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RESEARCH ARTICLE

Antifungal activity of castor leaf extract against *Fusarium oxysporum f sp. cubense*, the incitant of panama wilt of banana

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Abstract

Panama wilt is a serious disease affecting banana plants, caused by *Fusarium oxysporum* f. sp. *Cubense*. This study aimed to extract bioactive compounds from castor leaves using different solvents and investigate their antifungal activity against the pathogen. Castor leaf extracts prepared using ethanol, acetone, methanol, acetic acid, and water were tested at concentrations of 10% and 20% under *in vitro* conditions using the poisoned food technique. . The fungal pathogen was inoculated into the medium and incubated for seven days. Among the tested solvent, the acetic acid extract of castor leaves exhibited the highest inhibition of fungal growth, with 97.79 % inhibition observed at the 10 % concentration, followed by the acetone extract with 13.54 % inhibition. Water and methanol extracts showed inhibition rates of 11.38 % and 8.50 % respectively, while the ethanol extract showed the least inhibition of 6.86 %. A similar pattern was observed at the 20 % concentration. These results suggest that acetic acid extraction of castor leaves is highly effective in minimising the incidence of *Fusarium* wilt in bananas. However, further experimentation under field conditions are necessary to validate the effectiveness of castor leaf extraction against panama wilt.

Keywords: banana; castor; disease management; ethanol; panama wilt

Introduction

Banana is one of the healthiest fruits in the world because they are so rich in vitamins and minerals. It belongs to the family Musaceae and is among the oldest fruits known to India. Globally, it ranks as the fourth most widely consumed food crop by gross value, after rice, wheat, and maize.. India produces 33% of the worlds' fruit production and occupies 13 % of the total land area under fruit cultivation. In India, bananas are primarily farmed in the states of Maharashtra, Tamil Nadu, Andhra Pradesh, Kerala, Karnataka, Gujurat, Orissa and West Bengal . The rasthali, dwarf cavendish, robusta, champa and G9 varieties of banana are typically grown in Odisha. The state account for about 4.77 % of the total area under fruit cultivation and 2.58 % of total fruit production.

Banana plant has been infected by many diseases such as yellow sigatoka (*Mycospharella musicola*), anthracnose (*Gleosporium musarum*), banana buncy top (banana buncy top virus), *Eriwinia* rot (*Eriwinia carotovora* sub sp. *cartovora*), mokko wilt (*Ralstonia solanacerum*) and panama wilt (*Fusarium oxysporum* f.sp. *cubense*). One of these banana diseases caused by the fungus that inhibits the soil is called "panama wilt." It affects 80–90 % of cultivars that are susceptible across several Indian states. In Odisha, the disease has been causing considerable damage in coastal light soils and other affected regions.

Fusarium wilt is a vascular wilt disease in which the fungus blocks the xylem vessels, preventing the upward movement of water. . The symptom begins to manifest after 5 to 6 months after planting and are visible both internally and externally. In its latter stages, the disease leads to severe yield losses, characterised by pseudo stem splitting, hanging of leaves around the pseudostem, yellowing of the pseudostem, and yellowing of the leaf margins of older leaves. Wilt frequently results in unmarketable bunch production and finally kills the entire plant (1).

Fusarium oxysporum can be found in a variety of environments and locations. Warm, humid soils and high temperatures promote the disease development. The optimum soil temperature for root infection is 30 ^{0}C or higher. The disease is soil borne and the fungus enters the root through the fine laterals. The incidence is high in alluvial soils. The inoculum can be introduced through conidia dissemination in air. The pathogen is easily spread by infected rhizomes or suckers, farm implements or irrigation water.

Chemical management of the disease poses serious risks to human health and the environment. Additionally, continuous use of fungicides may result in the emergence of resistance to pathogenic species (2, 3). As a result, there is a growing interest in identifying natural antifungal agents for plant disease control (4, 5). Although these alternative approaches may be more time-consuming and costly, they are essential for prolonging the

effective use of existing fungicides. Moreover, consumers concern about the health and environmental impacts of synthetic fungicides, due to their active ingredients and co-formulants are increasing (6).

Worldwide, *Ricinus communisis*, commonlyknown as castor, is a multipurpose herbal plant that is utilized for both culinary and medicinal uses. Researcher has shown that this plant provides a variety of health benefits, including both medical and nutritional ones (7).

The present study used castor leaf as an alternative to toxic fungicides to investigate castor leaf antifungal effects against the *Fusarium oxysporum f.sp. cubense* under both *in vitro* and *in situ* conditions. The findings may help develop a new, efficient approach for controlling phytopathogenic fungi.

Materials and Methods

Collection of castor leaf

Fresh castor leaves were collected from fields near the Institute of Agricultural Sciences, Bhubaneswar, Odisha, for use in the experiment.

Preparation of leaf extract

The freshly collected castor leaves were washed with running tap water and weighed to 100g. The leaves were then cut into smaller pieces, crushed and mixed with 100 mL of various solvents (water extract (T1), ethanol extract (T2), acetone extract (T3), methanol extract (T4) and acetic acid extract (T5) in a 1:1 (w/v) ratio.. Each mixture was transferred to a separate conical flask and subjected to agitation in a rotary shaker for 12 hrs. The resulting extracts were filtered through Whatman No. 1 filter paper and subsequently centrifuged at 3000 rpm for 12 min to obtain the stock solutions. These stock solutions were stored in a refrigerator for further testing.

Test organism

Fusarium oxysporum f.sp. cubense was isolated and inoculated onto fresh potato dextrose agar medium to promote mycelial growth. The cultures were incubated at 37 °C for 24 hrs (8).

Isolation and Identification of the fungus

The fungal pathogen was isolated from the pseudostem of panama wilt-affected banana plants and cultured on Potato dextrose agar. The fungal culture was sent to Indian Type Culture Collection (ITCC), Indian Agricultural Research Institute (IARI), for identification, which confirmed the pathogen as *Fusarium oxysporum* f. sp. *cubense*.

Screening for antifungal activity using the poisoned food technique

The antifungal activity of the leaf extract was determined using the poisoned food technique. Stock solutions of the extracts were mixed into sterilised PDA medium to prepare treatments at concentrations of 10 % and 20 % (9). The medium was poured into sterile Petri plates and allowed to solidify. Mycelial discs from actively growing cultures were then placed at the centre of each plate The plates were incubated at 28°C and the radial growth of fungal mycelia was recorded after seven days (10). The percentage of growth inhibition compared to the control was calculated using the formula described by (11).

Fourier transform infrared spectroscopy (FTIR) analysis

FTIR was used to analyse the leaf extracts. This technique facilitates the identification and distinguishing different molecules based on their structural differences with higher sensitivity and accuracy.

Statistical analysis

All experimental data were subjected to statistical analysis using a completely randomised design, with four replicates per treatment. Data analysis was carried out using the OPSTAT statistical software.

Results

Screening for antifungal activity using the poisoned food technique

To evaluate the efficacy and effectiveness of different solvent extracts of leaf extract in inhibiting fungal mycelial growth, 5 solvent extracts were tested and compared to the control. The results presented in Table 1 and Fig. 1, 2 and 3 showed that the acetic acid extract exhibited the highest antifungal activity, with mean inhibition rates of 97.79 % at 10 % concentration and 97.85 % at 20 % concentration. In contrast, the ethanol extract showed the lowest inhibition at both concentrations.

FTIR analysis

FTIR spectroscopy was employed to identify functional groups present in the various castor leaf extracts. A wide range of functional groupssuch as alcohols, alkynes, amides, aromatic compounds, ketones, ethers, aldehydes, alkyl halides, etc., were present in the water extract (Table 2). Similar functional groups were identified in the ethanol, acetone, methanol and acetic acid extract. Table 3, 4, 5 and 6 summarise the tentative identification and characteristic peaks of the corresponding functional categories.

FT-IR analysis of the water extract of castor leaves

The FT-IR spectrum of the water extract (Table 2 and Fig. 4) showed characteristic peaks at 3307.96, 2188.69, 2158.93, 2108.18, 2027.09, 1922.59, 1637.83, 1500.89, 1365.28, 1270.44, 443.23, 430.65, 415.92 and 406.99 per cm. A robust, broad peak at 3307.96 per cm was attributed to the O-H stretch, indicating the presence of alcohols. . Strong peaks at 443.23, 430.95, 415.92 and 406.99 per cm were associated with alkyl halides (C-I stretch). The moderately strong peaks at 1500.98, 1365.28 and 1270.44 per cm corresponded to aromatic compounds (C=C stretch), alkynes and alkanes CH (CH3)2 and ethers (=C-O-C sym. & asym. stretch). Weak- to- moderate peaks at 2158.93, 2108.18, 2027.09, and 1922.59 per cm were attributed to alkynes (C=C stretch), while a moderate peak at 1637.83 per cm was attributed to amides (N-H bend).

FT-IR analysis of the ethanol extract of castor leaves

The absorption spectrum of the ethanol extract (Table 3 and Fig. 5) showed twenty-nine peaks at 3902.13, 3855.72, 3306.62, 2982.43, 2907.2, 2187.39, 2171.08, 2123.31, 1994.93, 1966.97, 1955, 1916.05, 1639.62, 1454.77, 1417.41, 1386.3, 1328.85, 1273.56, 1085.28, 1044.38, 876.88, 498.01, 474.79, 455.54, 435.69, 426.9, 415.56 and 402.96 per cm. The shape of peaks in the spectrum varied based on the nature of bonds and the intensity

Table 1. *In-vitro* bioassay of castor leaves extracted in different solvents against panama wilt of banana

Number	Castor leaves	Treatment	10% concentration	20% concentration
1.	Water extract	T1	11.38	12.36
2.	Ethanol extract	T2	6.86	7.97
3.	Acetone extract	T3	13.54	10.77
4.	Methanol extract	T4	8.50	7.02
5.	Acetic acid extract	T5	97.79	97.85
	SE (m)		3.963	1.827

Table 2. Water extract

Sample-1 (Water extract)			
Peak no.	**Peak value**	**Functional group**	**Assignment**
1	3307.96	Alcohols	O-H stretch
2	2188.69	Alkynes	C=C stretch
3	2158.93	Alkynes	C=C stretch
4	2108.18	Alkynes	C=C stretch
5	2027.09	Alkynes	C=C stretch
6	1922.59	Allene	C=C=N stretch
7	1637.83	Amides	N-H bend
8	1500.89	Aromatic compounds	ring C=C stretch
9	1365.28	Alkynes and Alkanes	CH(CH3)2
10	1270.44	Ethers	C-O-C sym. & asym. Stretch
11	443.23	Alkyl halides	C-I stretch
12	430.95	Alkyl halides	C-I stretch
13	415.92	Alkyl halides	C-I stretch
14	406.99	Alkyl halides	C-I stretch

Table 3. Ethanol extract

Sample-2 (Ethanol extract)			
Peak no.	**Peak value**	**Functional group**	**Assignment**
1	3902.13	Amines	N-H stretch
2	3855.72	Amines	N-H stretch
3	3306.62	Amides	N-H sym.& asym. Stretch
4	2982.43	Carboxylic acid	O-H stretch
5	2907.2	Carboxylic acid	O-H stretch
6	2206.38	Alkynes	C=C stretch
7	2187.39	Alkynes	C=C stretch
8	2171.08	Thiocyanate	S-C=N stretching
9	2123.31	Alkynes	C=C stretch
10	1994.93	Allene	C=C=C stretching
11	1966.97	Allene	C=C=C stretching
12	1955	Allene	C=C=C stretching
13	1916.05	Allene	C=C=C stretching
14	1639.62	Amides	N-H bend
15	1454.77	Aromatic compound	ring C=C stretch
16	1417.41	Carboxylic acid	O-H bending
17	1386.2	Alkynes and Alkanes	CH3-CH bend
18	1328.85	Alcohols	O-H bending
19	1273.56	Alcohols	C-O stretch
20	1085.28	Alcohols	C-O stretch
21	1044.38	Alcohols	C-O stretch
22	876.88	Alkyl halides	C-Br stretch
23	498.01	Alkyl halides	C-I stretch
24	474.79	Alkyl halides	C-I stretch
25	455.54	Alkyl halides	C-I stretch
26	435.69	Alkyl halides	C-I stretch
27	426.9	Alkyl halides	C-I stretch
28	415.56	Alkyl halides	C-I stretch
29	402.96	Alkyl halides	C-I stretch

Table 4. Acetone extract

Sample-3 (Acetone extract)			
Peak no.	**Peak value**	**Functional group**	**Assignment**
1	3903.16	Amines	N-H stretch
2	3856.03	Amines	N-H stretch
3	3352.62	Carboxylic acid	O-H stretch
4	2220.05	Alkynes	C=C stretch
5	2165.23	Alkynes	C=C stretch
6	2110.85	Alkynes	C=C stretch
7	2027.38	Allene	C=C=N stretching
8	1994.97	Allene	C=C=C stretching
9	1970.96	Allene	C=C=C stretching
10	1943.79	Allene	C=C=C stretching
11	1922.8	Allene	C=C=C stretching
12	1697.71	Aldehydes	C=O stretch
13	1639.48	Amides	N-H bend
14	1423.17	Carboxylic acid	O-H bending
15	1370.26	Nitro compound	N-O sym. & asym. Stretch
16	1237.75	Alcohols	C-O stretch
17	1141.4	Alcohols	C-O stretch
18	1093.66	Ethers	C-O-C stretch
19	535.55	Alkyl halides	C-Br stretch
20	518.24	Alkyl halides	C-Br stretch
21	495.06	Alkyl halides	C-I stretch
22	463..33	Alkyl halides	C-I stretch
23	455.57	Alkyl halides	C-I stretch
24	445.91	Alkyl halides	C-I stretch
25	436.1	Alkyl halides	C-I stretch
26	423.31	Alkyl halides	C-I stretch
27	411.49	Alkyl halides	C-I stretch
28	402.52	Alkyl halides	C-I stretch

Table 5. Methanol extract

Sample-4 (Methanol extract)			
Peak no.	**Peak value**	**Functional group**	**Assignment**
1	3284.71	Carboxylic acid	O-H stretch
2	2954.29	Carboxylic acid	O-H stretch
3	2842.93	Carboxylic acid	O-H stretch
4	253.14	Carboxylic acid	O-H stretch
5	2206.71	Alkynes	C=C stretch
6	2183.4	Alkynes	C=C stretch
7	2165.41	Alkynes	C=C stretch
8	2124.25	Alkynes	C=C stretch
9	2010.78	Allene	C=C=N stretching
10	1995.13	Allene	C=C=C stretching
11	1642.8	Allene	C=C=C stretching
12	1509.01	Aromatic compound	ring C=C stretch
13	1450.24	Aromatic compound	ring C=C stretch
14	1408.18	Aromatic compound	Ring C=C stretch
15	1269.35	Ethers	C-O-C sym. & asym. Stretch
16	1111.61	Alcohols	C-O stretch
17	1014.66	Alcohols	C-O stretch
18	490.9	Alkyl halides	C-I stretch
19	474.97	Alkyl halides	C-I stretch
20	455.57	Alkyl halides	C-I stretch
21	433.95	Alkyl halides	C-I stretch
22	422.89	Alkyl halides	C-I stretch
23	414.75	Alkyl halides	C-I stretch
24	402.65	Alkyl halides	C-I stretch

Table 6. Acetic acid extract

Sample-5 (Acetic acid extract)			
Peak no.	**Peak value**	**Functional group**	**Assignment**
1	3856.03	Amines	N-H stretch
2	3352.62	Amines	N-H stretch
3	2220.05	Carboxylic acid	0-H stretch
4	2165.23	Alkynes	C=C stretch
5	2110.85	Alkynes	C=C stretch
6	2027.38	Alkynes	C=C stretch
7	1994.97	Allene	C=C=C stretching
8	1970.96	Allene	C=C=C stretching
9	1943.79	Allene	C=C=C stretching
10	1922.8	Allene	C=C=C stretching
11	1697.11	Allene	C=C=C stretching
12	1639.48	Amides	C=O stretch
13	1423.17	Amides	N-H bend
14	1370.26	Sulfate	S=O stretching

15	1237.75	Nitro compound	N-O sym. & asym. Stretch
16	1141.4	Fluoro compound	S=O stretching
17	1093.66	Alcohol	C-O stretch
18	535.55	Alcohol	C-O stretch
19	518.24	Alkyl halides	C-Br stretch
20	495.06	Alkyl halides	C-Br stretch
21	463.33	Alkyl halides	C-I stretch
22	455.57	Alkyl halides	C-I stretch
23	445.91	Alkyl halides	C-I stretch
24	436.1	Alkyl halides	C-I stretch
25	423.31	Alkyl halides	C-I stretch
2	411.49	Alkyl halides	C-I stretch
27	402.52	Alkyl halides	C-I stretch
28	398.05	Alkyl halides	C-I stretch

Fig. 1. Inhibitory effect at 10 % concentration (T1 – water extract, T2 – ethanol extract, T3 – acetone extract, T4 – methanol extract, T5 – acetic acid).

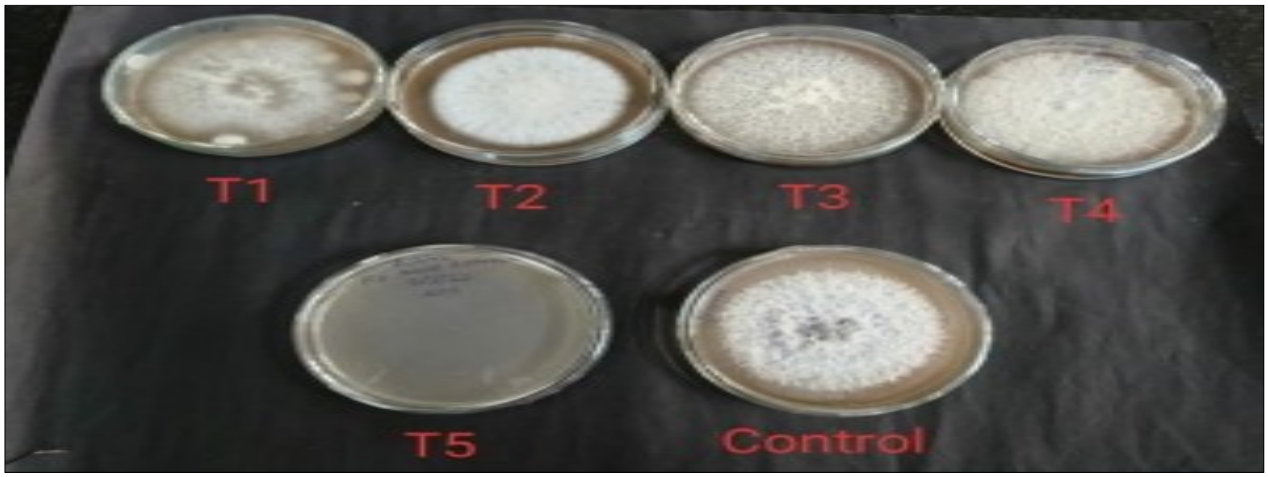

Fig. 2. Inhibitory effect at 10 % concentration (T1 – water extract, T2 – ethanol extract, T3 – acetone extract, T4 – methanol extract, T5 – acetic acid).

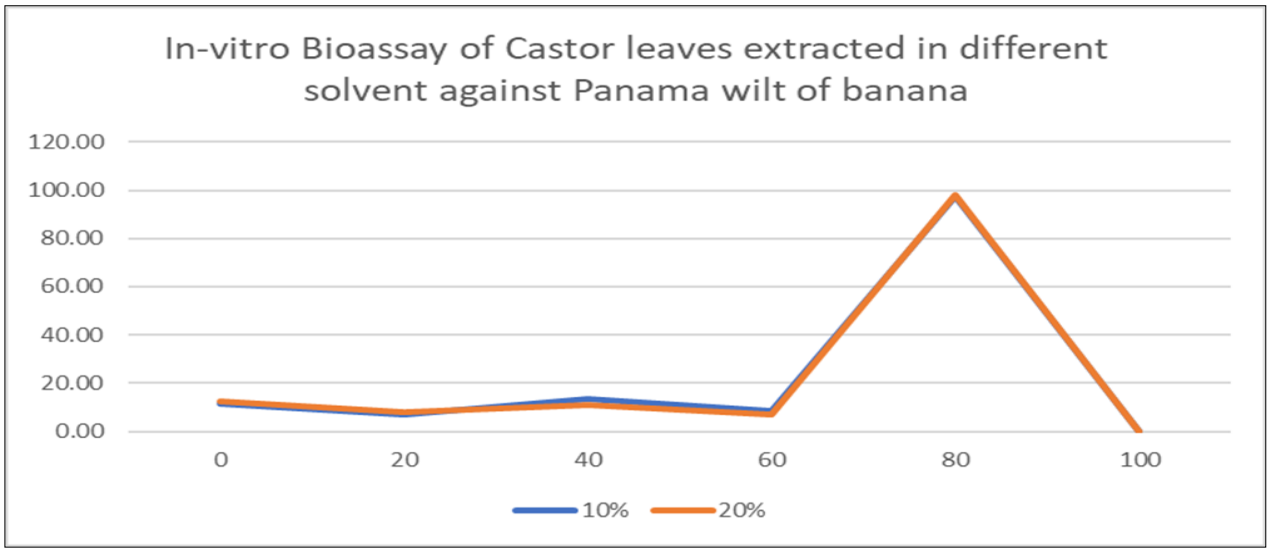

Fig. 3. *In-vitro* bioassay of castor leaves extracted in different solvents against panama wilt of banana.

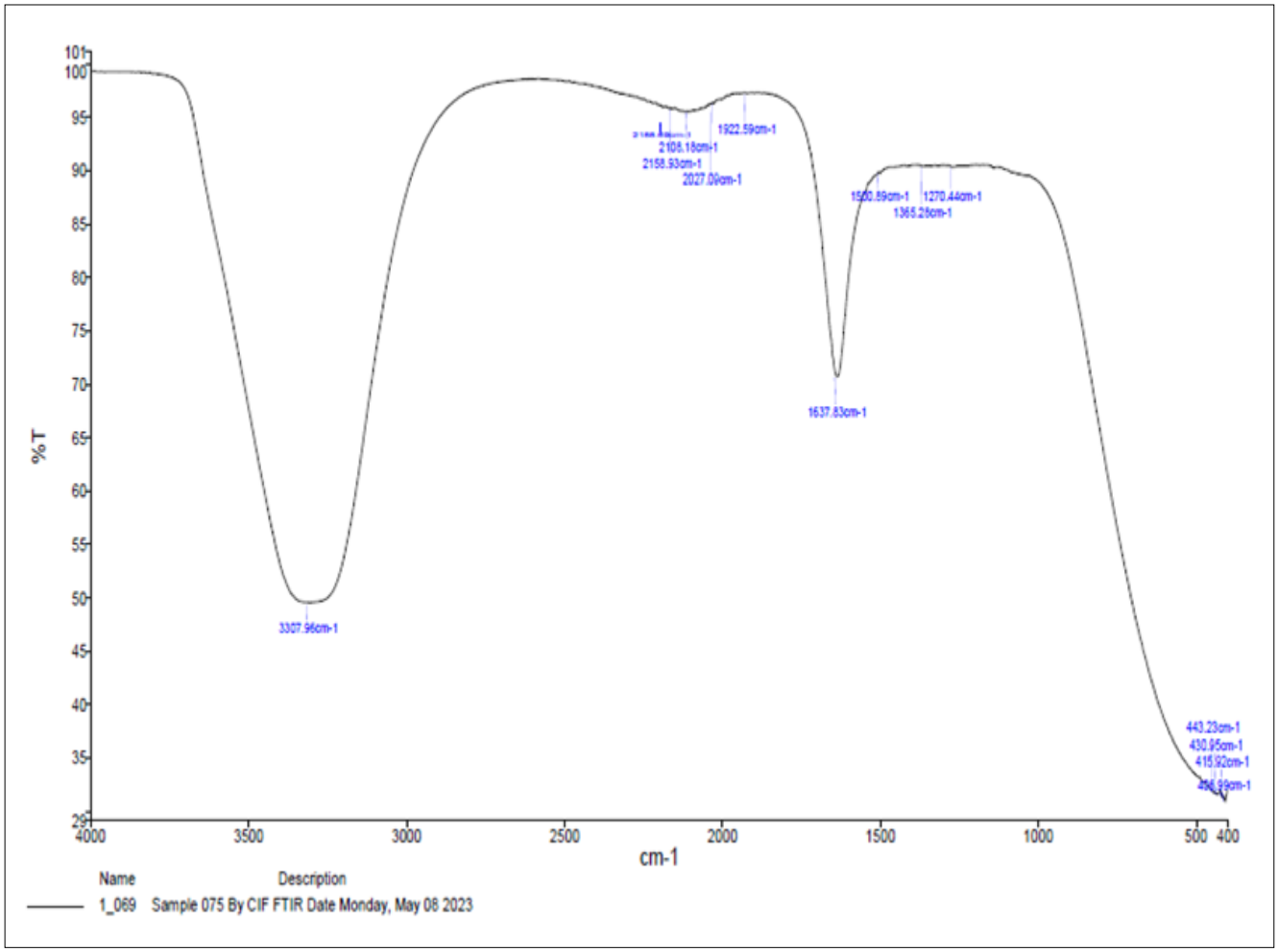

Fig. 4. FTIR spectrum of water extract.

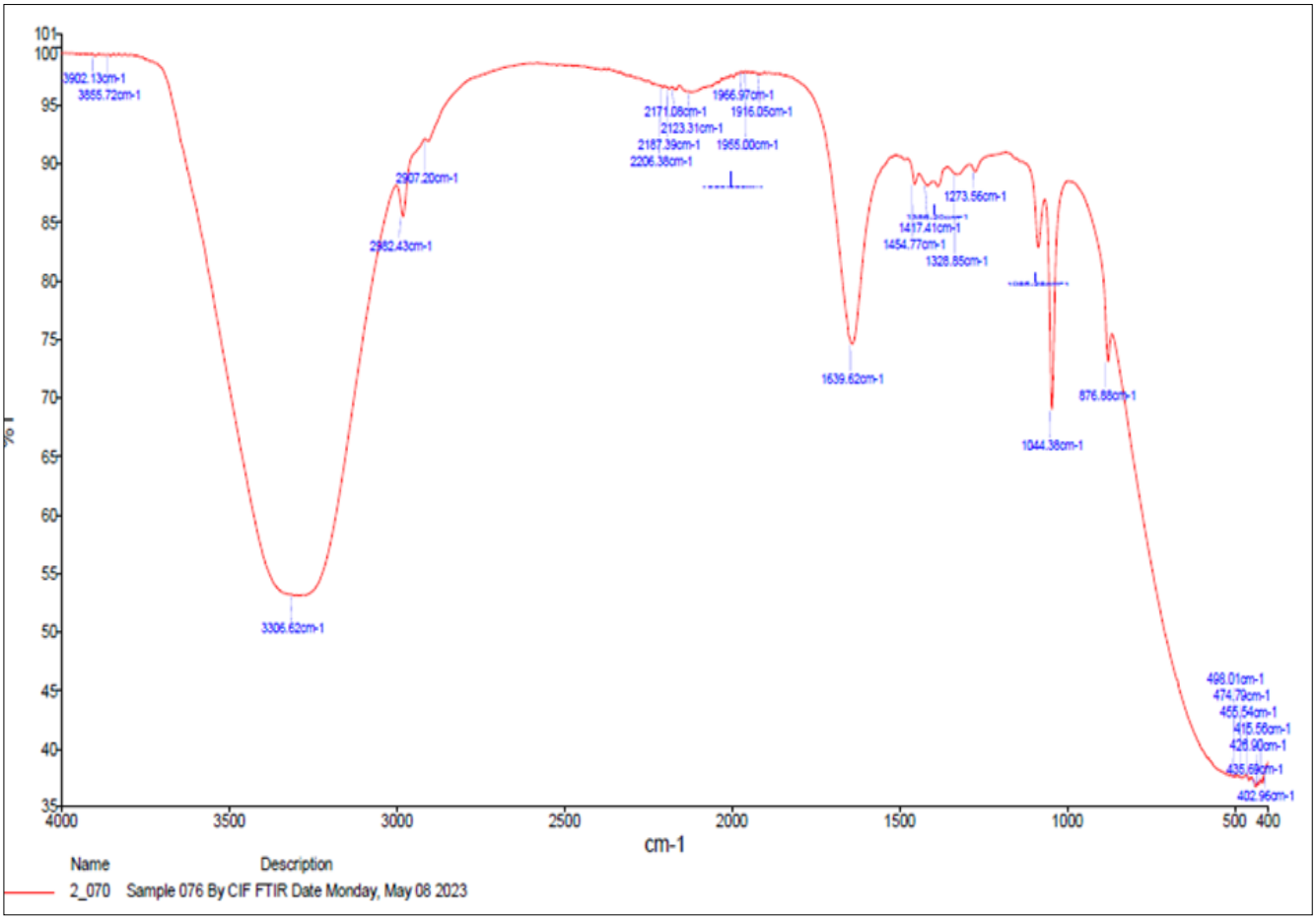

Fig. 5. FTIR spectrum of ethanol extract.

of vibration of bonds in the functional groups. The solid and broad peaks at 2982.43, 2907.2 and 1417.41 per cm indicated carboxylic acid (O-H stretch). Firm peaks at 876.88, 498.01, 474.79, 455.54, 435.69, 426.9, 415.56 and 402.96 per cm suggested the presence of alkyl halides (C-Br stretch) and (C-I stretch). Medium-strength peaks at 1639.62, 1454.77, 1328.85, 1273.56, 1085.28, 1386.2 and 1044.38 per cm were attributed to aromatic rings (C=C stretch), alcohols (C-O stretch) and alkynes and alkanes CH (CH3)2. Weak-to- moderate peaks at 2206.38, 2187.39, 2171.08, 2123.31, 1994.93, 1966.97, 1955 and1916.05 per cm were assigned to alkynes (C=C stretch) and allenes (C=C=C stretch). The weak, medium peaks at 3306.62 and 1639.62 per cm were associated with amides (N-H sym. and asym. stretch) and (N-H bend). A weak peak at 3902.13 and 3855.72 indicated amines (N-H stretch).

FT-IR analysis of the acetone extract of castor leaves

The result on the FT-IR spectrum of acetone castor leaf extract (Table 4 and Fig. 6) revealed peaks at 3903.16, 3856.03, 3352.62, 2220.05, 2165.23, 2110.85, 2027.38, 1994.97, 1970.96, 1943.79, 1922.8, 1697.71, 1639.48, 1423.17, 1370.26, 1237.75, 1141.4, 1093.66, 535.55, 518.24, 495.06, 463.33, 455.57, 445.91, 436.1, 423.31, 411.49 and 402.52 per cm. O-H stretched of two solid and broad peaks indicated carboxylic acid (O-H stretch) that had absorption of 3352.62 and 1423.17 per cm. The firm peaks at 1697.71, 1370.26, 535.55, 518.24, 495.04, 463.33, 455.57, 445.51, 436.1, 423.31, 411.49 and 402.52 per cm indicates aldehydes (C=O stretch), nitro compound (N-O sym. and asym. stretch) and alkyl halides (C-Br stretch) and (C-I stretch). A medium-to-strong peak was observed at at 1237.75, 1141.4 and 1093.66 per cm were linked to alcohols and ethers (C-O stretch and C-O-C stretch). A medium peak at 1639.48 per cm indicated amides (N-H bend). Weak-to-moderate peaks at 2220.05, 2165.23, 2113.85, 2027.38, 1994.97, 1970.96, 1943.79 and 1922.8 per cm suggested the presence of alkynes (C=C stretch) and allenes (C=C=C stretch) group. A weak peak at 3903.16 and 3856.03 per cm indicated amines (N-H stretch).

FT-IR analysis of the methanol extract of castor leaves

The FT-IR spectrum of the methanol castor leaf extract (Table 5 and Fig. 7) covered the fingerprint region from 3300 – 400 per cm, with characteristic peaks at 3284.71, 2954.29, 2842.93, 2523.14, 2206.71, 2183.4, 2165.41, 2124.25, 2010.78, 1995.13, 1642.8, 1509.01, 1450.24, 1408.18, 1269.35.1111.61, 1014.66, 490.9, 474.97, 455.57, 433.95, 422.89, 414.75 and 402.65 per cm. O -H stretched four firm, broad peaks that indicated carboxylic acids that had absorption of 3284.71, 2954.29, 2842.93 and 2523.14 per cm. Firm peaks at 490.9, 474.97, 455.57, 433.95, 422.89, 414.75 and 402.65 per cm corresponds to the alkyl halides (C-I stretch) group. The medium strong peak at 1509.01, 1450.24, 1408.18, 1269.35, 1111.61 and 1014.66 per cm indicated aromatic compound (C=C stretch) , ethers (=C-O-C sym. and asym. stretch) and alcohols (C-O stretch) . The very weak moderate peak was observed at 2206.71, 2183.4, 2165.41, 2124.25, 2010.78, 1995.13 and 1642.8 per cm were attributed to alkynes (C=C stretch) and allenes (C=C=N stretch) 40.

FT-IR analysis of the acetic acid extract of castor leaves

The absorption spectrum of acetic acid castor leaf extract (Table 6 and Fig. 8), showed twenty-eight peaks at 3856.03, 3352.62, 2220.23, 2165.23, 2110.85, 2027.38, 1994.97, 1970.96, 1943.79, 1922.8, 1697.11, 1639.48, 1423.17, 1370.26, 1237.75, 1141.9, 1093.66, 535.55, 518.24, 495.06, 463.33, 455.57, 445.91, 436.1, 423.31, 411.49 and 402.52 per cm. A strong O-H stretched and C=O stretch at 2220.05 and 1639.48 per cm indicated carboxylic acids and amides. The firm peaks at 1370.26 and 1237.75 per cm were attributed to sulphate (S=O stretching) and nitro compound (N-O sym. and asym. stretch). The strong peak at 518.24, 495.06, 463.33, 455.57, 445.91, 436.1, 423.31, 411.49 and 402.52 per cm was attributed to the alkyl halides (C-Br stretch) and (C-I stretch). A medium-to-strong peak at 1423.17, 1093.66 and 535.55 per cm corresponds to amides (N-H bend) and alcohol (C-O stretch). A weak-to- moderate peak at 2165.23, 2110.85, 2027.38, 1994.97, 1970.96, 1943.79, 1922.8 and 1697.11 per cm reflected alkynes (C=C stretch) and allenes (C=C=C stretch). A weak peak at 3856.03, 3352.62 and 1141.4 per cm indicated amines (N-H stretch) and fluorine compound (S=O stretch).

Discussion

In this study, castor leaf phytoextracts were evaluated for their effects on the mycelial growth of *Fusarium oxysporum* to determine the most effective solvent extract. Different solvents: water, ethanol, acetone, methanol, and acetic acid-were used to extract phytochemicals from castor leaves and tested against *Fusarium* wilt of banana.. At a 10% concentration, the acetic acid extract exhibited the highest inhibition rate of 97.79 %, followed by acetone extract at 13.54 %. Water and methanol extracts showed lower inhibition rates of 11.38 % and 8.50 % respectively. However, ethanol extract demonstrated the least antifungal inhibition rates. The same procedure was followed in the case of 20 % concentration.

Among the tested solvents, acetic acid proved to be the most efficient solvent in suppressing the growth of *fusarium* wilt of bananas compared to other solvents. These observations are supported by the findings of (12), who reported that acetic acid extract of castor leaves showed more activity than other chemical solvents.

FTIR analysis revealed of the extracts revealed the presence of various bioactive compounds, including alkaloids (indicated by N-H stretching) , polyphenols and flavonoids (O-H stretching) and terpenes (C-H group). These results are consistent with previous studies (13), (14) and (15), who identified alkenes, amines, carboxylic acids, amides, esters, alcohols, phenols, ketones, carboxylic acids and aromatic compounds in castor leaf extract. It is noticed that phenolic groups are generally involved in defence against aggression by pathogens. They act as protective agents, inhibitors, natural animal toxicants and pesticides against invading organisms, i.e. nematodes and fungal and bacterial pathogens.

The present study confirms that castor leaf extract contain several phytochemicals including carboxylic acid, alcohols, phenols, amines, amides, esters, ethers, etc., which are known to have remedial activity against disease-producing pathogens.

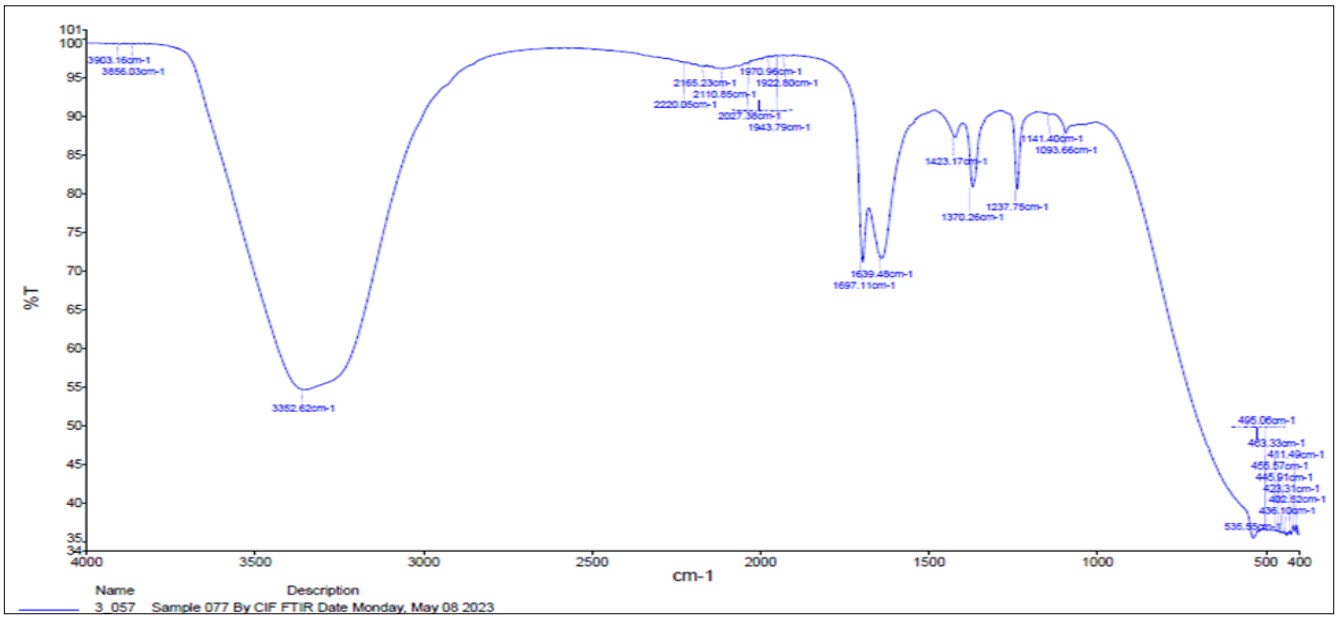

Fig. 6. FTIR spectrum of acetone extract.

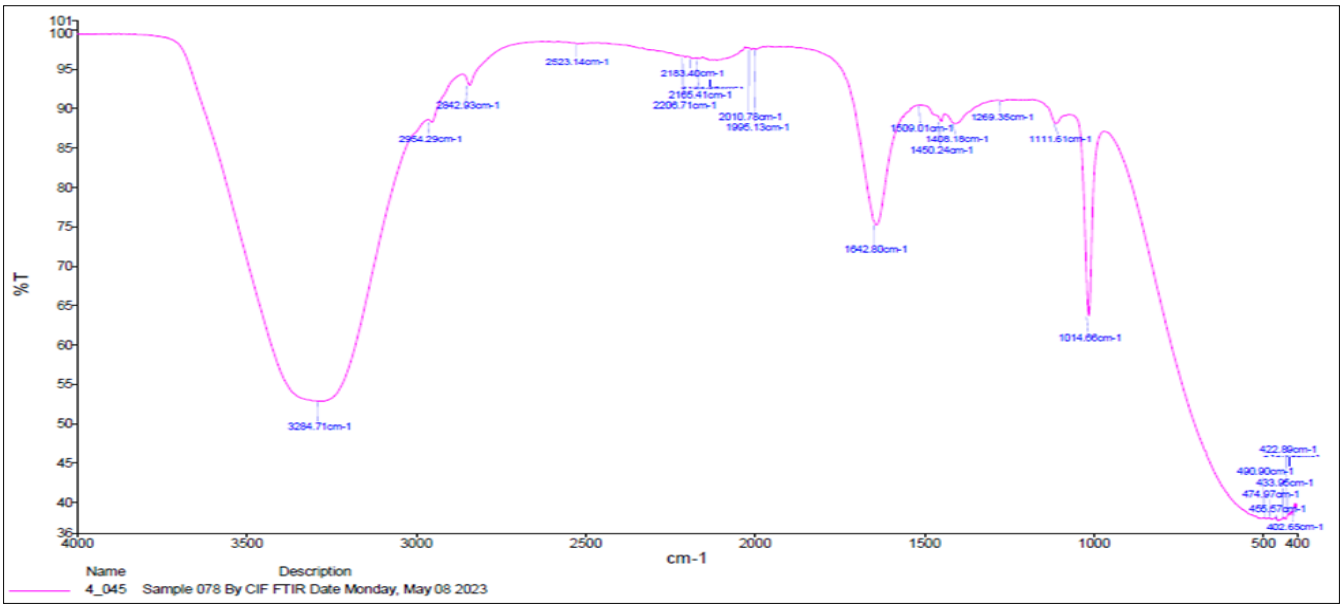

Fig. 7. FTIR spectrum of methanol extract.

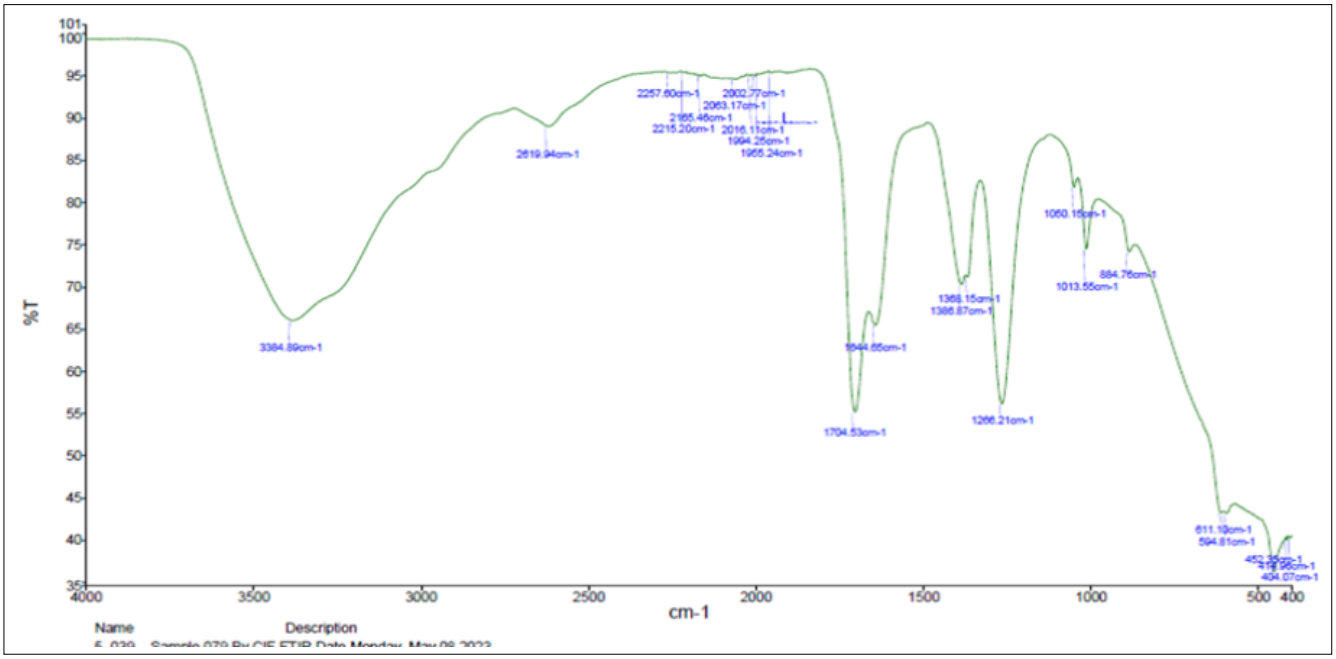

Fig. 8. FTIR spectrum of acetic acid extract.

Conclusion

Fusarium oxysporum is a soil-borne pathogen that is challenging to manage. The use of chemical fungicides, though are effective,has harmful effects on human health and the environment, including soil and groundwater contamination.

Organic alternatives are an excellent approach to manage the disease without affecting human health and the environment to a possible extent. The potential use of castor leaves, particularly prepared using acetic acid at a 10 % concentration, exhibited significant antifungal activity against *fusarium* wilt of banana under *in vitro* conditions. Therefore, plant extract can serve as a viable alternative to synthetic fungicides..

However, to validate the efficacy of these extracts under agricultural conditions, further trials must be conducted in the field. Only after successful field evaluation can such treatments be recommended for widespread use by farmers.

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Authors' contributions

AP carried out the experiments. RRS conceived of the study and participated in its design and coordination. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The author(s) declare that they have no competing interest.

Ethical issues: None

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