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Full Length Research Article

DETERMINATION OF SUSCEPTIBILITY PATTERNS OF GINGER (*ZINGIBER OFFICINALE* ROSCOE) GENOTYPES TO EPIDEMIC DISEASES IN KADUNA STATE, SOUTHERN GUINEA SAVANNA, NIGERIA

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ABSTRACT
Ginger (*Zingiber officinale* roscoe) is a herbaceous, perennial, tropical and subtropical rhizomatous plant, grown extensively in southern Kaduna. It has several uses from pharmaceutical to food industries. The occurrence and distribution of disease on ginger cultivated in Kaduna State and the disease pathogen responsible for ginger losses were determined in this study. In this study, field survey was carried out and samples of leaves, rhizomes and soils (under the rhizomes) were collected in two most cultivated locations in six (6) local government areas of Jema'a (KASU JSQ & KASU SSQ), Kachia (Gibir & U/Sarki), Kagarko (Dogon Kurmi & Kagarko), Kaura (GCK & KGR Pada), Jaba (Samban & Jaban Kogo), and Zongon Kataf (Zauru & U/Rimi). Several species of fungi, bacteria and nematodes were isolated from the collected samples across the sampling locations. Incidences of fungal species (15); *Aspergillus fumigatus* & *Aspergillus niger* with 17 isolates each, and *Fusarium solani* with 15 isolates were recorded, while in bacteria, 10 species incidences existed with *Baccillus* spp., *Micrococcus* sp and *Citrobacter* spp with 22, 17 and 16 isolates occurrence respectively. Nematodes had 10 different species occurrences with 15 of *Trichodorus* sp and 13 of *Meloidogyne* spp. Overall, fungi were the most frequently encountered pathogens across all LGAs, followed by bacteria, with nematodes being the least prevalent.

Keywords: Susceptibility patterns, ginger, genotypes

INTRODUCTION

Ginger (*Zingiber officinale* Roscoe) is a tropical and subtropical perennial, herbaceous plant revered as one of the most popular and valued spices of the world (Sodangi, 2020; Uddin *et al.,* 2023). The ginger plant takes its origin from South-Eastern Asia but has over the centuries been introduced to various parts of the world (Ravindran and Nirmal, 2016; Bodhare, 2023). Though the entire plant is refreshingly aromatic, the most useful part of this plant is the underground rhizome. Ginger is in the family *Zingiberaceae*, which also includes turmeric (*Curcuma longa* L.), and cardamom (*Elettaria cardamomum* L.). The ginger plant has a thick, branched rhizome (underground stem) with a brown outer layer and yellow centre that has a spicy, citrusy aroma (Wang, 2020; IUCN, 2022). Every year, it grows pseudostems (false stems made of tightly wrapped leaf bases) from the rhizome which bears narrow leaves (IUCN, 2022). The inflorescences bear flowers which grow on separate, shorter stems in a cone-shaped spike and are pale yellow in colour with purplish edges. The shoot measures about 30-100 cm above the ground with long, narrow, ribbed leaves which are 15-20 cm long and 1-3 cm wide (Yang and Rahmawati, 2022). Besides being used as a spice, ginger is also used to produce oil, oleoresin, essences, soft drinks, and non-alcoholic beverages. Ginger also has manifold medicinal properties as a carminative and stimulation of gastro-intestinal tracts (Aregawi *et al.,* 2022). Its uses extend to food and beverages industries, and pharmaceutical. It has great economic potentials with export for Nigeria and in the producing communities because of the value chain and several other uses (Bulus, 2020; Jamir, 2022).

In 2021, ginger production in Nigeria stood at 768,304 tonnes as the second highest producer in the world after China (FAOSTAT, 2021). Although ginger cultivation has now spread all over the geographical zones of Nigeria (Duniya, 2003; Bernard, 2008; Odifa, 2022), Kaduna State is the traditional home of ginger production in Nigeria (Erinle, 1988; Nair, 2013) and remains the country's leading producer of the crop, mainly from Jaba, Jama'a, Kachia, Kagarko and Zangon Kataf Local Government Areas (Nmadu and Marcus, 2013; USAID-NEXTT, 2017; Odifa, 2022).

Nematodes feed on the rhizomes, roots and base of the pseudo stems (Bulus *et al.,* 2020). It causes swellings or knots, rot of root, root cracking and deformation (Bulus *et al.,* 2020). In the above ground parts, it causes stunting of the plant, chlorosis and marginal necrosis of leaves. It also causes reduced vigor and tillering and dark brown necrotic lesion. These symptoms are caused not only by a single nematode species but different species of nematodes in a complex. Nematodes also predisposes the rhizome to fungal and bacterial attack through their entry points on the rhizome. As a result of these, about 74% weight of the rhizome can be loss (Meenu and Jeba, 2019). *Meloidogyne* sp., *Radopholus similis* and *Pratylenchus* sp. are major nematodes that cause significant loss to ginger (Meenu and Jeba, 2019).

Fungal diseases found in all ginger growing countries, reported as the most dangerous and destructive disease of ginger which can reduce the production by 50–90% (Dohroo, 2001). Disease cause significant losses during warm and humid conditions. Symptoms first appear on the aerial parts of the plant. Yellowing (chlorosis) symptoms appear in the tips, which then spread downward along the margin involving the rest of the leaf blade and eventually, the leaf sheath. Later, chlorosis from the older leaves progress to younger leaves, start developing a similar symptom progression until the entire plant dies (Meenu and Jeba, 2019). The appearance of lesion in pseudo stem and chlorosis in the leaf indirectly show

the sign of rhizome rot. Due to fungal infection, rhizomes appear soft, brown; water soaked, rotten, and decays gradually. Soft rots, wet rot, yellows, leaf spot, and storage rots are examples of fungal diseases of ginger (Meenu and Jeba, 2019).

Bacterial diseases of ginger constitute the most serious rhizome-borne diseases. Bacterial diseases are widespread and exceedingly destructive for ginger growing in tropical, subtropical and warm temperate regions of the world (Kumar and Sarma, 2005). Severity of bacterial diseases occurs during the favorable environmental conditions like high rain fall and warm weather. Symptoms include water soaked patches or linear streaks at the collar region of the pseudo stems. In the advanced stage, infected ginger exhibit intense yellowish and wilting symptoms. The leaves roll up and the whole plant dries up finally. Bacterial wilt and soft rot are common bacterial diseases of ginger (Kumar and Sarma, 2005).

As one of the top 10 cultivated crops in Nigeria (Omotayo *et al.,* 2021), it is also plague by pests and diseases caused by bacteria, fungi, viruses, mycoplasma and nematodes which largely affects production of ginger. Diseases cause severe reduction of rhizome yield (Sharma *et al.,* 2021; Meenu and Jebasingh, 2019). Some of these diseases have a worldwide distribution (Chikh-Ali *et al.,* 2019). The impact of these diseases is increased in the tropics because tropical conditions favour continuous presence of both primary and secondary hosts. Generally, Disease pathogens are significant constraints in agricultural production worldwide and sustainable crop production with losses in quality and quantity of spice crops and yield (Dohroo, 2016; Akhter *et al.,* 2019; Akhter *et al.,* 2021). The objectives of the research are to determine the occurrence and distribution of diseases on ginger in Kaduna state and to determine the disease pathogens responsible for ginger losses.

MATERIALS AND METHODS

Field Surveys and Sampling of Ginger Fields

Field survey was conducted during the 2024 rainy season to determine the occurrence of diseases on fields in six (6) Local Government Areas of Kaduna State. Namely; Jema'a(JEMA), Jaba(JBA), Kachia(KCH), Kagarko(KGK), Kaura (KUR) and Zangon Kataf (ZKW). These locations were selected based their recorded high ginger cultivation.

Experimental Site

The experiment was basically laboratory and was carried out at the Microbiology & Postgraduate laboratories of Nasarawa State University, Keffi - Nigeria and Kaduna State University, Kafanchan Campus respectively.

Sample Collection

Ginger plant rhizome, leaves and soils samples were collected in two (2) points for symptomatic per farm and two (2) farms each in six (6) Local Government Areas (L.G.As) of southern Kaduna State. The region is known for cultivation of higher quality ginger. The samples collected were twenty-four (24) (2 samples × 2 farms × 6 LGAs = 24). This basically is for determination of the presence of any of the disease pathogens of fungi, bacteria and nematodes.

Data collection

Ginger leaves showing symptoms of disease infection and their rhizomes were randomly selected harvested fresh from fields and put into polythene bags for isolation and identification of the pathogen associated with the samples.

Samples were collected from the rhizosphere of the plants with the aid of a soil auger. This was collected at a depth of 0 – 30 cm and within a radius of 25 cm from the base of the plants. Selected farms were surveyed in each LGA. Each of the composite sample were packaged in a polyethylene bag, properly labeled and then transported for Nematology laboratory for nematode extraction.

Sample Preparation and Isolation of Nematodes, Fungi and Bacteria

Nematodes

Extraction of the nematodes from the soil samples was done using the modified sieving and decanting techniques as described by Coyne *et al.* (2007). One hundred millilitres (100 ml) of soil was collected from each of the composite soil sample and poured gently into a fifteen-litre plastic bucket containing five litres of water. These were stirred thoroughly, then allowed to settle for 30 seconds. Three quarters of the water was then slowly poured through a set of sieves (with 75µm nested on 45µm). The remaining soil in the bucket was filled with the same volume of water and the initial procedure to be repeated. Nematodes and tiny soil particles trapped by sieves were gently rinsed with water into a labelled beaker which was then poured into a setup of extraction tray containing a double cotton wool filter paper held in place by a clamping ring. These were allowed to stay for 24 hrs. After 24 hours, the filtrate containing nematodes was standardized to 100 ml by adding distilled water using a measuring cylinder. Ten millilitres of the nematode/water suspension was poured into a Doncaster (1962) counting dish for visual identification and counting of the different nematode genera using a dissecting microscope at X40 magnification.

Fungi

The rhizomes were washed with tap water and small portions of tuber samples about 5 mm around the periphery of rot lesions were excised with a knife. The tissues were sterilized in 5% sodium hypochlorite solution for two to three minutes and then rinsed three times with sterilized distilled water. The tissues were then plated on sabouraud dextrose agar (SDA) in Petri dishes and incubated at 25°C for five days. Sub-culturing of the various fungi was done on SDA to obtain pure cultures of the fungal isolates for identification. The isolated fungi were identified based on their colony morphology and conidial characteristics with the aid of a compound microscope (Hund Wetzlar, H-500, Germany), with reference to the laboratory manuals developed by Mathur and Kongsdal (2003) and Barnett and Hunter (1998).

Bacteria

Isolation of bacteria from the ginger rhizome was carried out by standard microbiological culture technique adapted by Agu *et al.* (2015) with slight modification. The rhizome was washed with running distilled water and then surface sterilized with 70% ethanol and cut open. About 3mm diameter of the infected tissues was picked with a flamed sterilized forceps and inoculated in solidified Sabouraud Dextrose Agar (SDA) and Nutrient Agar (NA) medium. Each inoculum was placed on the surface of the solid medium and spread evenly on the plate with the aid of a sterile bent glass rod.

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The inoculated NA plates was incubated at 37 degree Celsius for 24 hours at room temperature for 2-7days for the SDA plates.

Statistical Analysis

Descriptive statistics was used to determine occurrences and distribution of fungi, bacteria and nematodes in the six samples collected and ginger growing areas in southern Kaduna.

RESULTS

Ginger (*Zingiber officinale*) leaves, rhizomes and soils under the rhizomes of two (2) samples each from three farms in six prominent ginger cultivated local government areas of Kaduna State were collected. These samples were tested in the laboratory to determine the presence and possibly type of bacteria, fungi and nematodes responsible for the diseases affecting ginger cultivation in southern Kaduna State.

The disease symptoms shown on leaves and rhizomes were cultured in sabouraud dextrose agar (SDA) for fungi and nutrient agar (NA) for bacteria, while the soil samples were for the presence of nematodes.

Incidences of Fungi on ginger leaves and rhizomes

Fifteen Fungal pathogens were isolated in the sample locations with various level of occurrences: *Aspergillus fumigatus*(17), *Mucor racemosus* (11), *Rhizopus spp* (11), *Penicillium restrictum*(7), *Trichoderma viride*(12) ,*Aspergillus niger* (17) ,*Cladophialophora carrionii* (10) , *Fusarium Graminearum* (13) *Fusarium solani* (15), *Alternaria tenuis* (13), *Lichtheimia corymbifera (9)*, *Microsporum canis* (14), *Alternaria tenuis* (11), *Lichtheimia corymbifera* (3), *Microsporum ferrugineum* (9). *A. fumigatus and* A. *niger* had equal and highest occurrences, while *L. corymbifera* was the least occurring fungal pathogen recorded. However, the distribution of disease incidences in ginger fields across the six LGAs is presented in Figure 1. Fungi were the most dominant group of pathogens, with incidences per field ranging from 9 to 19. The highest fungal incidence was recorded in Kachia LGA (19 in Gibin) and Zangon Kataf LGA (18 in Zauru), while the lowest was in Kachia (9 in U/Sarki).

Incidences of Bacteria on ginger leaves and rhizomes

The presence of various species of bacteria when cultured on nutrient agar (NA) suggests potential bacterial infection on ginger. The following bacteria were isolated on the growth media: *Pseudomonas* sp.; *Gluconbacter* sp.; *Proteus* sp.; *Bacillus* sp.; *Enterococci* sp.; *Acetobacter* sp.; *Flavobacterium* sp.; *Micrococcus* sp.; *Simulium* sp.; *Citrobacter* spp (Table 2). All these were found on either the leaves or rhizomes of ginger in the 6 ginger cultivated L.G.As. However, not all the ten bacteria were found in each of the locations. The presence of *Bacillus* sp. was observed from the rhizomes and leaves of ginger in all locations of Zangon Kataf, Jaba, Kaura, Kagarko and Jema'a L.G.As, *Gluconbacter species* and *Micrococus species* were found in all the locations and samples (rhizomes and leaves) in Kachia and Jema'a L.G.As respectively.

The total occurrences of the bacteria diseases recorded among the most cultivated L.G.A is shown in Figure 1, which indicates the presence of *Bacillus species* in all the sample location in the 6 areas, followed by *Micrococcus species* and *Citrobacter species*.

Incidences of Nematodes on ginger rhizomes and soil

The ginger rhizosphere is infested with a complex of nematodes that cause direct root damage (galls, lesions, stunting) and act as vectors for other diseases. In Table 3, diverse community of 10 genera of plant-parasitic nematodes were identified in the surveyed areas. *Trichodorus* sp. and *Meloidogyne* sp. are the two most significant nematode pathogens identified. The most predominant nematodes being *Trichodorus* sp. with 15 isolates, closely followed by *Meloidogyne* sp. with 13 isolates and *Aphelenchoides* spp. (10 isolates). However, other nematodes of concerned that were identified included, *Tylenchorhynchus* sp. (8 isolates) *Helicotylenchus* sp. (8 isolates), *Pratylenchus* sp. (6 isolates) and *Scutellonema* sp. (6 isolates). The overview of pathogen groups across the six LGAs is as shown in Figure 1. Fungi were found in every single location and consistently had the highest or near-highest number of occurrences.

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Table 1: Occurrence of Fungi in Six (6) Ginger Cultivated L.G.A in southern Kaduna, Kaduna State-Nigeria

Isolates (Bacteria)	**Number of Isolates**																								
	Z/KF-Zauru	Z/KF-Zauru	Z/KF-	Z/KF-	JABA-	[illegible]	JABA-Jaban	JABA-Jaban	KRA-GCK	KRA-	KRA-Pada	KRA-Pada	KCH-Gibir	KCH- Gibir	KCH-U/Sarki	KCH- U/Sarki	KGK-Dogon Kurmi(RZ)	KGK-Dogon	KGK-	KGK-	JEMA- KASU	JEMA-KASU	JEMA-KASU	JEMA-KASU	TOTAL OCCURRENC
Pseudomonas sp	3	2	0	2	3	1	2	0	2	0	2	1	0	2	0	3	3	1	3	0	1	2	2	0	14
Gluconobacter sp	2	0	0	0	2	0	2	1	2	0	0	0	1	2	1	2	2	0	2	0	3	3	0	1	12
Proteus sp	0	2	1	0	2	1	0	0	0	0	2	0	2	0	0	2	2	1	0	1	2	0	0	2	12
Bacillus sp	2	1	1	2	3	1	2	1	2	1	3	1	1	0	0	3	3	1	3	2	1	3	3	4	22
Enterococci sp	0	2	0	0	1	0	2	0	2	1	0	1	0	2	1	1	0	0	0	0	2	1	0	0	10
Acetobacter sp	1	2	1	0	2	1	2	0	3	0	0	0	1	2	0	2	1	0	0	0	1	0	3	2	14
Flavobacterium spp	2	3	0	0	2	0	2	0	1	0	2	2	0	2	0	2	0	0	3	0	0	2	1	0	12
Micrococcus sp	0	0	3	1	1	1	3	0	2	0	3	1	0	2	1	2	2	1	2	0	3	3	1	0	17
Simulium sp	0	1	1	0	3	0	2	0	1	0	0	0	0	0	0	3	1	0	1	0	1	3	0	0	10
Citrobacter spp	2	0	2	0	3	2	1	0	0	0	2	1	0	2	1	1	1	0	3	1	1	1	0	1	16

Z/KF-Zauru RZ (N=3) means out of 3 samples 3 *Aspergillus fumigatus* were isolated; JEMA-KASU RZ (N=3) means out of 3 samples 0 no *Aspergillus fumigatus* were isolated. Z/KF-Zauru RZ (N=3) means out of 3 samples 0 number of *Mucor racemosus* were isolated, out of 3 samples from Z/KF-Zauru LF (N=3) 1 *Mucor racemosus* was isolated; LF- leaf samples; RZ-Rhizomes; Z/KF- Zongon Kataf; Jema-Jema'a; KRA-Kaura; KCH-Kachia; KGK-Kagarko.

Table 2: Occurrence of bacteria isolated from root (Rhizomes) and leaves of Ginger in Six (6) most cultivated L.G.A in southern Kaduna, Kaduna State-Nigeria

Isolates (Fungi)	**Number Isolated**																							
	Z/KF-Zauru (RZ)	Z/KF -Zauru (LF)	Z/KF-Lalmi/Rimi (RZ)	Z/KF-Lalmi/Rimi (LF)	KCH- Gibir (RZ)	KCH- Gibir (LF)	KCH- U/Sarki (RZ)	KCH- U/Sarki (LF)	KRA-KGR Pada (LF)	KRA-KGR Pada (RZ)	KRA-GCK (RZ)	KRA-GCK (LF)	JARA-Samban (LF)	JARA-Jaban Kogo	JARA-Jaban Kogo	JARA-Samban (RZ)	JEMA-KASU JO (RZ)	JEMA-KASU JO (LF)	JEMA-KASU SO(LF)	JEMA-KASU SO(RZ)	KGK-Kagarko 1 (RZ)	KGK-Kagarko 1 (LF)	KGK-Dogon Kurmi	KGK-Dogon	TOTAL OCCURRENCE
Aspergillus fumigatus	3	1	0	2	2	1	2	0	1	0	2	2	1	3	1	3	2	1	0	0	3	0	1	0	17
Mucor racemosus	0	1	0	0	0	0	0	1	0	1	2	1	0	2	2	2	0	0	0	2	2	0	0	2	11
Rhizopus spp	0	0	1	0	1	2	2	0	0	0	0	0	1	0	0	2	2	0	2	2	0	1	0	1	11
Penicillium restrictum	0	0	1	0	2	0	2	0	1	0	2	0	0	0	0	0	3	0	0	1	0	0	0	0	7
Trichoderma viride	2	1	0	0	3	2	0	0	0	2	2	2	0	1	0	1	0	1	0	0	0	0	1	1	12
Aspergillus niger	2	2	1	0	0	0	1	1	1	2	3	2	1	2	1	2	0	0	2	3	0	0	1	2	17
Cladophialophora carrionii	2	2	0	0	2	0	0	1	1	0	0	0	0	0	0	2	2	2	0	0	3	0	0	2	1 0
Fusarium Graminearum	0	0	1	1	1	1	2	0	0	2	2	1	0	3	1	0	0	0	2	2	2	0	0	0	13
Fusarium solani	2	1	3	1	0	2	2	0	0	0	1	0	1	0	0	1	3	1	1	1	0	0	1	2	15
Alternaria tenuis	0	2	1	0	3	2	0	0	2	2	2	0	0	3	3	0	1	0	2	1	2	0	0	0	13
Lichtheimia corymbifera	2	1	1	0	0	1	0	0	0	0	0	0	0	2	0	3	0	0	0	1	1	0	1	0	9
Microsporum canis	0	0	2	0	3	1	2	0	0	0	2	3	2	2	0	1	2	1	0	1	3	1	0	0	14
Alternaria tenuis	3	1	-	-	0	0	0	0	1	2		1	-	3	2	-	-	-	4	2	-	-	2	2	11
Lichtheimia corymbifera	0	0	-	-	3	1	-	-	0	0	-	-	-	-	-	-	-	-	0	1	-	-	-	-	3
Microsporum ferrugineum	2	1	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	3	3	3	3	9

(N=3) means out of 3 samples 2 *Pseudomonas* sp were isolated; KRA-GCK LF (N=3) means out of 3 samples 0 no *Pseudomonas* sp were isolated. KRA-GCK RZ (N=3) means out of 3 samples 2 *Gluconbacter* sp were isolated; RZ-Rhizomes; LF-Leaf; Z/KF- Zongon Kataf; Jema-Jema'a; KRA-Kaura; KCH-Kachia; KGK-Kagarko.

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Table 3: Occurrence of Nematodes in Six (6) Ginger Cultivated L.G.A in southern Kaduna, Kaduna State-Nigeria

Isolates (Nematode)	Number of Isolates																						
	Z/KF-Zauru (Soil)	Z/KF-Zauru (RZ)	Z/KF-U/Rimi (RZ)	Z/KF-U/Rimi (Soil)	JEMA-KASU JQ	JEMA-KASU JQ	JEMA- KASU SQ	JEMA- KASU SQ	KRA-KGR Pada	KRA-KGR Pada	KRA-GCK (RZ)	KRA-GCK (Soil)	KCH- Gibir (RZ)	KGK- Gibir (Soil)	KCH- U/Sarki (RZ)	KCH- U/Sarki	JABA-Jaban Kogo (RZ)	JABA-Jaban Kogo	JABA-Sambam	JABA-Sambam	KGK-Kagarko	KGK-Kagarko (LF)	KGK-Dogon Kurmi	KGK-Dogon Kurmi	TOTAL
Meloidogyne sp	0	2	1	0	3	0	1	2	0	0	0	0	2	0	2	1	0	3	0	0	2	1	1	2	13
Pratylenchus sp	0	0	0	0	0	2	0	0	1	1	-	-	-	-	-	-	-	-	1	1	0	0	2	0	6
Criconema sp	0	1	-	-	0	3	0	0	0	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Rotylenchus sp	1	0	-	-	2	0	0	0	3	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3
Scutellonema sp	2	2	-	-	0	1	2	0	0	0	0	0	0	1	0	2	0	0	-	-	-	-	-	-	6
Trichodorus sp	0	0	0	0	2	0	1	3	2	0	2	0	2	0	1	2	2	1	0	1	1	2	1	1	15
Tylenchorhynchus sp	2	0	-	-	0	3	0	0	0	2	1	1	3	2	0	0	1	0	-	-	-	-	-	-	8
Hoplolaimus sp	-	-	-	-	-	-	-	-	-	-	2	0	0	2	1	0	0	2	-	-	-	-	-	-	4
Helicotylenchus sp	-	-	1	2	-	-	-	-	-	-	1	2	0	0	3	0	1	0	0	0	1	1	0	1	8
Aphelenchoides spp	-	-	1	1	-	-	-	-	-	-	2	0	0	2	0	1	0	1	1	2	3	0	3	0	10

Note: Z/KF-Zauru (N=3) out of the 3 samples 2 *Meloidogyne sp* were detected; out of the 3 samples from Z/KF-Zauru (N=3) 0 number of *Meloidogyne sp* were detected; RZ-Rhizomes; LF-Leaf; Z/KF- Zongon Kataf; Jema-Jema'a; KRA-Kaura; KCH-Kachia; KGK-Kagarko.

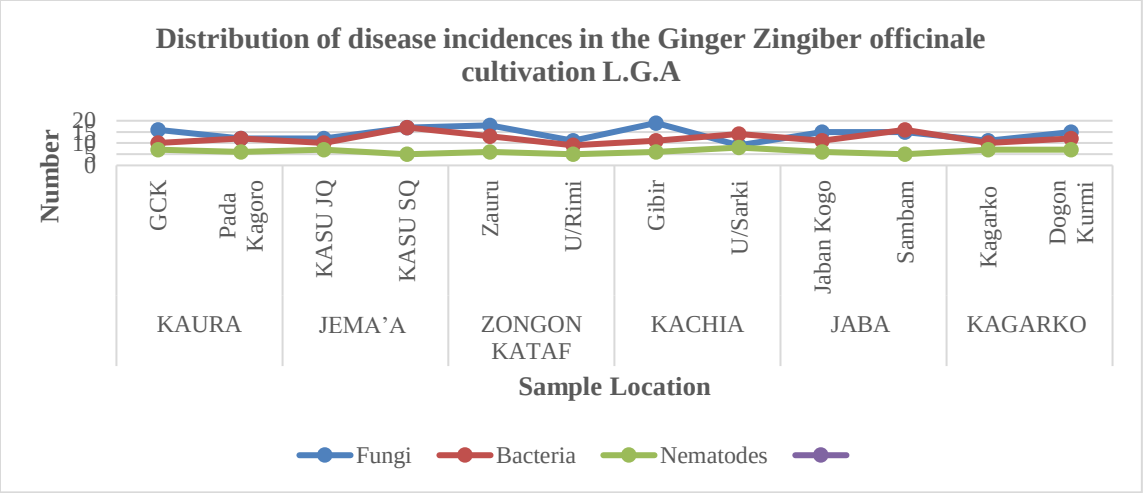

Figure 1: Distribution of disease incidences in the Ginger *Zingiber officinale* cultivation L.G.A

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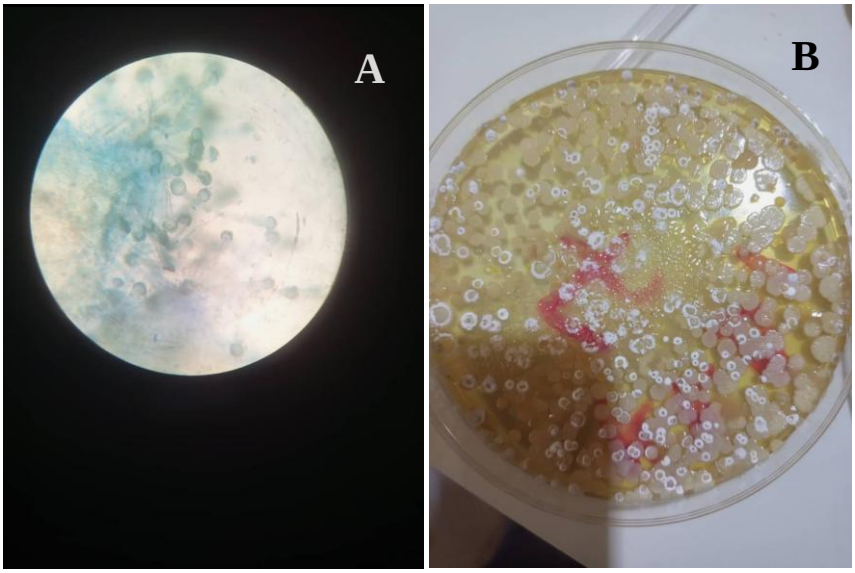

Figure 2: Microscopic view of fungi (A) & Bacteria growth culture media

DISCUSSION

Occurrence of Fungi in Six (6) Ginger Cultivated LGAs in Southern Kaduna, Kaduna State-Nigeria

In Table 1, *Aspergillus fumigatus* recorded the highest frequency of isolation (17 occurrences), followed closely by *Fusarium solani* (15), *Microsporum canis* (14), and *Alternaria tenuis* (13). The high frequency of *Aspergillus spp.* and *Fusarium spp.* is consistent with their known role as primary causal agents of rhizome rot in ginger fields and during storage (Anandaraj *et al.,* 2014). These fungi are opportunistic and thrive under warm and humid conditions typical of Southern Kaduna, suggesting that environmental factors play a critical role in disease establishment (Okigbo and Nmeka, 2005; Sharma *et al.,* 2019). The relatively lower frequencies of *Microsporum ferrugineum* (9) and *Lichtheimia corymbifera* (3) indicate that while these fungi are present, they may not represent major threats under current field conditions.

The distribution of fungal diseases in Figure 1 highlights the dominance of fungal pathogens, with incidences ranging from 9 to 19 per field, compared to bacteria (9 to 7) and nematodes (5 to 8). This reinforces the evidence from Table 1 that fungi are the primary agents of ginger decline in the region. Particularly noteworthy is the high fungal incidence in Kachia (19 in Gibir) and Zangon Kataf (18 in Zauru), suggesting these LGAs may serve as hotspots for pathogen buildup.

The bacterial presence, although secondary to fungi, was significant in Jema'a (17 in KASU SQ), indicating that bacterial wilt could also represent a notable threat in some locations. The predominance of fungal species over bacteria and nematodes across locations aligns with earlier reports that fungi constitute the major constraint to ginger cultivation and storage in tropical regions (Okigbo and Nmeka, 2005; Sharma *et al.,* 2019).

The co-occurrence of fungi, bacteria, and nematodes in the same locations underscores the multifactorial nature of ginger decline (Bhuyan *et al.,* 2010), where synergistic interactions between pathogens exacerbate disease severity (Nirmal Babu *et al.,* 2015). For instance, nematode damage may predispose rhizomes to colonization by *Fusarium* spp., while bacterial infections could weaken host resistance, thereby facilitating fungal invasion. This interaction could explain the high cumulative disease incidences recorded in some locations such as Jema'a and Kachia.

The variations across LGAs may also reflect differences in soil type, cultural practices, and microclimatic conditions. For example, areas with heavier soils and poor drainage may favor fungal pathogens such as *Rhizopus* and *Mucor*, which thrive in anaerobic conditions. Meanwhile, the higher bacterial incidence in Jema'a could be linked to irrigation practices or soil moisture levels that favor bacterial wilt pathogens.

Occurrence of Bacteria in Six (6) Ginger Cultivated LGAs in Southern Kaduna, Kaduna State- Nigeria

Early wilting, chlorosis (yellowish) and rotten rhizomes were observed on some collected samples. Bacteria and fungi also are known to affect leaves of most crops. Akos *et al.* (2019abc); Akos *et al.* (2021); Akos. (2023) also confirm this with their work on the pathogens. Bacteria has been found to exhibit these symptoms in ginger, wilting (yellowish leaves) and rotten of the rhizomes. Kumar and Sarma (2005) agrees that ginger exhibit such symptoms. From the several bacteria isolated from culture of the leaves and rhizomes. The bacteria so isolated are found to contain some pathogenic types such as *Pseudomonas species* which was found to cause wilting and soft rot in ginger. *Bacillus species* is known to be both beneficial and harmful to ginger. *B. pumilus* is pathogenic and causes rhizome rot. Sharma *et al.* (2021); Meenu and Jebasingh (2019) also confirms categorization of ginger into pathogenic and non-pathogenic. However, *B. subtilis* and *B. safensis* enhances ginger growth and yield as plant growth-promoting rhizobacteria (PGPR) (Jabborova *et al.,* 2021; Singh and Shyu, 2024).

The PGPR act in inducing plant resistance, enhancing nutrient uptake, and producing antifungal compounds (Aramesh and Ajoudanifar 2017). *Citrobacter species* is also known to cause

ginger rot, a disease characterized by wilting, chlorosis (yellowing) of leaves, and soft, brown rot and maceration of the rhizome (ginger root) with a foul smell. This bacterial pathogen was first reported in China, infecting ginger plants, and can lead to significant decay and loss of the ginger crop (Zhao *et al.,* 2021). The isolation of the disease in Nigeria ginger corroborate with Chikh-Ali *et al.,* (2019) that it has a worldwide distribution. Non pathogenic bacteria of *Gluconobacter species* (*non-infectious to ginger,* rather, the ginger's inherent antimicrobial properties affect bacteria including *Gluconobacter* if present)*, Proteus species,* ginger compounds such as 6-shogaol, can stop the growth and multiplication of bacteria, including *Proteus species*, especially *P. mirabilis.* Huh *et al*. (2023) reported that ginger additional, suppressed *P. mirabilis*-induced intestinal barrier disruption. This could be that the impact of the other pathogenic organisms might have weakened its ability to create a resistance. *Enterococcus species*, *Flavobacterium species*, the mere presence of these bacteria does not necessarily suggest that it must be pathogenic. Report shows that gingers antimicrobial properties inhibit the growth of some bacteria (Dharmapala and Amarakoon, 2024). *Micrococcus species* exist in human skin and soil. *Acetobacter* and *Similium species*. *A. aceti*, cause rotting in fruits like pears, apples and citrus (Amadi-Ikpa *et al*., 2025) while genera *Similium* that causes Onchocercasis (river blindness) in humans and was also found in Ginger. (WHO 2025)

Occurrence of Nematodes in Six (6) Ginger Cultivated LGAs in Southern Kaduna, Kaduna State-Nigeria

In Table 3, a total of 10 plant-parasitic nematodes were identified across the different ginger cultivation LGAs in the study area. The overall total indicates a high occurrence of *Trichodorus* sp (stubby-root nematode), followed by *Meloidogyne* sp (root-knot nematode), and notable occurrences of other nematodes such as *Pratylenchus* sp, *Criconema* sp, *Rotylenchus* sp, *Scutellonema* sp, *Tylenchorhynchus* sp, *Hoplolaimus* sp, *Helicotylenchus* sp and *Aphelenchoides* spp. This agrees with Bulus *et al.* (2020), who reported that a total of 19 plant-parasitic nematodes were identified to be associated with ginger in Kaduna state.

Trichodorus sp recorded the highest occurrences with 15 isolates, especially noted in KRA-GCK (RZ) and KRA-KGR Pada (Soil) with 3 isolates each, highlighting its significance in the nematode complex affecting ginger in 9 locations in the region. This is in agreement with Bulus *et al* (2020), who reported that a total of 19 plant-parasitic nematodes including *Trichodorus* sp were identified to be associated with ginger in Kaduna state.

Meloidogyne sp was the second most common with 13 isolates and predominantly found in certain areas such as Jema'a-KASU JQ (RZ) and KRA-GCK (Soil) with 3 occurrences each, indicating its widespread impact on ginger cultivation. This corroborates with Adegbidi *et al*. (2022) who reported that *Meloidogyne* sp was prevalent in Kaduna State, affecting ginger roots and leading to significant reductions in yield. Aphelenchoides and other nematode species had fewer total occurrences compared to Meloidogyne and Trichodorus, indicating a lesser but still notable presence.

These discoveries underscore the importance of nematode management in ginger cultivation, as nematodes such as *Meloidogyne* sp and *Trichodorus* sp were frequently found in both rhizomes and Soils, indicating systemic infection and are recognized for their detrimental effects on root systems, leading to stunted growth and reduced yields.

Nematode infections were consistently lower but non-negligible, as nematodes are known to predispose plants to fungal invasion by creating entry points in root tissues (Bridge and Starr, 2007; Elisha and Adeniyi, 2023). It also agrees with the report of the Kaduna State Ministry of Agriculture (2023) which showed a complex interplay between nematodes and fungal pathogens leading to a devastating disease complex in ginger.

Conclusion

The total fungal count (171) is significantly higher than for bacteria (135) and nematodes (71). Bacteria were found in all 12 locations. Fungi are the dominant pathogens isolated in every single location sampled, which suggests fungal diseases as the most likely widespread pathogen and the primary cause of ginger losses in the region.

Bacterial occurrences were also found to be a significant and widespread in every location, indicating it is a common problem of ginger in these areas. The numbers are consistently high, often second only to fungi. Locations like Jema'a (KASU SQ) and Sambam (Jaba) showed bacterial counts equal to or nearly equal to fungal counts. Bacterial infections are a major co-factor in ginger disease complexes and signify a serious menace to ginger production and survival.

Nematodes were found in all 12 locations, confirming they are a widespread soil-borne issue for ginger farmers. However, the number of nematode occurrences per location is generally lower than for fungi and bacteria. Nematodes are a constant, core stress factor across all ginger cultivation areas in the study zone.

Overall, the results provide strong evidence that ginger cultivation in Southern Kaduna is under serious threat from a complex of pathogens, with fungi as the dominant group. This has significant implications for ginger production in Nigeria, given that Kaduna State is the leading producer of ginger in the country. This also provides a vital awareness into the complex interactions between multiple pathogens affecting ginger in Kaduna State. The findings call for integrated disease management strategies combining cultural, chemical, and biological control approaches. Emphasis should be placed on crop rotation, the use of resistant cultivars, biological antagonists (Harman et al., 2004), and careful post-harvest handling to minimize fungal contamination (Naidu and Naik., 2017; Adeniji and Nwankwo, 2018).

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