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Pathogenicity and *In vivo* Susceptibility Test of *Fusarium* Isolates on Potato (*Solanum tuberosum* L.) Using *Syzygium aromaticum* (Clove)

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Abstract

Fungal pathogens of plant play important role in the quality, quantity and profitability of plant in production. Persistently, these pathogens avoid plant defences causing disease, affecting the quality of yield globally. Incurring losses of billions US dollars annually. Farmers depends on synthetic fungicides to control plant diseases which results in drawbacks such as development of resistance, environmental toxicity associated with the chemicals as well as health hazards. These setbacks have spur researchers to investigate other alternatives to chemicals used. This study revealed the potentials of *Syzygium aromaticum* as suitable alternative to synthetic fungicide in the control of *Fusarium* wilt of Potato.

Keywords: Fungal pathogens, fusarium wilt, syzygium aromaticum, synthetic fungicide, potato disease

Introduction

Potato (*Solanum tuberosum* L.) is the fourth largest food crop after rice, wheat and corn (Farkhondeh *et al.*, 2013) [6]. Potato is a major crop produced in Plateau State and it is known as a staple crop in many countries of the world (Anonymous, 2010). *Fusarium* is a global disease of importance particularly to potato, which can be transmitted by seed cuts, spores and other modes (Farkhondeh *et al.*, 2013) [6]. For a long time farmers depend on Chemical pesticides for management of pest and disease because of their availability and effectiveness (Sen *et al.*, 2020) [10]. Excessive and inappropriate use of the chemical pesticides has also been cited as a setback to international trade because of the presence of harmful residues in fresh agricultural produce meant for export (Kussaga *et al.*, 2014) [15s].

Worldwide destruction of potato due to disease is high with an estimated economic loss of 3 to 5 billion dollars annually (Eduardo *et al.*, 2007) [4]. Management of diseases are mostly the use of synthetic fungicide though, its usage has detrimental effects (Van de Mortel *et al.*, 2009) [13]. There is an increase in public demand to minimize pesticide residue in potato products resulting in forcing agro-chemical companies and growers to develop safer compounds (Strange, 2003) [14]. Moreover, phytopathogens develop resistance to some synthetic fungicide rendering them ineffective and leading to increased pathogen aggressiveness (Fontem *et al.*, 2005) [7].

The potatoes produced in Jos, Plateau State are predisposed to the development of fungal diseases which may lead to food insecurity, economic deterioration and environmental pollution (Chuwang *et al.*, 2014) [3]. Global losses due to pest and diseases on food crops are large ranging by means from 8.1 to 21% in potato (FAO, 2021) [5].

Alternative crop protection strategy to synthetic chemical is mainly the use of natural products either from plants or microorganisms (Adhikari *et al.* 2024) [11]. As a result of the difficulties associated with the management of the pathogen using chemicals with respect to environmental challenges, health hazards and persistence of the chemical residue in potato and potato products, it is necessary to employ the use of plant extracts (bio-control) in plant disease management as suitable alternative. Plant extract was selected for this study because of the potentials it possess as an alternative remedy to curb *Fusarium* wilt of potato. Botanical Fungicide (s) will benefit a lot of small scale farmers since it will reduce the excessive use of synthetic chemicals and the challenges associated with them.

Materials and Methods

Syzygium aromaticum was obtained from Farin Gada market in sterile polythene bag, conveyed to the Department of Plant Science and Biotechnology, University of Jos for identification and voucher number administration: *Syzygium aromaticum* (UJH000319). The plant was prepared after washing in three changes of sterile distilled running water, air-dried and pulverized. This was followed by extraction using water and ethanol as solvents. The yield was determined using the formula:

Yield (%) = Weight of extract ÷ Weight of plant material before extraction X 100

In vitro assay was carried out after isolating *Fusarium* from soils obtained from three Local Government Areas of Plateau State, known to have cultivated potato for at least three farming seasons; Jos-North, Barkin Ladi and Mangu Local Government using Potato Dextrose Agar (PDA). The *Fusarium* obtained was preserved until required for use. Agar well diffusion method as described by Amienyo and Onunze (2015) [1] was adopted five concentrations of 500 mg/ml, 250 mg/ml, 125 mg/ml, 62.5 mg/ml and 31.25 mg/ml were dispensed into petri dishes containing *Fusarium* isolates spread on the surface of PDA. The extracts were applied in clockwise direction and a standard synthetic fungicide was used as positive control. Negative control with *Fusarium* isolates was grown alongside the treatments. The plates were incubated at 25±2°C for 5 days in an inverted form after allowing extracts to diffuse into medium, zones of inhibitions were measured using metre rule and results were recorded in mm.

In vivo anti-fungal assay was carried out using complete randomized block design in an experimental layout as shown below in triplicates. The experiment was laid out in a 16 treatment combinations of four potato varieties and four concentrations replicated three times

13 ⁴¹	14 ⁴²	16 ⁴⁵	15 ⁴⁴	10 ⁴⁵	9 ⁴⁶	12 ⁴³	11 ⁴⁸
4 ³³	3 ³⁴	2 ³⁵	1 ³⁶	8 ³⁷	6 ³⁹	6 ³⁹	5 ⁴⁰
9 ²⁵	10 ²⁶	11 ²⁹	12 ²⁶	1 ²⁹	2 ³⁰	3 ³¹	4 ³²
5 ¹⁷	6 ¹⁸	7 ¹⁹	8 ²⁰	16 ²¹	15 ²²	14 ²³	13 ²⁴
16 ⁹	15 ^N	14 ¹¹	13 ¹²	9 ¹³	10 ¹⁴	11 ¹⁵	12 ¹⁶
1 ¹	2 ²	3 ³	4 ⁴	5 ⁵	6 ⁶	7 ⁷	8 ⁸

Colors

Red= 500 mg/ml numbers in superscript: Plots
 Blue: 250 mg/ml Numbers: Pant stand
 Green= Synthetic fungicide
 Yellow= Water

Pathogenicity test was carried out on the isolates both *in vitro* and *in vivo*, Koch's postulate was also conducted to ascertain that causative agent. Extracts of clove with best activity was applied forth-nightly, 6 WAP and infecting the potato plants.

6WAP, the height, number of stems and number of leaves were determined after emergence of the plant and treatment application. Yield of the harvested potatoes were determined. Data generated were subjected to 2-way Analysis of variance and conclusions drawn

In Vitro Pathogenicity test

Result: Yield of extract revealed that aqueous extracts had more yield (6.28%) than ethanolic extracts (2.88%) as presented on Table 1. Antifungal activity was observed at the highest concentration of 500 mg/ml for both aqueous and ethanolic extracts while lowest activities were observed at lowest concentration of 31.25 mg/ml. At 500 mg/ml, the mean diameter of isolates from Jos north, B/Ladi and Mangu had zones of inhibition of 2.13 mm, 8.20 mm and 3.13 mm respectively for aqueous extract while at 31.25 mg/ml, high resistance was observed across all the isolates because no observable inhibition. The activities were more with ethanolic extract of clove as the zones measured were 9.20 mm, 11.20 mm and 12.20 mm for 500 mg/ml. however, at 31.25 mg/ml 1.0 mm, 3.30 mm and 2.0 mm for Jos North, Barkin-Ladi and Mangu respectively.

The minimum inhibitory concentration and Minimum Fungicidal Concentration (MFC) of the extracts were determined as presented on Table 2.

Table 1: Percentage yield of the *Syzygium aromaticum*

Solvents	Weight & Dry Plant (g)	Dry extract	Yield
Clove (aq)	200	12.56	6.28
Clove (ethanolic)	200	5.76	2.88

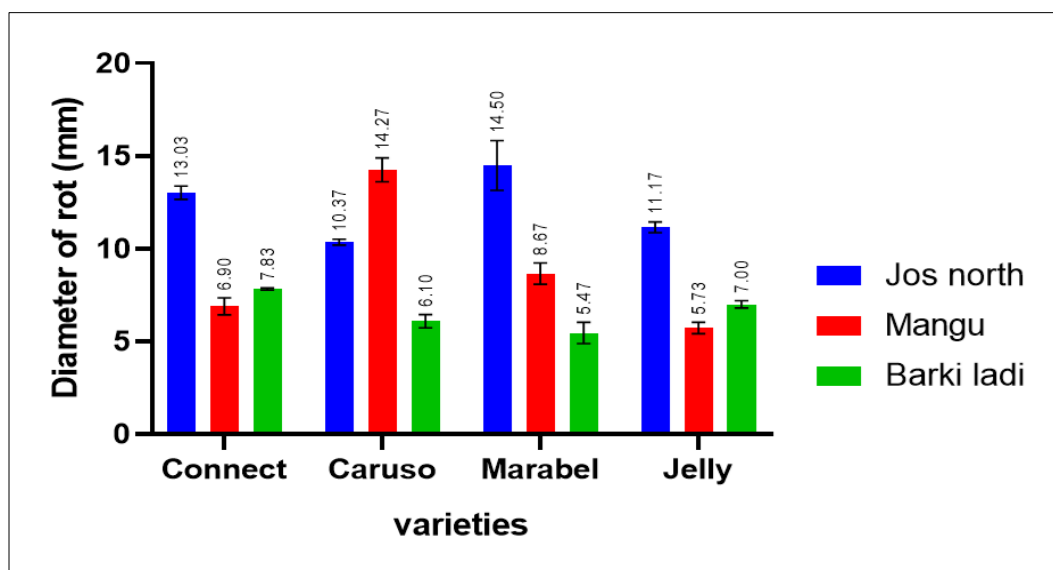


Fig 1: Pathogenicity Rate of *Fusarium* Species on Four Healthy Varieties of *Solanum tuberosum*

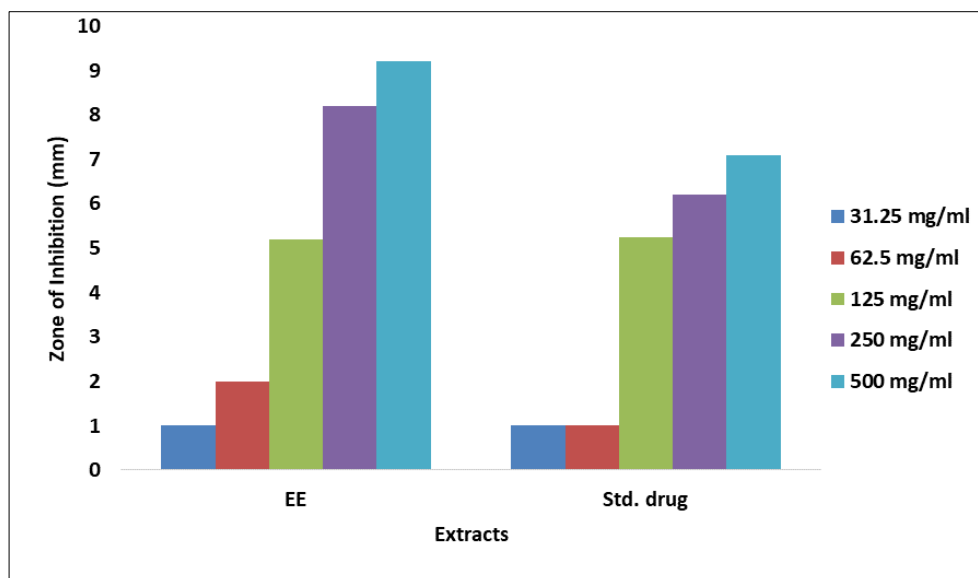


Fig 2: Antifungal Activity of *Fusarium* Isolated from Jos North

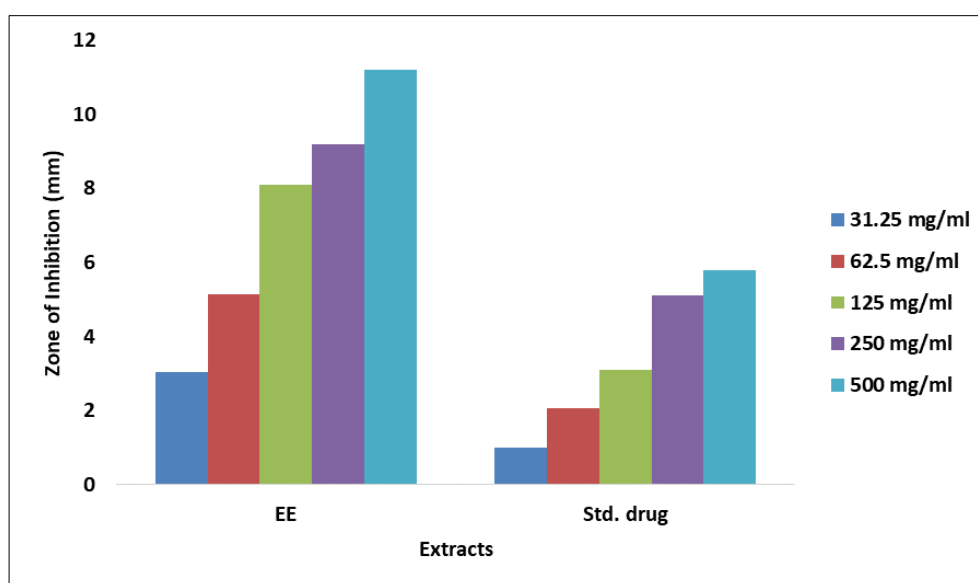


Fig 3: Antifungal Activity of *Fusarium* Isolated from B/Ladi

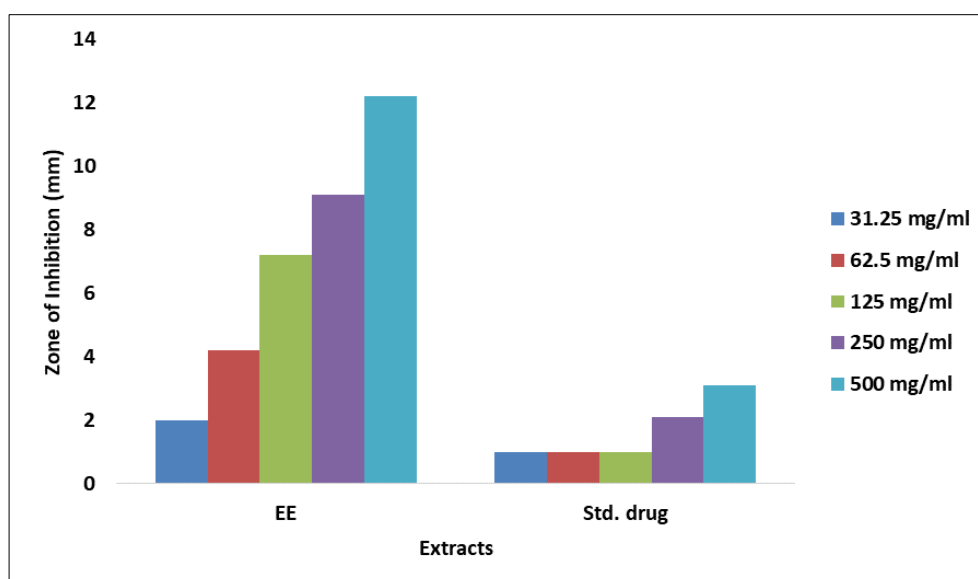


Fig 4: Antifungal Activity of *Fusarium* Isolated from Mangu

Table 2: Minimum Inhibitory Concentration and Minimum Fungicidal Concentration of fungal Isolates

Source & Inoculum	Extracts	MIC	MFC
Jos-North	Aqueous	500mg/ml	ND
	Ethanollic	62.5	125
Barkin-Ladi	Aqueous	62.5	125
	Ethanollic	31.25	62.5
Mangu	Aqueous	250	500
	Ethanollic	31.25	62.5

**Plate 1:** *In vitro* Antifungal Assay of Ethanollic Extract of *Syzygium aromaticum* Against Barkin-Ladi Isolate**Plate 2:** *In vitro* Antifungal Assay of Ethanollic Extract of *Syzygium aromaticum* Against Isolate from Mangu

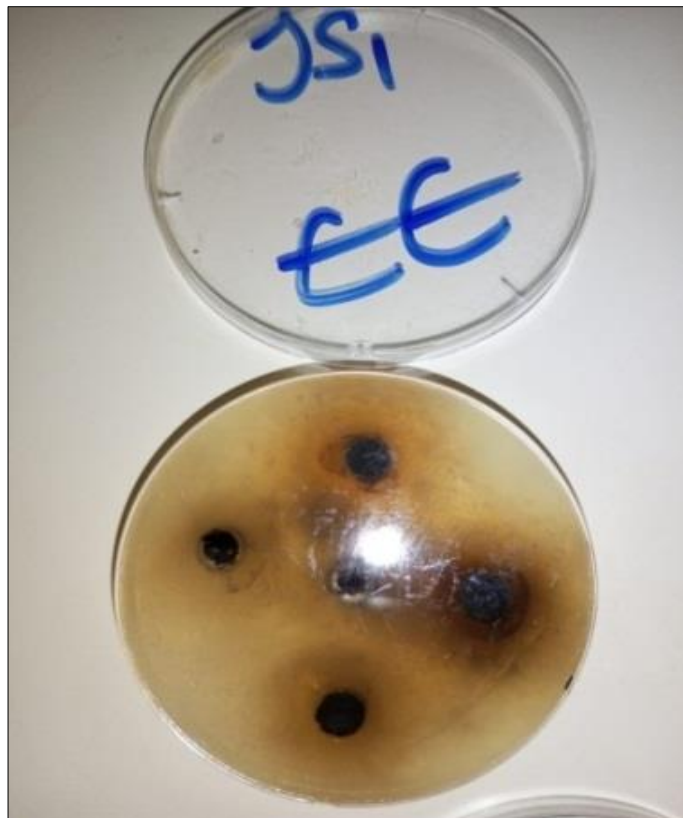


Plate 3: *In Vitro* Antifungal Assay of Ethanolic Extract of *Syzygium aromaticum* Against Isolate from Jos-Nort

Table 3: Effects of Variety and Concentration of Extracts on Emergence Count at 2 WAP at Mangu, Barkin-Ladi and Jos-North Local Government Area

Treatment	Location			
	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	2.91±1.37 ^a	2.41±1.16 ^a	3.33±1.23 ^a	2.88±1.28 ^a
Connect	2.41±1.37 ^a	2.91±1.31 ^a	3.41±0.79 ^a	2.91±1.22 ^a
Jelly	2.66±1.49 ^a	3.08±1.37 ^a	3.00±0.95 ^a	2.91±1.27 ^a
Marabel	2.66±1.07 ^a	2.25±1.48 ^a	1.50±1.16 ^b	2.13±1.31 ^b
Concentration of extracts				
250 mg/ml	3.25±0.86 ^a	3.41±1.16 ^a	2.91±1.37 ^a	3.19±1.14 ^a
500 mg/ml	3.00±1.20 ^a	3.25±0.62 ^a	2.83±1.40 ^a	3.02±1.10 ^a
Negative control	1.50±1.56 ^b	1.16±1.11 ^a	2.83±1.03 ^a	1.83±1.42 ^b
Positive control	2.91±0.79 ^a	2.83±1.11 ^a	2.67±1.43 ^a	2.80±1.11 ^a
LSD	0.94	0.85	0.95	0.52
Level of significance				
Variety	NS	NS	≤0.001	≤0.001
Concentration	≤0.001	NS	NS	≤0.001
Location				NS
Interaction				
VarietyxConcentration	NS	≤0.001	NS	NS
Variety x Location				≤0.05
Concentration x Location				≤0.05
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 4: Interaction Effects of Variety and Concentration of Extracts on Emergence Counts at 2 WAP at Barkin-Ladi Local Government Area

Variety	Concentration of extracts			
	250 mg/ml	500 mg/ml	Negative control	Positive control
Caruso	3.66±0.57 ^a	3.00±0.00 ^{abc}	1.33±0.57 ^{cd}	1.66±1.15 ^{bcd}
Connect	4.00±0.00 ^a	3.33±0.57 ^{ab}	1.33±1.52 ^{cd}	3.00±1.00 ^{abc}
Jelly	3.66±0.57 ^a	4.00±0.00 ^a	1.00±1.00 ^d	3.66±0.57 ^a
Marabel	2.33±2.08 ^{abc}	2.66±0.57 ^{abcd}	1.00±1.73 ^d	3.00±1.00 ^{abc}
LSD	1.69			

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 5: Effects of Variety and Concentration of Extracts on Emergence Counts at 4WAP at Mangu, Barkin-Ladi and Jos-North Local Government Area

Treatment	Location			
	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	3.83±0.38 ^a	3.50±0.79 ^a	3.66±0.49 ^a	3.66±0.58 ^a
Connect	3.75±0.62 ^a	3.75±0.45 ^a	3.58±0.51 ^a	3.69±0.52 ^a
Jelly	3.66±0.65 ^a	3.83±0.38 ^a	3.50±0.52 ^a	3.66±0.53 ^a
Marabel	3.75±0.45 ^a	3.50±0.67 ^a	3.75±0.45 ^a	3.66±0.53 ^a
Concentration of extracts				
250 nmg/ml	3.91±0.28 ^a	3.91±0.28 ^a	3.75±0.45 ^a	3.86±0.35 ^a
500 mg/ml	3.83±0.38 ^a	3.75±0.45 ^a	3.75±0.45 ^a	3.77±0.42 ^a
Negative control	3.50±0.79 ^a	3.33±0.77 ^a	3.41±0.51 ^a	3.41±0.69 ^b
Positive control	3.75±0.45 ^a	3.58±0.66 ^a	3.58±0.51 ^a	3.63±0.54 ^{ab}
LSD	0.46	0.43	0.44	0.25
Level of significance				
Variety	NS	NS	NS	NS
Concentration	NS	NS	NS	≤0.05
Location				NS
Interaction				
Varietyx Concentration	NS	NS	NS	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 6: Effects of Variety and Concentration of Extracts on Leaf Counts at 4WAP at Mangu, Barkin-Ladi and Jos-North Local Government Area

Treatment	Location			
	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	18.91±6.08 ^b	25.16±5.573 ^a	25.41±7.50 ^a	23.16±6.95 ^a
Connect	17.50±6.02 ^b	26.83±8.23 ^a	25.16±9.04 ^a	23.16±8.68 ^a
Jelly	17.66±6.61 ^b	25.33±11.10 ^a	30.50±8.08 ^a	24.50±10.08 ^a
Marabel	24.08±7.89 ^a	23.08±9.42 ^a	26.75±13.06 ^a	24.63±10.17 ^a
Concentration of extracts				
250 mg/ml	22.50±9.45 ^a	28.00±8.74 ^a	24.16±7.38 ^a	24.88±8.64 ^a
500 mg/ml	21.83±5.47 ^a	23.16±6.57 ^a	27.33±14.93 ^a	24.11±9.93 ^a
Negative control	17.41±5.46 ^b	24.00±11.57 ^a	29.83±6.54 ^a	23.75±9.56 ^a
Positive control	16.41±5.51 ^b	25.25±7.09 ^a	26.50±7.44 ^a	22.72±7.96 ^a
LSD	4.08	7.34	8.7	3.96
Level of significance				
Variety	≤0.001	NS	NS	NS
Concentration	≤0.001	NS	NS	NS
Location				≤0.001
Interaction				
Varietyx Concentration	≤0.05	NS	NS	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 7: Interaction Effects of Variety and Concentration of Extracts on Leaf Count at 4WAP at Mangu Local Government Area

Variety	Concentration of Extracts			
	250 mg/ml	500 mg/ml	Negative control	Positive control
Caruso	15.00±3.00 ^{de}	22.33±7.02 ^{bcd}	21.66±4.04 ^{bcd}	16.66±8.32 ^{cde}
Connect	24.33±3.21 ^{abc}	18.66±7.02 ^{bcd}	12.00±1.00 ^e	15.00±3.46 ^{de}
Jelly	19.00±7.81 ^{bcd}	25.33±2.51 ^{ab}	14.33±4.16 ^{de}	12.00±0.00 ^e
Marabel	31.66±13.31 ^a	21.00±5.00 ^{bcd}	21.66±4.16 ^{bcd}	22.00±2.64 ^{bcd}
LSD _(0.05)	8.16			

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 8: Effects of Variety and Concentration of Extracts on Leaf Counts at 6WAP at Mangu, Barkin-Ladi and Jos-North Local Government Area

Treatment	Location			
	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	38.08±13.49 ^a	33.16±5.47 ^a	42.25±11.68 ^a	37.83±11.12 ^b
Connect	39.58±10.24 ^a	39.91±12.95 ^a	49.00±8.12 ^a	42.83±11.22 ^a
Jelly	35.08±7.17 ^a	35.33±8.33 ^a	48.41±5.50 ^a	39.61±9.35 ^{ab}
Marabel	35.83±15.89 ^a	38.91±11.03 ^a	44.75±13.23 ^a	39.83±13.66 ^{ab}
Concentration of extracts				
250 mg/ml	44.33±13.66 ^a	39.33±12.88 ^a	49.00±12.33 ^a	44.22±13.21 ^a
500 mg/ml	38.58±13.54 ^a	38.83±9.74 ^a	45.00±10.18 ^a	40.80±11.36 ^{ab}
Negative control	31.25±8.65 ^b	31.33±7.92 ^a	46.58±8.28 ^a	36.38±10.87 ^b
Positive control	34.41±7.45 ^b	37.83±7.20 ^a	43.83±10.00 ^a	38.69±8.99 ^b
LSD	8.53	6.75	8.46	4.84
Level of significance				
Variety	NS	NS	NS	NS
Concentration	≤0.05	NS	NS	≤0.05
Location				≤0.001
Interaction				
Varietyx Concentration	NS	NS	NS	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 9: Effects of Variety and Concentration of Extracts on Leaf Counts at 8WAP at Mangu, Barkin-Ladi and Jos-North Local Government Area

Treatment	Location			
	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	37.66±16.82 ^a	28.08±7.62 ^a	47.25±11.86 ^a	37.66±14.64 ^a
Connect	38.25±9.65 ^a	35.75±14.80 ^a	34.41±8.20 ^b	36.13±11.04 ^{ab}
Jelly	31.25±11.90 ^a	29.91±9.60 ^a	34.91±9.27 ^b	32.02±10.25 ^b
Marabel	31.25±11.90 ^a	32.75±18.78 ^a	45.58±19.72 ^a	36.52±17.89 ^{ab}
Concentration of extracts				
250 mg/ml	36.16±11.04 ^{ab}	37.41±12.70 ^a	47.08±19.31 ^a	40.22±15.19 ^a
500 mg/ml	43.25±14.75 ^a	34.25±10.71 ^a	38.25±9.63 ^b	38.58±12.14 ^a
Negative control	30.58±9.61 ^a	22.33±6.97 ^b	41.08±14.64 ^a	31.33±13.12 ^b
Positive control	28.41±11.56 ^a	32.50±17.18 ^a	35.75±8.79 ^b	32.22±12.97 ^b
LSD	9.75	8.52	9.01	5.62
Level of significance				
Variety	NS	NS	≤0.05	NS
Concentration	≤0.05	≤0.05	≤0.05	≤0.001
Location				≤0.001
Interaction				
Variety x Concentration	NS	NS	≤0.05	NS
Variety x Location				≤0.05
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 10: Interaction Effects of Variety and Concentration of Extracts on Leaf Count at 8WAP at Jos North Local Government Area

Variety	Concentration of extracts			
	250 mg/ml	500 mg/ml	Negative control	Positive control
Caruso	41.33±10.40 ^{bcd}	45.66±8.73 ^{bc}	55.33±18.77 ^{ab}	46.66±9.07 ^{bc}
Connect	31.00±11.26 ^{cd}	33.00±7.00 ^{cd}	38.33±10.26 ^{bcd}	35.33±6.65 ^{cd}
Jelly	46.66±2.08 ^{bc}	36.66±9.29 ^{cd}	27.00±5.29 ^d	29.33±1.52 ^{cd}
Marabel	69.33±25.14 ^a	37.66±13.05 ^{bcd}	43.66±8.38 ^{bcd}	31.66±5.50 ^{cd}
LSD	18.03			

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 11: Effects of Variety and Concentration of Extracts on Stem Counts at 4WAP at Mangu, Barkin-Ladi and Jos-North Local Government Area

Treatment	Location			
	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	2.50±1.00 ^{ab}	2.41±0.99 ^a	2.16±0.38 ^{ab}	2.36±0.83 ^a
Connect	2.16±1.02 ^b	2.50±1.38 ^a	2.91±0.99 ^a	2.52±1.15 ^a
Jelly	2.50±1.00 ^{ab}	2.33±1.30 ^a	2.00±0.60 ^b	2.27±1.00 ^a
Marabel	3.16±2.08 ^a	2.91±1.31 ^a	2.41±1.67 ^{ab}	2.83±1.69 ^a
Concentration of extracts				
250 mg/ml	3.33±2.18 ^a	3.41±1.37 ^a	2.16±0.71 ^a	2.97±1.61 ^a
500 mg/ml	2.75±0.75 ^{ab}	2.33±0.98 ^b	2.58±1.72 ^a	2.55±1.20 ^{ab}
Negative control	2.08±0.90 ^b	2.33±1.37 ^b	2.50±0.90 ^a	2.30±1.06 ^b
Positive control	2.16±0.83 ^b	2.08±0.79 ^b	2.25±0.62 ^a	2.16±0.73 ^b
LSD	0.81	0.91	0.90	0.52
Level of significance				
Variety	NS	NS	NS	NS
Concentration	≤0.001	≤0.05	NS	≤0.05
Location		NS		NS
Interaction				
Variety x Concentration	≤0.05	NS	NS	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 12: Interaction eEffects of Variety and Concentrations of Extracts on Stem Count at 4WAP at Mangu Local Government Area

Variety	Concentration of extracts			
	250 mg/ml	500mg/ml	Negative control	Positive control
Caruso	2.00±1.00 ^{bc}	3.33±0.57 ^b	3.00±1.00 ^{bc}	1.66±0.57 ^c
Connect	2.66±2.08 ^{bc}	2.33±0.57 ^{bc}	2.00±0.00 ^{bc}	1.66±0.57 ^c
Jelly	3.00±0.00 ^{bc}	2.66±1.15 ^{bc}	1.66±1.15 ^c	2.66±1.15 ^{bc}
Marabel	5.66±3.05 ^a	2.66±0.57 ^{bc}	1.66±0.57 ^c	2.66±0.57 ^{bc}
LSD	1.63			

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 13: Effects of Variety and Concentration of Extracts on Stem Counts at 6WAP at Mangu, Barkin-Ladi and Jos-North Local Government Area

Treatment	Location			
	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	3.00±1.53 ^a	2.41±0.66 ^a	2.50±0.52 ^a	2.63±1.01 ^a
Connect	1.75±1.05 ^a	2.66±1.77 ^a	2.66±1.30 ^a	2.36±1.43 ^a
Jelly	2.50±0.67 ^a	2.50±0.90 ^a	2.16±0.93 ^a	2.38±0.83 ^a
Marabel	2.50±0.90 ^a	2.83±0.83 ^a	3.08±1.50 ^a	2.80±1.11 ^a
Concentration of extracts				
250 mg/ml	2.91±1.08 ^a	3.16±1.46 ^a	3.00±1.85 ^a	3.02±1.46 ^a
500 mg/ml	2.58±0.99 ^a	2.50±1.08 ^{ab}	2.66±1.07 ^a	2.58±1.02 ^{ab}
Negative control	2.16±1.40 ^a	2.00±0.60 ^b	2.25±0.62 ^a	2.13±0.93 ^b
Positive control	2.08±0.99 ^a	2.75±0.86 ^{ab}	2.50±0.52 ^a	2.44±0.84 ^b
LSD	0.94	0.83	1.01	0.53
Level of significance				
Variety	NS	NS	NS	NS
Concentration	NS	NS	NS	≤0.05
Location	NS	NS	NS	NS
Interaction				
Variety x Concentration	NS	NS	NS	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				Ns

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 14: Effects of Variety and Concentration of Extracts on Stem Counts at 8WAP at Mangu, Barkin-Ladi and Jos-North Local Government Area

Treatment	Location			
	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	3.25±1.65a	2.08±0.66a	2.50±0.67a	2.61±1.17a
Connect	1.91±0.90b	2.16±0.93a	2.58±0.79a	2.22±0.89ab
Jelly	2.16±1.02b	1.91±0.79a	2.00±0.60a	2.02±0.81b
Marabel	2.58±1.16ab	2.25±0.86a	3.00±1.41a	2.61±1.17a
Concentration of extracts				
250 mg/ml	3.25±0.62a	2.66±0.77a	3.08±1.50 a	3.00±1.04a
500 mg/ml	2.58±1.08ab	2.08±0.66ab	2.66±0.77ab	2.44±0.87b
Negative control	2.25±1.71b	1.66±0.88b	2.25±0.45b	2.05±1.14bc
Positive control	1.83±1.19b	2.00±0.60b	2.08±0.51b	1.97±0.81c
LSD	0.83	0.6	0.79	0.43
Level of significance				
Variety	≤0.05	NS	NS	≤0.05
Concentration	≤0.05	NS	NS	≤0.001
Location				NS
Interaction				
Variety x Concentration	NS	NS	NS	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 15: Effects of Variety and Concentration of Extracts on Plant Height at 4WAP at Mangu, Barkin-Ladi and Jos -North Local Government Area

Treatment	Location			
	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	28.58±5.07 ^a	33.00±6.12 ^a	31.83±6.08 ^a	31.13±5.92 ^a
Connect	27.25±5.59 ^a	32.75±8.18 ^a	30.41±8.27 ^a	30.13±7.59 ^a
Jelly	28.91±4.99 ^a	28.33±5.83 ^a	36.00±5.42 ^a	31.08±6.34 ^a
Marabel	28.08±5.43 ^a	33.33±5.75 ^a	33.16±6.86 ^a	31.52±6.37 ^a
Concentration of extracts				
250 mg/ml	29.75±4.24 ^a	35.16±6.42 ^a	32.91±7.46 ^a	32.61±6.41 ^a
500 mg/ml	29.83±5.98 ^a	33.08±8.49 ^a	33.33±8.24 ^a	32.08±7.60 ^{ab}
Negative control	26.00±5.76 ^a	29.50±5.99 ^a	32.50±6.68 ^a	29.33±6.55 ^b
Positive control	27.25±3.79 ^a	29.66±3.96 ^a	32.66±5.63 ^a	29.86±4.94 ^b
LSD	4.43	5.24	5.98	2.93
Level of significance				
Variety	NS	NS	NS	NS
Concentration	NS	NS	NS	≤0.05
Location				≤0.001
Interaction				
Variety x Concentration	NS	NS	NS	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5%

Table 16: Effects of Variety and Concentration of Extracts on Plant Height at 6WAP at Mangu, Barkin-Ladi and Jos-North Local Government Area

Treatment	Location			
	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	44.75±8.99 ^b	50.66±10.69 ^b	59.00±5.44 ^a	51.47±10.28 ^a
Connect	52.25±11.47 ^a	57.00±13.16 ^a	54.66±7.36 ^a	54.63±10.80 ^a
Jelly	45.58±5.28 ^b	50.75±7.35 ^b	58.08±9.82 ^a	51.47±9.11 ^a
Marabel	46.75±9.15 ^{ab}	49.75±6.38 ^b	58.58±11.99 ^a	51.69±10.50 ^a
Concentration of extracts				
250 mg/ml	48.08±8.05 ^b	54.75±4.30 ^a	60.58±5.91 ^a	54.47±8.00 ^b
500 mg/ml	54.58±10.84 ^a	60.66±12.22 ^a	62.25±7.54 ^a	59.16±10.64 ^a
Negative control	43.08±7.89 ^b	45.50±7.11 ^b	56.41±11.05 ^{ab}	48.33±10.41 ^c
Positive control	43.58±4.81 ^b	47.25±6.26 ^b	51.08±6.47 ^b	47.30±6.51 ^c
LSD	5.73		6.85	3.5

Level of significance				
Variety	NS	NS	NS	NS
Concentration	≤0.001	≤0.001	≤0.05	≤0.001
Location				≤0.001
Interaction				
Variety x Concentration	≤0.05	NS	NS	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 17: Interaction Effects of Variety and Concentration of Extracts on Plant Height at 6WAP at Mangu Local Government Area

Variety	Concentration of extracts			
	250 mg/ml	500 mg/ml	Negative control	Positive control
Caruso	43.33±10.26 ^{cd}	52.33±12.58 ^{bc}	40.66±7.09 ^d	42.66±3.21 ^{cd}
Connect	55.66±4.16 ^b	68.00±2.00 ^a	43.00±6.08 ^{cd}	42.33±0.57 ^{cd}
Jelly	44.33±7.23 ^{bcd}	43.00±2.64 ^{cd}	48.66±1.52 ^{bcd}	46.33±8.02 ^{bcd}
Marabel	49.00±6.24 ^{bcd}	55.00±1.73 ^b	40.00±13.52 ^d	43.00±6.08 ^{cd}
LSD	11.46			

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 18: Effects of Variety and Concentration of Extracts on Plant Height at 8WAP at Mangu, Barkin-Ladi and Jos-North Local Government Area

Treatment	Location			
	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	55.33±11.24 ^{ab}	53.66±12.14 ^a	74.33±9.77 ^a	61.11±14.37 ^a
Connect	56.83±17.68 ^a	60.25±14.00 ^a	64.58±18.16 ^a	60.56±16.55 ^a
Jelly	54.00±6.63 ^{ab}	56.91±10.20 ^a	70.00±9.21 ^a	60.30±11.09 ^a
Marabel	49.41±9.17 ^b	55.91±11.32 ^a	68.66±12.13 ^a	58.00±13.37 ^a
Concentration of extracts				
250 mg/ml	54.25±7.31 ^{ab}	61.41±9.69 ^a	69.25±9.46 ^{ab}	61.63±10.63 ^b
500 mg/ml	64.91±15.10 ^a	66.25±11.43 ^a	75.58±15.24 ^a	68.91±14.45 ^a
Negative control	48.08±6.66 ^b	47.33±7.21 ^b	68.25±12.87 ^{ab}	54.55±13.37 ^c
Positive control	48.33±8.46 ^b	51.75±8.80 ^b	64.50±12.38 ^b	54.86±12.03 ^c
LSD	7.22	8	10.51	4.89
Level of significance				
Variety	NS	NS	NS	NS
Concentration	≤0.001	≤0.001	NS	≤0.001
Location				≤0.001
Interaction				
Variety x Concentration	NS	NS	NS	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 19: Interaction Effects of Variety and Concentration of Extracts on Plant Height at 8WAP for Mangu Local Government Area

Variety	Concentration of extracts			
	250 mg/ml	500 mg/ml	Negative control	Positive control
Caruso	56.33±9.60 ^{bc}	65.66±13.01 ^b	53.00±7.21 ^{bc}	46.33±9.50 ^c
Connect	53.33±7.5 ^{bc}	84.33±7.09 ^a	43.66±4.61 ^c	46.00±1.73 ^c
Jelly	58.00±2.64 ^{bc}	56.00±10.00 ^{bc}	50.33±3.51 ^c	51.66±8.02 ^{bc}
Marabel	49.33±8.50 ^c	53.66±7.76 ^{bc}	45.33±8.62 ^c	49.33±14.29 ^c
LSD	14.45			

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 20: Effects of Variety and Concentration of Extracts on Total Number of Tubers at Mangu, Barkin-Ladi and Jos North Local Government Area

Treatment	Location			
	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	9.66±5.14 ^a	9.75±6.01 ^a	8.66±3.55 ^b	9.36±4.88 ^a
Connect	9.75±2.73 ^a	11.16±7.44 ^a	10.08±4.69 ^{ab}	10.33±5.20 ^a
Jelly	7.27±3.69 ^a	9.72±4.45 ^a	12.08±4.58 ^a	9.61±4.53 ^a
Marabel	7.66±4.88 ^a	8.08±4.03 ^a	10.25±4.55 ^{ab}	8.66±4.52 ^a

Concentration of extracts				
250 mg/ml	7.58±3.11 ^a	11.50±8.14 ^a	12.25±5.46 ^a	10.44±6.12 ^a
500 mg/ml	10.08±5.07 ^a	11.66±5.51 ^a	8.91±3.98 ^a	10.22±4.89 ^{ab}
Negative control	8.50±4.35 ^a	6.33±2.80 ^b	9.25±3.76 ^a	8.02±3.80 ^b
Positive control	8.27±4.38 ^a	9.18±2.60 ^{ab}	10.66±3.91 ^a	9.27±3.70 ^{ab}
LSD	3.5	4.3	3.36	2.33
Level of significance				
Variety	NS	NS	NS	NS
Concentration	NS	NS	NS	NS
Location				NS
Interaction				
Variety x Concentration	NS	NS	NS	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 21: Main Effects of Variety and Concentration of Extracts on Weight of Tubers at Mangu, Barkin-Ladi and Jos-North Local Government Area

	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	0.39±0.23 ^{ab}	0.37±0.14 ^a	0.42±0.16 ^b	0.39±0.17 ^a
Connect	0.45±0.12 ^a	0.43±0.20 ^a	0.43±0.20 ^b	0.44±0.17 ^a
Jelly	0.30±0.17 ^b	0.43±0.21 ^a	0.60±0.16 ^a	0.43±0.21 ^a
Marabel	0.30±0.16 ^b	0.30±0.16 ^a	0.46±0.18 ^{ab}	0.35±0.18 ^a
Concentration of extracts				
250 mg/ml	0.30±0.11 ^a	0.35±0.19 ^a	0.46±0.21 ^a	0.37±0.18 ^b
500 mg/ml	0.36±0.21 ^a	0.40±0.18 ^a	0.42±0.21 ^a	0.40±0.20 ^{ab}
Negative control	0.39±0.13 ^a	0.33±0.18 ^a	0.48±0.11 ^a	0.40±0.15 ^{ab}
Positive control	0.40±0.25 ^a	0.45±0.16 ^a	0.55±0.18 ^a	0.46±0.21 ^a
LSD	0.14	0.2	0.14	0.08
Level of significance				
Variety	NS	NS	NS	NS
Concentration	NS	NS	NS	≤0.05
Location				≤0.001
Interaction				
Variety x Concentration	NS	NS	NS	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 22: Main Effects of Variety and Concentration of Extracts on Seed Size (35-55 mm) At Mangu, Barkin-Ladi and Jos-North Local Government Area

	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	2.83±2.16 ^a	3.41±2.15 ^a	4.00±2.00 ^a	3.41±2.10 ^a
Connect	4.16±1.99 ^a	4.08±3.08 ^a	4.16±2.88 ^a	4.13±2.62 ^a
Jelly	3.27±2.79 ^a	4.00±2.19 ^a	4.16±1.64 ^a	3.80±2.17 ^a
Marabel	3.41±2.27 ^a	3.25±2.17 ^a	3.25±2.83 ^a	3.30±2.37 ^a
Concentration of extracts				
250 mg/ml	2.83±1.58 ^a	2.75±1.95 ^b	5.16±2.16 ^a	3.58±2.18 ^a
500 mg/ml	4.08±2.19 ^a	4.83±2.55 ^a	3.25±2.37 ^b	4.05±2.40 ^a
Negative control	4.00±2.76 ^a	2.25±1.60 ^b	3.25±1.86 ^b	3.16±2.19 ^a
Positive control	2.72±2.41 ^a	5.00±2.23 ^a	3.91±2.67 ^{ab}	3.86±2.50 ^a
LSD	3.56	1.98	1.9	1.09
Level of significance				
Variety	NS	NS	NS	NS
Concentration	NS	≤0.001	NS	NS
Location				≤0.001
Interaction				
Variety x Concentration	NS	NS	NS	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 23: Effects of Variety and Concentration of Extracts on Seed Size (<35 mm) At Mangu, Barkin-Ladi and Jos-North Local Government Area

	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	3.83±1.64 ^a	2.91±2.87 ^a	2.58±1.92 ^b	3.11±2.21 ^a
Connect	3.33±2.42 ^a	4.41±4.29 ^a	3.91±1.56 ^{ab}	3.88±2.93 ^a
Jelly	3.27±2.93 ^a	3.90±2.02 ^a	5.33±3.08 ^a	4.05±2.78 ^a
Marabel	3.66±4.37 ^a	4.25±2.83 ^a	5.00±3.07 ^a	4.30±3.43 ^a
Concentration of extracts				
250 mg/ml	3.83±2.72 ^{ab}	5.00±4.41 ^a	5.91±3.60 ^a	4.91±3.64 ^a
500 mg/ml	5.16±4.06 ^a	5.00±3.10 ^a	3.75±1.48 ^b	4.63±3.05 ^{ab}
Negative control	1.91±1.50 ^b	2.16±1.46 ^b	3.25±2.05 ^b	2.44±1.74 ^c
Positive control	3.18±1.99 ^{ab}	3.27±1.61 ^{ab}	3.91±2.50 ^b	3.36±2.04 ^{bc}
LSD	3.1		1.57	1.29
Level of significance				
Variety	NS		≤0.05	NS
Concentration	NS		≤0.05	≤0.001
Location				NS
Interaction				
Variety x Concentration	NS		≤0.05	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 24: Interaction Effects of Variety and Concentration of Extracts on Seed Size (<35 mm) At Jos-North Local Government Area

Variety	Concentration of extracts			
	250 mg/ml	500 mg/ml	Negative control	Positive control
Caruso	2.66±3.05 ^{cd}	2.33±1.15 ^{cd}	2.00±2.00 ^d	3.33±2.08 ^{cd}
Connect	3.66±0.57 ^{cd}	3.33±1.15 ^{cd}	4.00±2.00 ^{cd}	4.66±2.51 ^{bcd}
Jelly	10.00±1.00 ^a	4.33±0.57 ^a	4.66±1.15 ^{bcd}	2.33±1.15 ^{cd}
Marabel	7.33±3.05 ^{ab}	5.00±1.73 ^{bc}	2.33±2.51 ^{cd}	5.33±3.78 ^{bc}
LSD	3.15			

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 25: Effects of Variety and Concentration of Extracts on Seed Size (>55 mm) at Mangu, Barkin Ladi and Jos-North Local Government Area

	Mangu	B/Ladi	J/North	Pooled
Variety				
Caruso	1.58±1.88 ^{ab}	2.41±1.24 ^a	1.66±1.87 ^a	1.88±1.68 ^{ab}
Connect	2.25±2.26 ^a	2.66±2.01 ^a	1.91±1.88 ^a	2.27±2.02 ^a
Jelly	0.63±0.92 ^b	3.09±3.17 ^a	2.58±2.19 ^a	2.11±2.39 ^a
Marabel	0.75±1.21 ^b	0.58±0.99 ^b	2.08±2.50 ^a	1.13±1.79 ^b
Concentration of extracts				
250 mg/ml	1.08±1.08 ^a	2.83±3.21 ^a	1.25±1.54 ^a	1.72±2.23 ^a
500 mg/ml	0.75±1.71 ^a	1.75±1.60 ^a	1.66±2.10 ^a	1.38±1.82 ^a
Negative control	1.5±1.44 ^a	2.25±2.09 ^a	2.58±1.56 ^a	2.11±1.73 ^a
Positive control	2.00±2.48 ^a	1.81±1.32 ^a	2.75±2.76 ^a	2.19±2.21 ^a
LSD	1.32	1.22	1.67	0.95
Level of significance				
Variety	NS	NS	NS	NS
Concentration	NS	NS	NS	≤0.001
Location				NS
Interaction				
Variety x Concentration	NS	NS	NS	NS
Variety x Location				NS
Concentration x Location				NS
Variety x Concentration x Location				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Table 26: Effects of Variety and Concentration of Extracts on Disease Severity at Mangu, Barkin-Ladi and Jos-North Local Government Area

Treatment	Isolates			
	Mangu	B/Ladi	Jos North	Pooled
Variety				
Caruso	16.66±16.28 ^b	33.33±12.30 ^a	25.00±10.66 ^a	25.00±14.63 ^b
Connect	18.75±18.84 ^b	33.33±19.46 ^a	22.91±12.87 ^a	25.00±17.92 ^b
Jelly	37.50±13.05 ^a	43.75±24.13 ^a	31.25±15.53 ^a	37.50±18.41 ^a
Marabel	18.75±15.53 ^b	31.25±18.84 ^a	22.91±16.71 ^a	24.30±17.40 ^b
Concentration of extracts				
250mg/ml	25.00±21.32 ^a	37.50±22.61 ^a	29.16±14.43 ^a	30.55±19.92 ^a
500 mg/ml	27.08±16.71 ^a	27.08±16.71 ^a	22.91±12.87 ^a	25.69±15.21 ^a
Negative control	20.83±17.94 ^a	35.41±19.82 ^a	22.91±16.71 ^a	26.38±18.84 ^a
Positive control	18.75±15.53 ^a	41.66±16.28 ^a	27.08±12.87 ^a	29.16±17.42 ^a
LSD	12.5	16.97	10.65	7.94
Level of significance				
Variety	≤0.05	NS	NS	≤0.05
Concentration	NS	NS	NS	NS
Isolates				≤0.05
Interaction				
VarietyxConcentration	NS	NS	NS	NS
Variety x Isolates				NS
Concentration x Isolates				NS
Variety x Concentration x Isolates				NS

Means followed by the same letter (s) within the same column are not significantly different at 5% level of probability

Discussion

Yield of Plant extract revealed that the extract could be best extracted using water however, ethanolic extract, though less in yield had better activities in the susceptibility testing. This implies that the ethanol used in extraction has the ability to extraction has the ability to extract active compounds that cannot be achievable with water.

Fusarium species isolated from soil samples of B/Ladi showed high susceptibility to clove than the standard control drug Emyxyl used. However, the isolates from B/Ladi soil samples did not show positive pathogenicity *in vitro*. This may imply that the isolates had more effect or pathogenicity with respect to wilting than rotting. *Fusarium* is known to cause wilting of potato in the field and rot in storage. Against all the incula obtained, ethanolic extract had best/high activities against standard positive control. Though, it revealed that the higher the concentration the better the activity. The antifungal activities with ethanolic extracts created wider zones of inhibition. Microorganisms are regarded as concealed enemies of mankind responsible for causing devastating damages to living organism (Sundar *et al.*, 2013) [12]. The major factor that determines the quality of potato yield is proper and early cultivation. This is even necessary in the era of climate changes, which makes agricultural plant such as potatoes exposed to various stress factors, and can be mitigated using appropriate methods of cultivation. In this study, cultivated potatoes were assessed for emergence at two and four weeks after planting, results revealed there was no significant difference at two and four weeks. Although, when the emergence count was determined, not all the planted potatoes emerged at two weeks after planting however, at four weeks after planting, all the potatoes planted emerged. Leaves were well established at six weeks. Caruso was the only variety that produced flowers (whitish- yellow in appearance), unlike the other three varieties (Connect, Marabel and Jelly) which did not produce any observable flower throughout their growing period. Caruso are said to be resistant to infections unlike Marabel that seems susceptible. This may be as a

result of high moisture content. This may be as a result of high moisture content, although cultivar differences in *Fusarium* resistance are also known to reflect inducible hormone-mediated defence responses (Nguyen *et al.*, 2024) [8]. It is the variety that had the highest vegetative growth while Jelly appeared to be shorter with reduced vegetative growth. Connect and marabel had moderate vegetative growth. Connect having broad and bunchy leaves. The leaves of Jelly were fewer in number, stem short. At six weeks, plants growth had peaked and they were infected with *Fusarium* spores of which disease was established within 10-14 days after infection (at eight weeks), the plants had shown the symptoms of *Fusarium* wilt which appeared less than 14 days after inoculation. Barkin-Ladi isolate was most pathogenic on the plants generally with minimal exception on Jelly and Caruso varieties. Mangu and Jos-North isolates did not show susceptibility to the pathogen on the four varieties used. What was striking was the fact that the Barkin-Ladi isolate in the *in vitro* pathogenicity test, showed resistance of the potato tubers to the *Fusarium* isolate however, the reverse was the case under field trial. The potato under Barkin-Ladi was more susceptible to *Fusarium* wilt compared to the other two isolates (Mangu and Jos-North). The untreated (negative control) was highly susceptible to the pathogen unlike the potatoes that were infected and treated with the extract of *Syzygium aromaticum* and the standard (positive) control. Potato had started wilting at 8 weeks. Most effect of the pathogen was observed on the leaves while the disease severity progressed toward maturation and harvest. This implies that, the disease must be avoided by all means on farms, early planting is key and practice of crop rotation is necessary.

Plants provide a variety of resources ranging from basic to economic importance. Vegetables including potato are known to be affordable and richest sources of calories, minerals, vitamins, dietary fiber hence, referred to as “protected foods”. They are necessary to tackle the problems of malnutrition and improve healthy life. Diseases are classified into groups based on the pathogen(s)

responsible. In this study, it was observed in a pilot study that *Fusarium* once it infects the plant, within two weeks, the plant is destroyed depending on the *Fusarium* species involved hence, they were infected with the pathogen at 6 weeks to allow the plants attain certain level of maturity. The disease incidence rate for B/Ladi was the highest. Severity assessment revealed that Marabel was severely affected. This may be possible due to the high moisture content of the variety compared to the other three, as monitored across the three local government areas under study. The *Fusarium* isolates varied in their severity assessment, B/Ladi isolate on physical observation exerted more effect than Mangu and Jos-North isolate. This agrees with the report of Nadia (2021) who reported that *Fusarium* isolated from infected plants tissues varied in pathogenicity this is in conformity with the reports of Ray *et al.* (2007)^[9]. With B/Ladi isolate showing strongest symptoms of wilting compared to the other two (Mangu and Jos-North). Nadia (2021) also reported a species of *Fusarium* that is most aggressive (*F. oxysporum*) among tested *Fusarium* species such as *F. solani* and *F. sambucinum*. Considering the three locations, there are diverse *Fusarium* species associated with potato in these regions and the list may likely be incomplete.

Conclusion

Variation of the antifungal activity both *in vitro* and *in vivo* revealed the possibility of different species of *Fusarium* isolated from sources they were obtained. Also the *in vitro* pathogenicity confirm that however, the *in vivo* antifungal activities of the extracts against the isolate took a little deviation and the Barkin-Ladi isolate which seemed a bit less pathogenic *in vitro* was highly pathogenic in the field.

Syzygium aromaticum has the required potentials of antifungal activities against *Fusarium* wilt. This is because, it delayed expression of wilting after infection and as such could be used to develop a biofungicide in managing *Fusarium* wilt particularly, the ethanolic extract.

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