., Adekunle A.A., Ogundipe O.T., Solanki M.K., Sadhasivam S. and Sionov E. (2019). Identification and toxigenic potential of fungi isolated from capsicum peppers. *Microorganisms*, **7** (9), 303. <https://doi.org/10.3390/MICROORGANISMS7090303>
- Fu T., Han J.H., Shin J.H. *et al.* (2021). Homeobox transcription factors are required for fungal development and the suppression of host defense mechanisms in the *Colletotrichum Scoville*-pepper pathosystem. *Mbio*, **12** (4), 10-1128. <https://doi.org/10.1128/mbio.01620-21>
- Gul R., Jan S.U., Syed F., Sherani F. and Nusrat J. (2017). Preliminary phytochemical screening, quantitative analysis of alkaloids, and antioxidant activity of crude plant extracts from *Ephedra intermedia* indigenous to Balochistan. *The Sci. World J.*, **2017** (1), 5873648. <https://doi.org/10.1155/2017/5873648>
- Hazim A.W. (2022). Environmental study comparison between normal and standard culture media for the growth of fungi. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1029, No. 1, p. 012005). IOP Publ. <https://doi.org/10.1088/1755-1315/1029/1/012005>
- He D.C., Zhan J.S. and Xie L.H. (2016). Problems, challenges and future of plant disease management: from an ecological point of view. *J. Integr. Agric.*, **15** (4), 705-715. [https://doi.org/10.1016/S2095-3119\(15\)61300-4](https://doi.org/10.1016/S2095-3119(15)61300-4)
- Hosni K., Jemli M., Dziri S. *et al.* (2011). Changes in phytochemical, antimicrobial and free radical scavenging activities of the Peruvian pepper tree (*Schinus molle* L.) as influenced by fruit maturation. *Ind. Crops Products*, **34** (3), 1622-1628. <https://doi.org/10.1016/j.indcrop.2011.06.004>
- Jaiswal V., Gahlaut V., Kumar N. and Ramchiary N. (2021). Genetics, genomics and breeding of chili pepper *Capsicum frutescens* L. and other *Capsicum* species. *Advances in Plant Breeding Strategies: Vegetable Crops*, Vol. 9 (pp. 59-86). *Fruits and Young Shoots*. https://doi.org/10.1007/978-3-030-66961-4_2
- Jayawardena R.S., Hyde K.D., Chen Y.J. *et al.* (2020). One stop shop IV: taxonomic update with molecular phylogeny for important phytopathogenic genera: 76–100 (2020). *Fungal Diversity*, **103**, 87-218. <https://doi.org/10.1007/s13225-020-00460-8>
- Khan N., Ahmed M.J. and Shah S.Z.A. (2019). Comparative analysis of mineral content and proximate composition from chilli pepper (*Capsicum annum* L.) germplasm. *Pure Appl. Biol.*, **8** (2), 1338-1347. <https://dx.doi.org/10.19045/bspab.2019.80075>
- Knez E., Kadac-Czapska K. and Grembecka M. (2023). Effect of fermentation on the nutritional quality of the selected vegetables and legumes and their health effects. *Life*, **13** (3), 655. <https://doi.org/10.3390/life13030655>
- Kumakech A. and Opio T. (2023). Culture media influence on vegetative growth and mycelia weight of *Mycosphaerella fijiensis*: implication for inoculum production. *Brazilian Journal of Science*, **2** (7), 103-107. <https://doi.org/10.14295/bjs.v2i7.356>

- Kumar N., Petkoska A.T., AL-Hilifi S.A. and Fawole O.A. (2021). Effect of chitosan–pullulan composite edible coating functionalized with pomegranate peel extract on the shelf life of mango (*Mangifera indica*). *Coatings*, **11** (7), 764. <https://doi.org/10.3390/coatings11070764>
- Lee Y., Robbins N. and Cowen L.E. (2023). Molecular mechanisms governing antifungal drug resistance. *npj Antimicrob Resist*, **1**, 5. <https://doi.org/10.1038/s44259-023-00007-2>
- Leslie J.F. and Summerell B.A. (2006). The *Fusarium* Laboratory Manual (pp. 230-239), Blackwell Publishing, Ames, Iowa
- Li K., Qiao K., Xiong J., Guo H. and Zhang Y. (2023). Nutritional values and bio-functional properties of fungal proteins: Applications in foods as a sustainable source. *Foods*, **12** (24), 4388. <https://doi.org/10.3390/foods12244388>
- Liu L., Ma L., Feng J. and Lu X. (2022). Dynamic fluctuation and niche differentiation of fungal pathogens infecting Bell Pepper plants. *Appl. Environ. Microbiol.*, **88** (18), e01003-22. <https://doi.org/10.1128/aem.01003-22>
- Majid M.U., Awan M.F., Fatima K. et al. (2017). Genetic resources of chili pepper (*Capsicum annuum* L.) against *Phytophthora capsici* and their induction through various biotic and abiotic factors. *Cytology and Genetics*, **51**, 296-304. <https://doi.org/10.3103/S009545271704003X>
- Manzi P., Marconi S., Aguzzi A. and Pizzoferrato L. (2004). Commercial mushrooms: nutritional quality and effect of cooking. *Food Chem.*, **84** (2), 201-206. [https://doi.org/10.1016/S0308-8146\(03\)00202-4](https://doi.org/10.1016/S0308-8146(03)00202-4)
- Mapuranga J., Zhang N., Zhang L., Chang J. and Yang W. (2022). Infection strategies and pathogenicity of biotrophic plant fungal pathogens. *Front Microbiol.*, **13**, 799396. <https://doi.org/10.3389/fmicb.2022.799396>
- Mohammad S.A., Hayat K., Mabood H.F. et al. (2022). Effects of different solvent extractions on total polyphenol content, HPLC analysis, antioxidant capacity, and antimicrobial properties of peppers (red, yellow, and green (*Capsicum annuum* L.)). *Evidence-Based Compl. Alt. Med.*, **2022** (1), 7372101. <https://doi.org/10.1155/2022/7372101>
- Navarrete-Perea J., Gygi S.P. and Paulo J.A. (2021). Growth media selection alters the proteome profiles of three model microorganisms. *J. Proteomics*, **231**, 104006. <https://doi.org/10.1016/j.jprot.2020.104006>
- Nair K.P. and Nair K.P. (2020). The future of the global pepper economy. *The Geography of Black Pepper (Piper nigrum) The "King" of Spices*–Vol. 1, 91-99. https://doi.org/10.1007/978-3-030-52865-2_10
- Ningsih D.R., Raharjo T.J., Haryadi W. and Wikandari R. (2023). Antifungal activity and identification of bioactive peptide from Etawa crossbreed goat (*Capra hircus*) milk protein hydrolyzed using trypsin enzyme. *Arabian J. Chem.*, **16** (11), 105249. <https://doi.org/10.1016/j.arabjc.2023.105249>
- Obani F.T. and Ikotun B. (2021). Efficacy of three botanicals on postharvest fungal contaminants of melon (*Citrullus colocynthis*) kernels. *Agro-Science*, **20** (1), 1-8. <https://dx.doi.org/10.4314/as.v20i1.1>
- Omotayo O.P. and Babalola O.O. (2023). *Fusarium verticillioides* of maize plant: Potentials of propitious phytomicrobiome as biocontrol agents. *Front. Fungal Bio.*, **4**, 1095765. <https://dx.doi.org/10.3389/ffunb.2023.1095765>
- Pandey A.K., Sain S.K. and Singh P. (2016). A Perspective on integrated disease management in agriculture. *Bio Bulletin*, **2** (2), 13-29
- Prusky D.B. and Sionov E. (2021). Special Issue “Interplay between Fungal Pathogens and Harvested Crops and Fruits”. *Microorganisms* **2021**, **9** (3), 553. <https://doi.org/10.3390/MICROORGANISMS9030553>
- Rad A.K., Zarei M., Astaikina A., Streletskii R. and Etesami H. (2022). Effects of microbial inoculants on growth, yield, and fruit quality under stress conditions. In *Sustainable Horticulture* (pp. 1-38). Academic Press. <https://doi.org/10.1016/B978-0-323-91861-9.00014-8>
- Ragasová L., Hakalová E., Ferby V., Čechová J., Klapcová G. and Pokluda R. (2022). Effect of plant growth promoting microorganisms on pepper plants infected with tomato brown rugose fruit virus. *Diversity*, **14** (8), 635. <https://doi.org/10.3390/d14080635>
- Roy A., Khan A., Ahmad I. et al. (2022). Flavonoids a bioactive compound from medicinal plants and its therapeutic applications. *Biomed. Res. Int.*, **2022** (1), 5445291. <https://doi.org/10.1155/2022/5445291>
- Silva G.O., Abeyesundara A.T. and Aponso M.M. (2017). Extraction methods, qualitative and quantitative techniques for screening of phytochemicals from plants. *Am. J. Essential Oils Natural Prod.*, **5** (2), 29-32
- Singh V. and Kumar R. (2017). Study of phytochemical analysis and antioxidant activity of *Allium sativum* of Bundelkhand region. *Int. J. Life-Sci. Sci. Res.*, **3** (6), 1451-1458. <https://doi.org/10.21276/ijlssr.2017.3.6.4>
- Trivedi P., Mattupalli C., Eversole K. and Leach J.E. (2021). Enabling sustainable agriculture through understanding and enhancement of microbiomes. *New Phytologist*, **230** (6), 2129-2147. <https://doi.org/10.1111/nph.17319>
- Umadevi P. and Anandaraj M. (2019). Proteomic analysis of the tripartite interaction between black pepper, *Trichoderma harzianum* and *Phytophthora capsici* provides insights into induced systemic resistance mediated by *Trichoderma* spp. *Europ. J. of Plant Pathol.*, **154**, 607-620. <https://doi.org/10.1007/s10658-019-01685-3>
- Vallejo-Gutiérrez A.J., Mejía-Carranza J., García-Velasco R. and Ramírez-Gerardo M.G. (2019). Response of *Capsicum pubescens* genotypes to damage caused by the fungal wilt complex. *Revista Mexicana de Fitopatología*, **37** (1), 50-70. <https://doi.org/10.18781/R.MEX.FIT.1809-3>
- Wahab A., Muhammad M., Munir A. et al. (2023). Role of arbuscular mycorrhizal fungi in regulating growth, enhancing productivity, and potentially influencing ecosystems under abiotic and biotic stresses. *Plants*, **12** (17), 3102. <https://doi.org/10.3390/plants12173102>
- Wang J., Wang S., Zhao Z., Lin S., Van Hove F. and Wu A. (2019). Species composition and toxigenic potential of *Fusarium* isolates causing fruit rot of sweet pepper in China. *Toxins*, **11**(12), 690. <https://doi.org/10.3390/TOXINS11120690>
- Zakaria L. (2021). Diversity of *Colletotrichum* species associated with anthracnose disease in tropical fruit crops—A review. *Agriculture*, **11**, 297. <https://doi.org/10.3390/agriculture11040297>