Survey of Soil-Borne Pathogenic Fungi Affecting Some Vegetables in Gerio Irrigation Farm, Adamawa, Nigeria

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ABSTRACT

Introduction: Microorganisms abound in the soil, especially fungi that have high propensity of causing a diverse range of diseases to plants like vegetables. This study sought to establish the presence of some pathogenic fungi present in soil and vegetables grown in Gerio irrigation farm of Adamawa, Nigeria.

Methods: From this cross-sectional study, 50 grams each of 3 sets of soil samples from *Amaranthus hybridus* (African spinach), *Hibiscus sabdariffa* (Roselle) and *Sesamum radiatum* (Vegetable saseme) vegetable farms totaling 450g with same sets of stunted sick vegetables to their roots were collected through stratified random sampling techniques. Soil fungi were identified using Waksman's plate dilution method, while infected plant parts were aseptically processed and cultured on Potato dextrose agar (PDA) prior to identifying fungi using standard fungal detection techniques at Modibbo Adama University of Technology laboratory in the department of Plant Sciences, Yola from July to September 2016. Data was processed using excel and analysed using ANOVA SPSS 23.

Results: The study at Gerio irrigation site, Yola, Adamawa State, assessed soil particle types, porosity, moisture content, and fungal populations. Roselle farm soil had the highest sand content (82%), while sesame farm soil showed the highest silt (13%) and porosity (21.9%). Spinach farm soil recorded the highest particle (1.58) and bulk densities (1.45) but the lowest porosity (8.23%). Moisture content was highest in vegetable sesame farm soil (24%) and lowest in spinach soil (10%). Fungal analysis identified five species: *Fusarium oxysporum*, *Fusarium solani*, *Rhizoctonia solani*, *Aspergillus niger*, and *Aspergillus flavus*. *Fusarium oxysporum* was the most prevalent, dominating Roselle plants (58.3%) and soils. In contrast, *Aspergillus spp.* was rare, with *A. flavus* absent in spinach and Roselle soils.

Discussion: The study accentuates the impact of *Fusarium oxysporum* and *F. solani* on vegetables at Gerio irrigation farm, with roselle being highly susceptible. Poor irrigation practices could have exacerbated fungal damage, causing symptoms like wilting and root rot. Measures like crop rotation, fungicides, resistant varieties, and improved irrigation can address these problems. The findings emphasize the importance of understanding soil properties and crop-specific fungal interactions for sustainable agriculture and integrated pest management strategies.

Keywords: Vegetables, Fungi, Potato Dextrose Agar (PDA), stratified sampling techniques, *Fusarium oxysporum*, Gerio Adamawa, Nigeria

INTRODUCTION

Soil pathogens like bacteria, nematodes, viruses, and most fungi, use the soil as a niche to infect plants, significantly limiting crop yields, particularly for vegetables (Klein et al., 2011; Koike et al., 2003). Fungi are abundant in terrestrial ecosystems (Jayaraman et al., 2018) often form synergetic relationships with plant roots. As obligate biotrophs, they rely on plants for their carbon supply (Watkinson, 2016). Some soil-borne pathogens survive in the soil as free-living organisms feeding on organic matter, while others persist on host plant debris (Farzana. et al., 2014). Key soil-borne fungal pathogens include *Fusarium, Rhizoctonia, Sclerotinia, Verticillium,* and *Spongospora* species (Rivard and Louis, 2006). These fungi can infect vegetables at any growth stage, causing early diseases like seedling blight or late-season conditions such as foliar blight, vine rot, stem lesions, fruit rot, root discoloration, and crown rot (Farzana et al., 2014). Fungi such as *Fusarium spp., Macrophomina phaseolina* and *Rhizoctonia solani* cause root-rot and root-knot diseases that severely affect crops like chili, okra, tomatoes, and spinach (Hussain et al., 2013; Maqbool et al., 1988). While some fungi are locally confined as opined by Ali, (2000); the damage they cause on root and crown tissues often remains hidden until severe symptoms, such as stunting, wilting, chlorosis, and plant death, appear above ground (Athar and Bokhari 2006; Koike et al., 2003).

Parameters like soil type, texture, pH, moisture, temperature, nutrient levels, and ecology influence pathogen activity (Jamala et al., 2012; Ghorbani et al., 2008). However, many fungi adapt to varying soil conditions by producing resilient survival structures like melanized hyphae, chlamydospores, oospores, and sclerotia (Pettit et al., 1996). Vegetables are particularly vulnerable to soil-borne pathogens, which damage essential plant parts, reduce yields, and render crops unmarketable. Globally, plant diseases reduce agricultural yields by up to 26%, and in tropical and subtropical regions, soil-borne fungal infections can lead to 80% losses in severely affected fields (Sikora and Fernandez, 2005; Adam and Hallmann, 2014; Khan et al., 2009). *Fusarium solani* along with *Rhizoctonia solani* are among the most noteworthy soil-borne infectious agents, causing damping-off and root-rot diseases in vegetables like tomatoes (Szczechura et al., 2013)

Vegetable farming is a vital component of agriculture and contributes to boosting food security and meeting the nutritional needs of lots of agrarian communities (Olaoye, 2014) with Gerio inclusive. These plants are rich in nutrients and offer households not only a source of income but also a balanced diet, improving public health. Since vegetables production plays a crucial role in income generation and nutrition this emphasizes the need to survey soil-borne pathogenic fungi affecting vegetables in Gerio irrigation farm, Yola North, Adamawa State.

MATERIALS AND METHODS

Study Area

This research was conducted at Gerio in Yola, Adamawa State, Nigeria, located at approximately 9°16'48" N latitude and longitude 12°27'36" East. The study area, situated around Lake Gerio (Figure 1), has a population of roughly 392,854 (NPC, 2006). Yola, the capital of Adamawa State in northeastern Nigeria, lies within latitude 9°06'–9°19' N and longitude 12°20'–12°30' E. It spans a landmass of approximately 830.85 km² and has a population of 196,197 (Tukur & Barde, 2014). Yola has a semi-arid, dryland climate with annual rainfall ranging between 700–1600 mm and agriculture is the dominant economic activity, employing over 90% of the area’s workforce. Thus, most residents are subsistence farmers, reflecting the importance of farming in the local economy.

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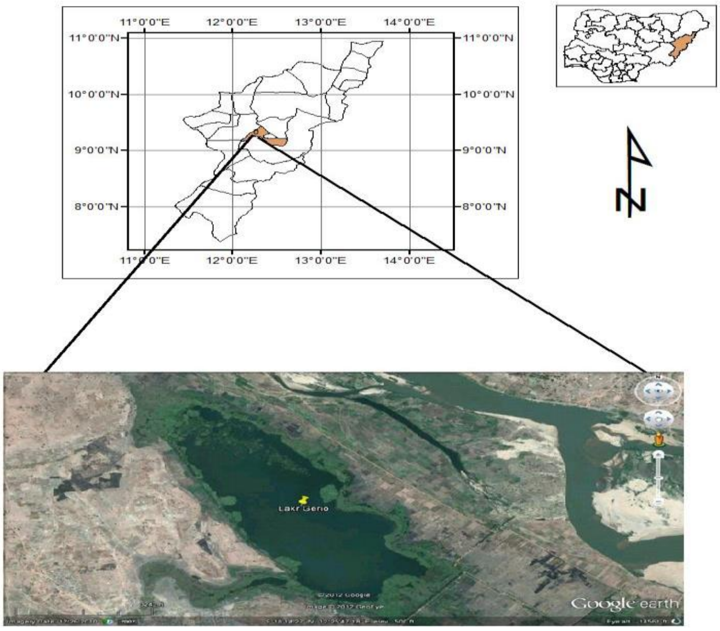

Figure 1. Map of lake Gerio, Yola North, Adamawa state showing surrounding irrigation sites. Source (Shinggu et al., 2015) [19].

Study Design

This work utilized a cross-sectional study strategy carried out within the period of 10 weeks (July-September 2020).

Sampling technique and sample collection

Stratified random sampling was employed to collect the study samples after enumerating the area into sections of square meters. Employing the method described by Nyongesa et al., (2015) hand trowel was used to obtain nine (9) samples containing around 50g each of topsoil 4cm deep from 3 each vegetable farm making a total of 450 grams in sterile polyethene bags from the irrigation site. Each time the sample was taken, the trowel was washed with water and sterilized by flooding it with sodium hypochlorite. They were properly labelled [i.e., Gerio irrigation soil sample (GISS) 1-9] sealed and kept in a cooler at a temperature of about 22-26˚C and then taken for analysis to the laboratory of Plant Science, Department of Modibbo Adama University of Technology, Yola.

For the vegetable, three (3) sets of stunted *Hibiscus sabdariffa* L. (roselle commonly called "Zobo" in Hausa), *Amaranthus hybridus* (spinach called "Aleho" in Hausa) and and *Sesamum radiatum* (Sesame frequently referred to as "Karkaashii" in Hausa) vegetable plants showing signs of root rot, chlorosis,

and wilting were collected from the study site. A total of 9 samples were collected in a sterilized polythene bag and taken to the Laboratory for analysis.

Soil physical parameters (particulate sizes, porosity and moisture)

Particulate sizes: The soil particle sizes were determined using the Hydrometer Method, that measures sand, silt, and clay percentages based on sedimentation rates in a soil suspension. The results were classified using the USDA Soil Texture Triangle. Bulk density (BD) and particle density (PD) were measured by means of a core sampler and pycnometer, respectively, to determine the mass and volume of soil solids.

Porosity: The porosity of the combined soil samples from each vegetable farm which gives an indirect indication of moisture retention capacity was determined using the formula below:

$$\text{Porosity} = \left(1 - \frac{BD}{PD}\right) \times 100\%$$

Soil moisture content: This was determined using the standard oven-drying method by first weighing an empty petri-dish, then adding precisely 1 gram of collected soil sample before placing in a hot air oven at 105˚C for 2 hours. Upon drying, the petri-dish soil sample was allowed to cool at room temperature and assessed for weight loss while noting the initial petri-dish with soil sample weight and that of the final to calculate the percentage moisture content of the soil sample. The moisture content percentage was calculated using the following formula (Jain et al., 2018)

$$\text{Soil moisture \%} = \frac{\text{Initial glass dish weight with 1g of soil (A)} - \text{Final weight of dish with soil (B)}}{\text{Soil sample weight taken (C)}} \times 100\%$$

Media/samples preparation and culturing

Fungal media preparation

Potato dextrose agar (PDA) was used for culturing the fungi in this study. From a standard 39-gram PDA bottle, the required amount was properly weighed and dissolved in its proportionate millilitres of distilled water according to the manufacturer's instructions in a conical flash. The mixture was well sealed with cotton wool, covered with aluminum foil, and sterilized in an autoclave at 121°C for 15 minutes. After sterilization, the media cooled to approximately 45°C before dispensing 10-12ml into required number of petri dishes. The prepared plates were incubated prior to culturing.

Samples preparation and culturing

Triplicate sets (i.e. 9 samples of 3 each of diseased vegetable leaves, stems, and roots) were aseptically washed in water containing vinegar. Lacerated parts were excised and disinfected for about 40 seconds in 50% alcohol and 0.5% sodium hypochlorite. Using sterilized inoculation forceps, the samples were rinsed with sterile distilled water, cultured on 27 PDA plates (i.e. 3 parts each of leaves, stems and roots for roselle, spinach and sesame) under a laminar flow hood, and incubated at 22 ± 3ºC with a 12-hour light cycle to promote mycelial growth for 3–7 days.

The soil dilution plate method described by Waksman (1922) was used to process the nine (9) soil samples with 3 coming from each vegetable farm. For each sample, 1g of soil was added to 10ml of distilled water in a sterile container to create a 1/10 stock dilution. Serial dilutions were then performed across five test tubes (10^{-5}) by transferring 1ml from the previous dilution into 9ml of sterile distilled water, with the final 1ml discarded. From the 10^{-3} dilutions of each sample, 0.5ml was pipetted onto pre-prepared PDA plates containing 1% chloramphenicol to inhibit bacterial growth. The spread plate method was used, and the plates were then incubated at 22 ± 3ºC for at least five days. Discrete fungal colonies were then analyzed macroscopically and sub-cultured onto fresh PDA to obtain pure cultures.

Identification of Fungal isolates

This study examined the morphological features of fungal isolates using macroscopic and microscopic methods to aid identification. The macroscopic examination was done by inspecting the colonial morphology of fungal visible structures like hyphae and mycelia on media plates (i.e., front and reverse growth patterns, color, shape, undulation etc.), whilst microscopic analysis employed lactophenol blue staining to reveal structural details of fungal spores and hyphae similar to ways employed by Salvamani & Nawawi, (2014). *Fusarium spp*. e.g *Fusarium oxysporum* produces hyaline, septate hyphae with conidiophores that may be single or branched, forming conidia at their tips shown below as Figure 2 (A). *Fusarium solani* features white-cream mycelium, macroconidia with 3–4 septa that are thick-walled and slightly curved, and abundant microconidia that are oval to kidney-shaped. Chlamydospores are also common (Fig. 2 B). *Rhizoctonia solani* presents as young, colorless hyphae that matures to a brown septate form, branching at right angles with diagnostic constrictions near the branches. It produces white to deep brown mycelium on potato dextrose agar (Fig. 2 C). While *Aspergillus spp***.** like A*spergillus niger* has pale brown or hyaline conidiophores with globose vesicles that form loose conidial heads. Conidia are brown, globose, and minutely echinulate (Fig. 2 D) *Aspergillus flavus* features short, hyaline conidiophores bearing single, brown, ovate to ellipsoidal conidia with smooth edges and transverse and longitudinal septa (Fig. 2 E).

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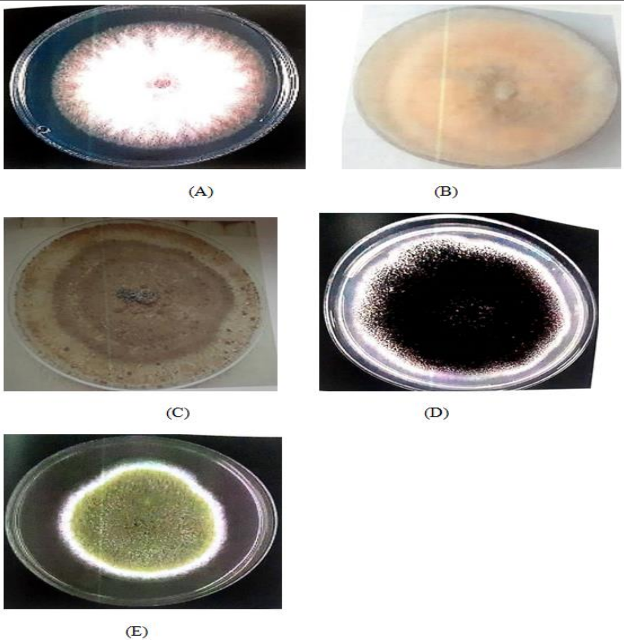

Fig. 2: **(A**)= A 7- day old culture of *Fusarium oxysporum* on PDA; **(B**)= *Fusarium solani* on a 7- day old PDA culture medium; **(C)**= *Rhizoctonia solani* on a 7- day old culture PDA medium showing sporulating edge; **(D)=** A 7: Seven-day old culture of *Aspergillus niger* on PDA; **(E)**= *Aspergilus flavus* on a 7-day old PDA culture medium

Quantitative analysis for fungal isolates

The percentage contribution, which is the total number of fungi isolated from 1 gram of soil sample,

was determined using the formula below, which is described by Jayaraman et al., (2018).

$$\text{Contribution percentage (\%)} = \frac{\text{Total CFU No. of individual fugal species}}{\text{Total CFU for all fungal species}} \times 100$$

Data analysis

The research data was managed using basic MS excel and SPSS 23 for providing descriptive statistics like frequencies, percentage, mean, and range for soil properties and fungal populations to derive insights from the study data.

Consent for samples collection and approval for laboratory analysis

The consent of vegetable farmers was sought to allow samples to be obtained from the study site, while the head of the Department of Plant Sciences, Modibbo Adama University of Technology Yola, gave verbal approval/permission for the laboratory tests to be carried out at the institution.

RESULTS

Soil Particle types and Porosity

From the soil particle sizes evaluated from the irrigation site (Table 1), Sand soil type recorded the highest mean percentage of all soil particle types with that from Roselle farm having the highest (82.0%). The highest (13%) mean value for silt soil type was seen in Sesame farm soil, with the least (8.0%) soil mean of clay recorded in roselle farm. The soil type with the most particle density average and bulk density came from Spinach farm (i.e. 1.58 and 1.45 respectively) while the least particle and bulk densities were recorded from sesame soil farm (1.51 and 1.18). Outcomes from the soil's porosity determination presented spinach soil samples to be the least porous (8.23%) while that from Sesame farm was the highest (21.9%).

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Table 1. Particulate soil types and Porosity from vegetable farm samples in Gerio irrigation site, Yola North, Adamawa, Nigeria

Sample source	Percentage (%)						
	Mean Sand value	**Mean Slit value**	**Mean Clay value**	**Texture**	**Mean PD**	**Mean BD**	**Porosity= (1 - $\frac{BD}{PD}$) x 100%**
Roselle farm	82.00	10.00	8.00	SL	1.55	1.25	19.35
Spinach farm	81. 00	9.00	10. 00	SL	1.58	1.45	8.23
Sesame farm	75.00	13. 00	12. 00	SL	1.51	1.18	21.85

Key: *SL= Sand Loam; BD = Bulk density; PD = Particle density*

Moisture content tests for soil types

The results from Table 2 indicate that Sesame farm soil sample exhibited the highest (24.0%) moisture content, followed by that obtained from Roselle farm (18.0%) and the lowest recorded in Spinach soil samples (10.0%)

Table 2. Percentage soil moisture content from vegetable farm samples in Gerio irrigation site, Yola North, Adamawa, Nigeria

vegetable soil sample		A (Initial glass dish weight + 1g soil sample)	B (Final glass dish weight + soil sample)	Mean A	Mean B	$\frac{A-B}{C}$	Percentage (%) Moisture
Roselle farm	1	1.25	1.08	1.25	1.07	0.18	18.00
	2	1.25	1.07				
	3	1.25	1.06				
Spinach farm	1	1.25	1.13	1.25	1.15	0.10	10.00
	2	1.25	1.15				
	3	1.25	1.17				
Sesame farm	1	1.25	0.99	1.25	1.01	0.24	24.00
	2	1.25	1.01				
	3	1.25	1.03				

Key: C= Weight of Soil sample taken (i.e. 1gram)

Fungal Population

The general Fungal population for the total soil samples ranged from 1-3 x10^{-3} CFU/gram of soil cultured on the media. The highest population values observed from the culture media prior to sub-culturing the fungi on fresh PDA for proper identification were recorded from Sesame farm (18 fungal CFUs) soils followed by Roselle (16 fungal CFUs) and few observed from Spinach farms (14 fungal CFUs). *Fusarium oxysporum* was the most prominent fungi seen in the soil samples with a mean percentage double frequency occurrence of 7 CFUs in Roselle (43.8%) and Sesame (38.9%) soils respectively, while *Aspergillus spp.* recorded the lowest CFUs with none of *A. flavus* found in Roselle and Spinach soil samples shown below.

Table 3. Fungi isolated from vegetables (roselle, spinach and sesame) soil samples in CFU/g obtained from Gerio Irrigation site in Yola, Adamawa state, Nigeria. September 2020.

Soil sample (SS)	Roselle farm	Farm 1	Farm 2	Farm 3	Mean percent occurrence/fungi
		CFU on PDA from 10^{-3} dilutions (%/Farm)			
Fungal isolates	*F. oxysporum* (%)	2 (33.3)	3 (50.0)	2 (50.0)	7 (43.8)
	F. *solani* (%)	2 (33.3)	2 (33.3)	1 (25.0)	5 (31.3)
	R. solani (%)	1 (16.7)	0 (0.0)	1 (25.0)	2 (12.5)
	A. niger (%)	0 (0.0)	1 (16,7)	0 (0.0)	1 (6.3)
	A. flavus (%)	1 (16.7)	0 (0.0)	0 (0.0)	1 (6.3)

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SS	**Spinach farm**				
Fungal isolates	*F. oxysporum* (%)	2 (33.3)	1 (25.0)	2 (50.0)	5 (35.7)
	F. *solani* (%)	2 (33.3)	1 (25.0)	1 (25.0)	4 (28.6)
	R. solani (%)	1 (16.7)	2 (50.0)	1 (25.0)	4 (28.7)
	A. niger (%)	1 (16.7)	0 (0.0)	0 (0.0)	1 (7.1)
	A. flavus (%)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
SS	**Vegetable Sesame farm**				
Fungal isolates	*F. oxysporum* (%)	3 (60)	2 (28.6)	2 (33.3)	7 (38.9)
	F. *solani* (%)	1 (20.0)	1 (14.3)	1 (16.7)	3 (16.7)
	R. solani (%)	0 (0.0)	1 (14.3)	0 (0.0)	1 (5.6)
	A. niger (%)	1 (20.0)	1 (14.3)	2 (33.3)	4 (22.2)
	A. flavus (%)	0 (0.0)	2 (28.6)	1 (16.7)	3 (16.7)

Key: SS=Soil sample; CFU= Colony forming units; F= *Fusarium;* R= *Rhizoctonia;* A=*Aspergillus*

Table 4 reveals notable fungal contamination among vegetables from the Gerio Irrigation site in Yola, Nigeria. *Fusarium oxysporum* was most prevalent in Roselle (58.3%), Spinach (44.4%), and Sesame (42.7%). Roselle also showed moderate contamination by *Fusarium solani* (17.3%) and *Rhizoctonia solani* (16.2%), while *Aspergillus flavus* was low (8.3%), and *Aspergillus niger* was absent. Spinach had the highest presence of *Rhizoctonia solani* (38.3%) and some *Aspergillus niger* (17.3%), with no traces of *Fusarium solani* or *Aspergillus flavus*. Vegetable Sesame was dominated by *Aspergillus flavus* (34.7%) and *Aspergillus niger* (22.6%), with no detection of *Fusarium solani* or *Rhizoctonia solani*.

From the Statistical tests, all fungal isolates showed a statistically significant probability of frequency ($P < 0.001$), with the least significant difference (LSD) values ranging from 1.153 observed from *Fusarium solani* and *Aspergillus flavus* to 1.998 for *Fusarium oxysporum*.

Table 4. Frequency occurrence for Fungal isolates on Vegetables (Roselle, Spinach and Vegatable Sesame) collected in Gerio Irrigation site in Yola, Adamawa state, Nigeria. September 2020.

Plant Sample	Frequency of Occurrence (%)				
	Fusarium oxysporum	*Fusarium solani*	*Rhizoctonia solani*	*Aspergillus niger*	*Aspergillus flavus*
Roselle	58.30	17.30	16.20	0.00	8.30
Spinach	44.40	0.00	38.30	17.30	0.00
Sesame	42.70	0.00	0.00	22.60	34.70
$P<f^a$	0.001	0.001	0.001	0.001	0.001
LSD^b	1.998	1.153	1.631	1.153	1.631

Key: **$P<f^a$**= Probability of frequency; **LSD^b**= Least significant difference

DISCUSSION

This study explores the soil properties and soil-borne fungi impacting vegetable cultivation at the Gerio irrigation site in Yola North, Adamawa state. The region’s soils, typical of Nigeria's Sudan savanna belt, are predominantly sandy, influenced by erratic rainfall, low humidity, and recurrent droughts, which collectively reduce fertility and vegetation compared to the Guinea savanna. These findings align with studies by Adedibu et al., (2022) and Challinor et al., (2007), which describe sandy to loamy topsoils and clayey subsoils shaped by high rainfall and erosion. Variations in soil properties across farms significantly influence agricultural productivity, with sesame farm soil showing higher silt content and porosity, promoting water infiltration and root growth, while spinach farm soil, characterized by higher density and lower porosity, may hinder aeration and water movement. These findings stress the importance of crop-specific soil management to optimize productivity, consistent with principles in soil science (Brady et al., 2008).

Fungal analysis revealed five pathogenic species: *Fusarium oxysporum*, *F. solani*, *Rhizoctonia solani*, *Aspergillus flavus* and *A. niger*. *Fusarium oxysporum* was the most prevalent, especially in Roselle, where it accounted for 58.3% of infections. These findings were consistent with studies by Magaji & Dakingari, (2023); Abd-El Khair et al., (2011) and Elewa et al., (2011) that identified *F. oxysporum* as a primary pathogen in parts of Nigeria and tropical regions, particularly implicated to causing wilt and root rot diseases in many vegetables' crops. The co-occurrence of *F. oxysporum* and *F. solani* exacerbates their impact, causing vascular wilt and root rot, leading to reduced yields and stunted growth (Akhtar, 2024). Interestingly, *A. flavus* was absent in Spinach, and *F. solani* was not detected in Sesame plants, indicating crop-specific interactions with fungal communities. This data's statistical variability in fungal occurrence across vegetable types, emphasizes the need for targeted interventions to manage fungal contamination in these crops.

The higher fungal population in Sesame farm soil compared to others suggests crop-specific associations influenced by host susceptibility, fertilizer used or soil conditions (Ahanger et al., 2014). *Fusarium oxysporum* dominated, but the presence of *Aspergillus spp.*, known for post-harvest spoilage, highlights their adaptability and resilience, with structural features like conidial formations reflecting unique reproductive strategies. The findings are consistent with reports by Godswill et al., (2011), who documented *F. oxysporum* and other fungi in tomatoes and spinach rots, underscoring their role as major pathogens in farming systems.

The relationship between soil physio-ecological properties, irrigation practices, and fungal proliferation highlights the need for integrated pest management (IPM) strategies. Poor drainage, excessive moisture, and nutrient imbalances could have created favorable conditions for pathogenic fungi (Dixon & Tilston, 2010). Interventions such as crop rotation, soil amendments, planting vegetable resistant varieties (Jamala et al, 2012), and improved irrigation management (Dixon, 2015) are essential to mitigate fungal threats. Regular monitoring and early detection of fungal infections, alongside evidence-based practices, are critical for sustainable vegetable production in the region.

This study provides valuable insights into soil and fungal dynamics, offering a baseline for further research in similar agro-ecological zones. By addressing these challenges through tailored management strategies, farmers can enhance crop health, productivity, and resilience in the face of environmental and biological stressors.

CONCLUSION

This study revealed various physical characteristics of soil from Gerio irrigation farm, and exposed some pathogenic fungi in vegetables grown there, emphasizing their impact on agriculture. Laboratory tests determined *Fusarium spp.*, *Rhizoctonia solani*, and *Aspergillus spp.*, showcasing their adaptability and pathogenic potential. *Fusarium oxysporum* and *F. solani* exhibited aggressive colonization traits, while *R. solani* displayed adaptive branching patterns suited to favourable conditions. These findings underline the importance of accurate fungal identification for targeted interventions in crop management and exposed the indirect role soil and irrigation practices could play in fostering fungal growth, leading to crop diseases like wilting and root rot. Recommendations include improved irrigation, crop rotation, resistant plant varieties, and fungicide use to develop sustainable agricultural practices and integrated pest management strategies.

Declarations

Conflict of Interest

The research authors attest to no conflict of interest regarding this work

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Authors' contributions

AM conceptualized the study, took part in the samples collection and microbiological analysis. ClB supervised the entire work. ACA spearheaded samples collection with YNL. DSA took part in writing the article's initial draft. BB supervised the Lab. analysis along with AMM who assisted in the same. MZP aided in the lab. analysis, worked on putting together the work's final draft and proofreading the article.

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