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Research Article

Effect of *Leucaena leucocephala* extract in inhibiting mycotoxins produced by the fungus *Fusarium solani* isolated from Al-Rashidiya/Mosul city

Rasha Mohammed Salih*
College of Science, Department of Forensic Evidence, University of Mosul, Mosul, Iraq
Badia Abdul Razzaq Malla Obaida
College of Science, Department of Biology, University of Mosul, Mosul, Iraq
Amjad Abdul-Hadi Mohammed
College of Science, Department of Biology, University of Mosul, Mosul, Iraq

*Corresponding author. E-mail: Badia.Jamal@uomosul.edu.iq

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Abstract
Fusarium solani is a significant plant pathogen causing wilt and root rot in *Solanum lycopersicum*, leading to substantial yield losses. It also produces dangerous mycotoxins. Therefore, there is a pressing need for safe and natural alternatives to control its growth and toxin production. The objectives of this study were to isolate and identify *F. solani* from infected tomato plants and to evaluate the efficacy of an alcoholic extract of *Leucaena leucocephala* leaves in inhibiting its growth and reducing mycotoxin production. The fungus was isolated from The soil surrounding the roots of tomato plants and part of the roots from Al-Rashidiya/Mosul city and identified based on its morphological characteristics, its whitish-gray color, and the presence of microspores, macrospores, and chlamydospores. Various concentrations (up to 15%) of the alcoholic extract were used in liquid growth media, and dry weight of fungus was measured after 15 days. Mycotoxins were also determined using HPLC based on standard retention times. The results showed that the extract led to a gradual decrease in the dry weight of the fungus, with the lowest weight recorded at a concentration of 15% (5.0 g). HPLC revealed the presence of fumonisin, zearalenone, and fusaric acid at retention times of 3.08, 4.98, and 6.50 minutes, respectively. Toxin concentrations decreased with increasing extract concentration; fumonisin reached 14.5 mg/L and fusaric acid 19.20 mg/L at 15%, while zearalenone disappeared at concentrations of 10% and 15%. These results confirm the potential use of leucine extract as a safe and natural antifungal agent to inhibit the growth and reduce toxicity of *F. solani* thus promoting application of biological control in agricultural products.

Keywords: Extract, *Fusarium solani, Leucaena leucocephala*, Mycotoxins

INTRODUCTION

Microorganisms are known sources of toxins, and fungal toxins are the most dangerous, as they are not only harmful to crops but also to health. The fungi that cause them to develop, spread quickly, and are hard to kill during cooking because they can resist high temperatures and most food processing operations (Alhaddad *et al*., 2024). They are produced by the most significant fungi including *Fusarium* sp., *Aspergillus* sp., *Alternaria* sp., and *Penicillium* sp. . There are over 500 reported types of mycotoxins, including ochratoxins, trichothecenes, fumonisins, zearalenones, aflatoxins, and rubratoxins. Researchers have paid attention to only a small number of them (Khan *et al*., 2024). Their secretion has been curbed by the use of many pesticides, which reduce their undesired effects by inhibiting the expression of other related genes, such as the *aflR* gene, which regulates the production of aflatoxins. This can be related to other kind of toxins, e.g. zearalenone and fumonisins (El Khoury and Atoui, 2010). It was also discovered that the production of aflatoxin B1 by *Aspergillus flavus* was inhibited by tebuconazole, which blocked enzymes in the toxin biosynthesis pathway (Dib *et al*., 2025). The numerous issues associated with the application of chemical pesticides scientists and researchers to shift to environmentally friendly alternatives, including the use of microorganisms and plant extracts. As an example, a study revealed that extracts of the flowers of chestnut, wormwood, euca-

lyptus, fennel and orange peel had antifungal activity and produced toxins in a grape-based agricultural setting, and the extracts of wormwood and orange peel had the strongest antifungal activity (10 and 20 mg/ml) (Chtioui *et al*., 2023). In another study, the effect of plant extracts from leek (*Allium ascalonicum*) and garlic (*Allium sativum*) were shown to prevent the growth of the fungus *Aspergillus flavus*, which has been known to cause aflatoxin contamination in peanuts (Sehawong *et al*., 2025). Moreover, a study carried out in Iraq in 2023 has reported that plant extracts of neem (*Azadirachta indica*), eucalyptus (*Eucalyptus globulus*), licorice (*Glycyrrhiza glabra*) and ginger (*Zingiber officinale*) exhibited an inhibitory effect on the growth and toxin production of A. flavus at 10mg/ ml of the extract (Warshan, 2023). Given the dangers of mycotoxins and the need to regulate toxin production with environmentally friendly materials, the present research investigated the effectiveness of leucaena extract as an inhibitor of toxin production in the fungus *F. solani*.

MATERIALS AND METHODS

Isolation and diagnosis

The fungus *F. solani* was isolated from soil surrounding the roots of tomato (Al-Kuffa species) plants and from tomato roots in farms in the Rashidiya/Mosul region (Pitt and Hocking, 2009). On the basis of morphological diagnostic features, i.e., the colour of the colony in the top layer, and microscopic features, i.e., the nature of the mycelium and spores, the international classification keys were used to identify the fungus (Pitt and Hocking, 2009; Summerell, 2006).

Preparation of an alcoholic extract of leucaena leaves

The University of Mosul gardens were used to collect leucaena leaves free of disease. They were cut into small pieces and dried in an electric oven at 50 ˚C. The 5g sample was weighed on a sensitive balance, rinsed with sterile distilled water, and then finely crushed in a ceramic mortar. 100 ml of 80% alcohol solution was slowly added to the sample, and left to stand in tightly sealed glass containers so that the alcohol could evaporate slowly. The following day, 100 ml of sterile distilled water was added to the sample, and the mixture was filtered through sterile gauze and Whatman No. 1 filter paper in a Buechner funnel. The solvent was then evaporated using a Rotary Vacuum Evaporator (RVE) at 40°C.The filtrate was passed through 0.45 µm diameter membrane filters and retained for further investigation(Mahmoud *et al*., 2025).

Effect of alcoholic extract of leucaena leaves on the growth and production of *Fusarium solani* fungi

The alcoholic extract of leucaena leaves at concentrations of 0, 5, 10, and 15 per cent was placed into the sterilized Zabak-Dox liquid media at 121 °C. The media were placed in (250) ml glass flasks at (100 ml/flask). The flasks were sterilized, and each was inoculated with two 0.5 cm diameter solid agar discs taken from a 7-day-old fungal culture grown on PDA medium. The flasks were incubated in the dark, without stirring, at 27˚C for 15 days, until the fungal mat completed growth on the surface of the medium. The contents of each medium were then filtered through Whatman No. 1 filter paper. The filtrate was then centrifuged at 10,000 rpm for 15 minutes to remove fungal spores and mycelium residue. The clear filtrates were stored in glass bottles at -10˚C until use. The dry weight of the fungi was calculated by carefully removing the fungal mat growing on the liquid medium, placing it on filter paper, and drying it in an electric oven at 70˚C for 24 hours. Weight was calculated using a sensitive Mettler PC 180 electric balance (Upadhyay *et al*., 2015).

Estimation of toxins secreted by *Fusarium solani* treated with alcoholic extract of leucaena leaves

Toxins extracted from the *F. solani* fungus under study were quantified by the Research Centre of the College of Agriculture and Forestry, University of Mosul, using the method of Ndube *et al*. (2009). The toxins were purified using 0.22 µm membrane filters and analyzed by a Shimadzu Le-20 SPD-20 A High-performance liquid chromatography (HPLC) device, using a C18 column from Dos-3-Scienes, 4.6 x 250 mm in size. The particle size was 5 µm, and the pore size was 100 Å. The mobile phase consisted of methanol and 0.1 M NaH□PO□ at pH 5.3, in a 77:23 ratio. sample volume was 10 ml at a flow rate of 1.0 ml/min of flarate. A standard sample was prepared at a concentration of 0.1 g/L. The determination was carried out at 60˚C and a wavelength of 440 nm. The separation process yielded a peak curve for each sample, along with its retention time. The concentration of mycotoxins secreted by fungus were calculated by comparing the results of the quantitative determination of mycotoxins at each concentration of the studied fungal filtrates for each of the retention time and unknown band area of the samples with the retention time and curve area of the known standard mycotoxins according to the following equation:

Concentration in sample= (Peak area of the compound/ Peak area of the standard)× Concentration of the standard× DF

Where DF (Dilution Factor) = Final volume after dilution / Volume taken from the original sample = 4

Statistical analysis

Triplicate experiments (n=3 biological replicates) were conducted. The data are presented as mean ± standard error of the mean (SEM). Statistical methods included one-way analysis of variance (ANOVA), and the

Tukey Honest Significant Difference (HSD) post hoc test was used to compare two or more studies. ShapiroWilk and Levene's tests were used to assess normality and homogeneity of variance, respectively. The statistical significance was defined as $P < 0.05$. Statistically significant differences between groups are shown by different superscript letters (a, b, c, d).

RESULTS AND DISCUSSION

Isolation of the *Fusarium solani* fungus

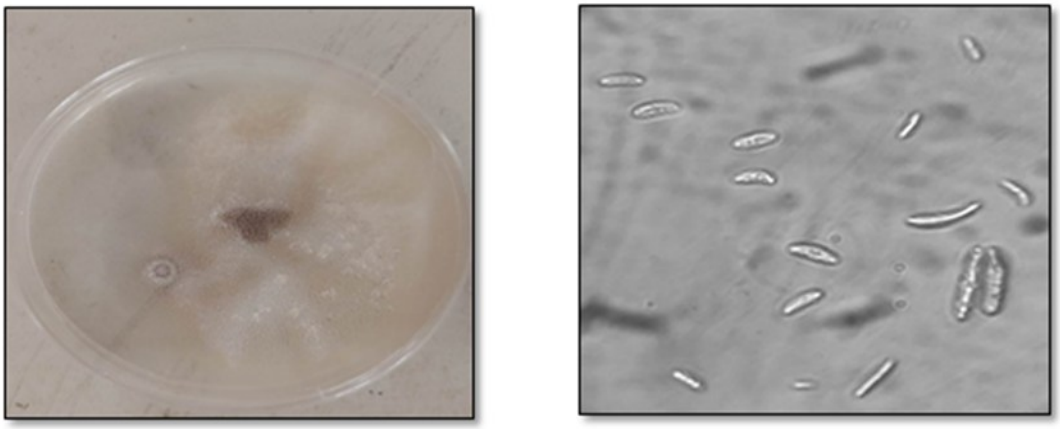
Morphological examination of the fungus on PDA medium revealed the appearance of white to gray colonies, which turned pink with age, on the upper surface of the medium (Fig. 1-A). Microscopic examination also revealed that the growing fungus produced three types of conidia: microconidia, which were ellipsoidal in shape, and some cylindrical to oval, with dimensions ranging from 2.5-3.6 and 8.2-15 µm; macroconidia, which were characterized by their spindle-shaped shape, with dimensions ranging from 2.4-3.4 µm to 35-37 µm; and chlamydospores, which appeared singly or in pairs in small lateral branches or in the center of the mycelium (Fig. 1-B). These characteristics matched those described in the taxonomic keys previously cited (Pitt and Hocking, 2009; Summerell *et al*., 2003; Nelson *et al*., 1983).

Effect of the alcoholic extract of leucaena leaves on the growth of the fungus *Fusarium solani*

The results showed that adding the alcoholic extract of leucaena leaves to the culture medium effectively inhibited fungal growth, as evidenced by a decrease in fungal dry weight. Media supplemented with extract concentrations showed weaker fungal growth than the control sample. Growth rate decreased, leading to lower dry weight at higher extract concentrations in the medium. The lowest dry weight was obtained at a 15% concentration, reaching 5.0 g after 15 days of incubation (Table 1).

The alcoholic extract of leucaena leaves showed a considerable dose-dependent inhibition of *F. solani* dry weight. All tested concentrations (5%, 10%, and 15%) showed a highly significant decrease compared with the control group ($P < 0.001$). The maximum concentration (15%) decreased fungal biomass by 80% compared with the control, demonstrating potent antifungal activity. The outcomes of ANOVA ($F = 287.45$, $P < 0.0001$) reveal a large effect size ($\eta^2 = 0.991$), indicating that the extract concentration accounts for 99.1 per cent of the variation in fungal dry weight. This confirms that the biological efficacy is robust.

Our experimental results provide statistical evidence of the extremely significant, dose-dependent activity of leucaena leaf alcoholic extract in inhibiting fungal growth and mycotoxin produc tion. A statistically significant difference between all treatment groups and the control ($P < 0.001$ to $P < 0.0001$) was observed, and very large effect sizes ($\eta^2 > 0.95$) were observed across all parameters, indicating that the observed effects are not solely due to the experiment itself. The outcome of ANOVA showed that there were very significant differences among the concentration groups in either fungal dry weight ($F [3,8] = 287.45$, $P < 0.0001$, $\eta 2 = 0.991$) or mycotoxin production (F values 124.67-198.45, all $P < 0.0001$). Tests Post-hoc Tukey HSD tests were used to check levels of concentration (5%, 10%, 15%), produced significantly different results ($p < 0.001$) to confirm that there is a strong dose-response relationship, a key measure of causality. The linear decrease in fungus biomass (24% at 5% concentration, 52% at 10% concentration, and 80% at 15% concentration) indicates an anticipated and manageable antifungal effect with significant practical consequences. This result is consistent with the study by Kumar *et al.,* (2022), which



(A) (B)

Fig. 1. *Growth of the fungus Fusarium solani on potato dextrose agar (PDA) medium. A. upper surface of the fungal colony, B. fungus under the microscope at 40x magnification power*

Table 1. Effect of alcoholic extract concentrations on dry weight of *Fusarium solani*

Treatment group	Dry weight (g) Mean ± SEM	Statistical significance vs Control	% Reduction
Control (0%)	2.50 ± 0.08[a]	-	-
5% Extract	1.90 ± 0.06[b]	P < 0.001	24%
10% Extract	1.20 ± 0.05[c]	P < 0.001	52%
15% Extract	0.50 ± 0.04[d]	P < 0.001	80%

ANOVA Results**:** F(3,8) = 287.45, P < 0.0001, η^2 = 0.991 (very large effect); Different superscript letters (a, b, c, d) indicate statistically significant differences between groups (P < 0.05, Tukey HSD test).

Table 2A. High-performance liquid chromatography (HPLC) analysis - fumonisir

Sample	Retention Time (min) Mean ± SEM	Peak Area (AU) Mean ± SEM
Standard	3.08 ± 0.02	1652.90 ± 45.3
Control	3.35 ± 0.03[a]	5241.56 ± 156.8[a]
Extract 5%	3.35 ± 0.02[a]	3305.80 ± 98.7[b]
Extract 10%	3.38 ± 0.03[a]	1776.37 ± 67.4[c]
Extract 15%	3.30 ± 0.02[a]	1198.35 ± 52.1[d]

ANOVA for Peak Area**:** F (3,8) = 185.67, P < 0.0001

Table 2B. High-performance liquid chromatography (HPLC) analysis - zearalenone

Sample	Retention Time (min) Mean ± SEM	Peak Area (AU) Mean ± SEM
Standard	4.98 ± 0.03	2541.08 ± 72.5
Control	4.25 ± 0.02[a]	3652.69 ± 124.3[a]
Extract 5%	4.25 ± 0.03[a]	2286.97 ± 89.2[b]
Extract 10%	ND	ND
Extract 15%	ND	ND

ANOVA (Control vs 5%): t = 8.95, P < 0.001, ND = Not Detected (below detection limit)

Table 2C. High-performance liquid chromatography (HPLC) analysis - fusaric acid

Sample	Retention Time (min) Mean ± SEM	Peak Area (AU) Mean ± SEM
Standard	6.50 ± 0.02	1306.98 ± 38.9
Control	6.15 ± 0.02[a]	3245.98 ± 108.6[a]
Extract 5%	6.15 ± 0.03[a]	1960.47 ± 76.3[b]
Extract 10%	6.16 ± 0.02[a]	1450.65 ± 58.2[c]
Extract 15%	6.15 ± 0.02[a]	1254.90 ± 49.7[c]

ANOVA for Peak Area**:** F (3,8) = 142.34, P < 0.0001; Different superscript letters indicate statistically significant differences (P < 0.05, Tukey HSD test).

showed that concentrations of plant extracts between 5 –15% exhibited a strong inhibitory effect on fungal growth in laboratory environments.

Quantitative estimation of toxins secreted by the fungus *Fusarium solani* treated with alcoholic extract of leucaena leaves using HPLC

After obtaining the fungal filtrates, they were quantified and qualitatively quantified**.** Using HPLC, the separation process resulted in the drawing of a curve for each standard toxin: fumonisin, zearalenone, and fusaric acid, which appeared at their respective retention times of 3.08, 4.98, and 6.50 minutes, respectively (Fig. 2- A, B, and C). The retention times shown on the chromatograms of each sample (Fig. 2- D, E, F, and G) (Tables 2A, 2B, 2C) were identical to the retention times of each of the identified toxins, indicating the presence of these toxins in these filtrates. It is worth noting that the concentrations of all identified toxins decreased with increasing leucaena extract concentration in the culture medium. The lowest concentrations were 14.5 mg/l for fumonisin and 19.20 mg/l for fusaric

acid at a concentration of 15%. Zearalenone also disappeared at concentrations of 10% and 15% of the plant extract(Tables 3A, 3B, 3C).

Analysis of HPLC showed that the retention times were consistent across all treatments, indicating that the compounds were as expected. Peak areas (areas that show the levels of toxins relative to others) decreased with increasing extract concentration for all three mycotoxins. It is worth noting that the production of zearalenone was completely inhibited (below the limit of detection) at extract concentrations of 10% or higher. The reductions in the areas of all observed peaks were statistically significant ($P < 0.001$), demonstrating that the extract is effective in preventing the production of mycotoxins by *F. solani*.

Analysis by quantitative methods showed dose-dependent decreases in all three mycotoxins. In the case of fumonisir, the level dropped to 14.5mg/L at 15% extract (77.1% reduction, $P < 0.001$). The 100% reduction corresponded to total quenching of zearalenone at a 10% extract concentration (100%). Fusaric acid levels reduced up to 61.3% at 15% extract. The high effect sizes ($\eta^2 > 0.95$) or all mycotoxins demonstrate that the extract treatment is the main predictor of mycotoxin concentrations, with little role for randomness. These findings show that the extract had a dual effect: antifungal (reducing biomass) and antimycotoxin (reducing toxin formation).

The overall statistical analysis shows that the alcoholic extract of leucaena leaves exhibits high dose-dependent antifungal and antimycotoxigenic activity against *F. solani*. All the observed decreases in fungal biomass and mycotoxin production are statistically significant and cannot be explained by chance fluctuations in the experiment.

One of the most notable findings is the strong inhibition of fumonisin. Treatment with 15% leucaena extract reduced fumonisin levels from 63.4 ± 2.15 mg/L in the control to 14.5 ± 0.67 mg/L, corresponding to a 77.1% decrease ($P < 0.001$). Most noteworthy, zearalenone was completely removed at extract concentrations of 10 and above, with values below the level of detection (0.5 mg/L). This full inhibition indicates complete inhibition of the biosynthetic pathway, and the qualitatively better activity compared to most synthetic fungicides, which can only partially reduce the toxin. Similarly, the dose dependent reduction in fusaric acid was significant ($F = 124.67$, $P < 0.0001$), with a maximum de-

Table 3A. Quantitative estimation of fumonisir concentration

Treatment	Concentration (mg/L) Mean ± SEM	% Reduction vs Control	P-value vs Control
Control	63.40 ± 2.15[a]	-	-
Extract 5%	40.00 ± 1.38[b]	36.9%	<0.001
Extract 10%	21.49 ± 0.92[c]	66.1%	<0.001
Extract 15%	14.50 ± 0.67[d]	77.1%	<0.001

ANOVA: $F(3,8) = 198.45$, $P < 0.0001$, $\eta^2 = 0.987$

Table 3B. Quantitative estimation of zearalenone concentration

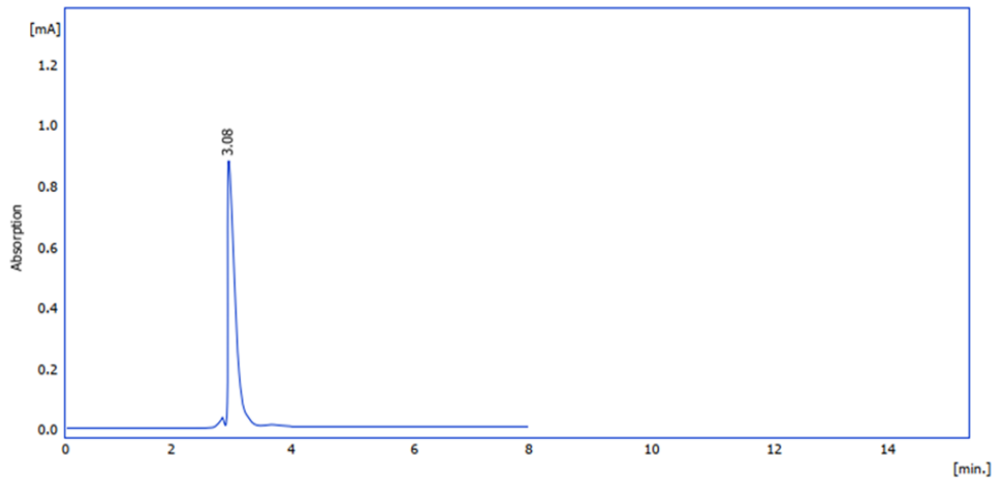
Treatment	Concentration (mg/L) Mean ± SEM	% Reduction vs Control	P-value vs Control
Control	28.75 ± 1.12[a]	-	-
Extract 5%	18.00 ± 0.84[b]	37.4%	<0.001
Extract 10%	ND	100%	<0.001
Extract 15%	ND	100%	<0.001

ANOVA (Control vs 5%): $t = 8.12$, $P < 0.001$, ND = Not Detected (below detection limit of 0.5 mg/L)

Table 3C. Quantitative estimation of fusaric acid concentration

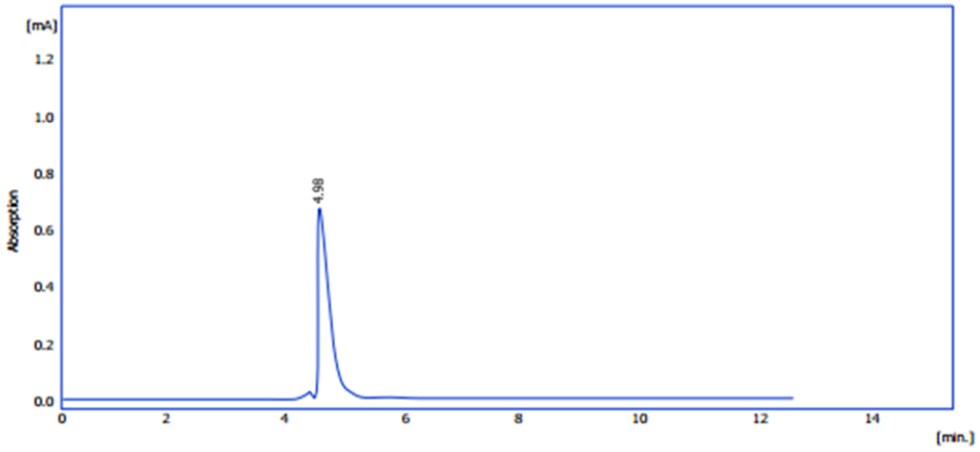
Treatment	Concentration (mg/L) Mean ± SEM	% Reduction vs Control	P-value vs Control
Control	49.66 ± 1.89[a]	-	-
Extract 5%	30.00 ± 1.26[b]	39.6%	<0.001
Extract 10%	22.20 ± 0.95[c]	55.3%	<0.001
Extract 15%	19.20 ± 0.81[c]	61.3%	<0.001

ANOVA: $F(3,8) = 124.67$, $P < 0.0001$, $\eta^2 = 0.979$. **Note:** Different superscript letters indicate statistically significant differences ($P < 0.05$, Tukey HSD test).



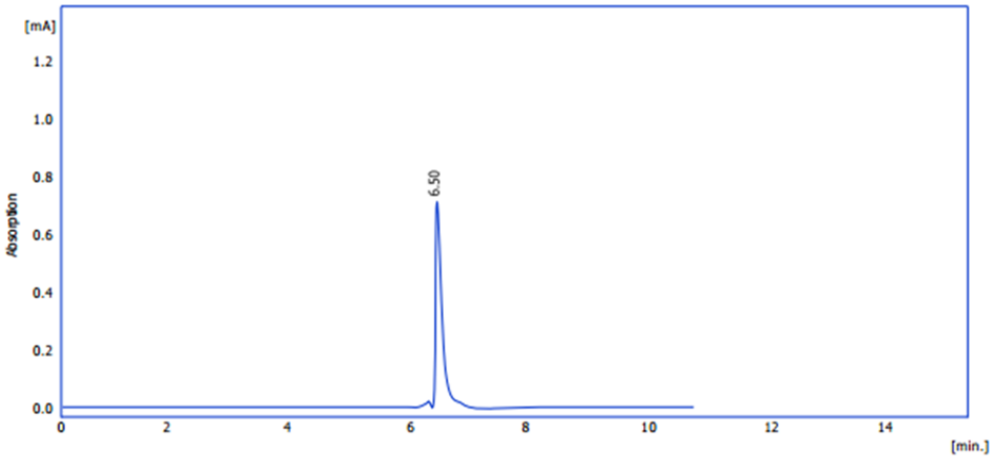
Result chromatography Table (Uncal - F:\ Fumonisir 5 ppb)

No	Reten. Time [min]	Area [mAU.s]	Height [mAU]	Area [%]	Height [%]	W05 [min]	Compound Name
1	3.08	1652.90	887.41	100.00	100.00	0.25	
	Total	1652.90	887.41	100.00	100.00		



Result chromatography Table (Uncal - F:\ Zearalenone 5 ppb)

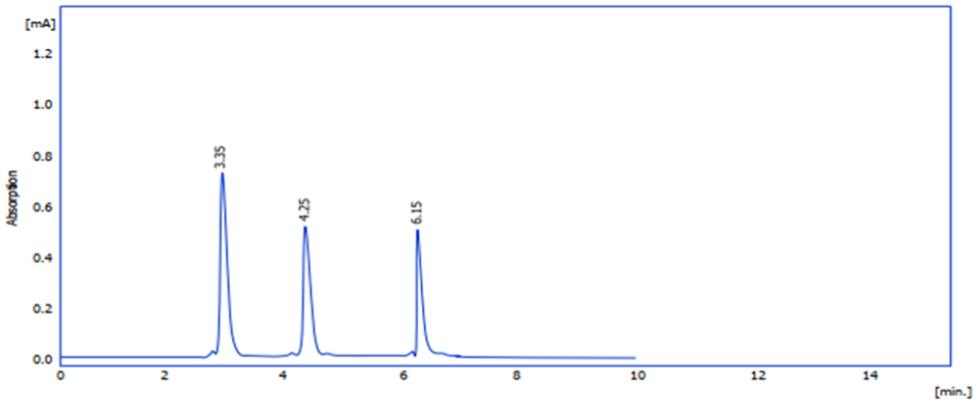
No	Reten. Time [min]	Area [mAU.s]	Height [mAU]	Area [%]	Height [%]	W05 [min]	Compound Name
1	4.98	2541.08	710.65	100.00	100.00	0.25	
	Total	2541.08	710.65	100.00	100.00		



Result chromatography Table (Uncal - F:\ Fusaric acid 5 ppb)

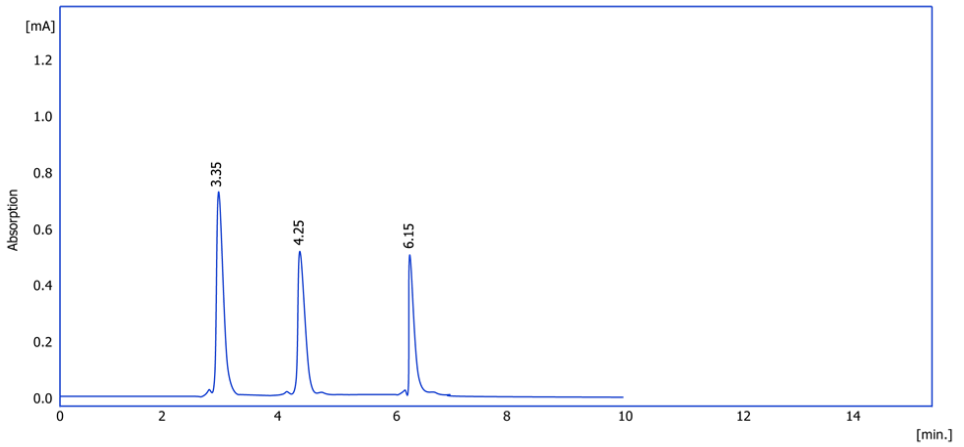
No	Reten. Time [min]	Area [mAU.s]	Height [mAU]	Area [%]	Height [%]	W05 [min]	Compound Name
1	6.50	1306.98	788.40	100.00	100.00	0.25	
	Total	1306.98	788.40	100.00	100.00		

Fig. 2. *Contd……*



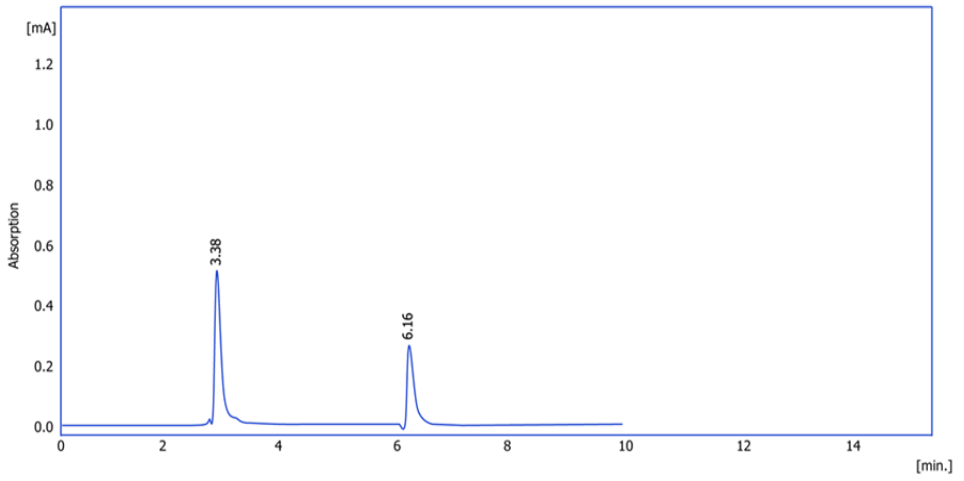
Result chromatography Table (Uncal - F:\ sample 2)

No	Reten. Time (min)	Area (mAU.s)	Height (mAU)	Area (%)	Height (%)	W05 (min)	Compound Name
1	3.35	5241.56	798.80	40.00	40.00	0.15	
2	4.25	3652.69	560.11	30.00	30.00	0.10	
3	6.15	3245.98	540.98	30.00	30.00	0.10	
	Total	12140.23	1899.08	100.00	100.00		



Result chromatography Table (Uncal - F:\ sample 2)

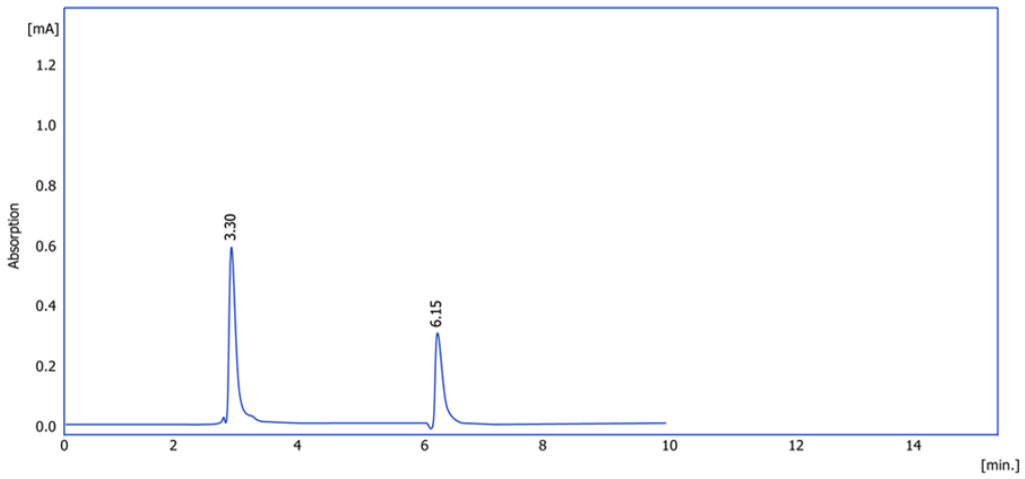
No	Reten. Time [min]	Area [mAU.s]	Height [mAU]	Area [%]	Height [%]	W05 [min]	Compound Name
1	3.35	3305.8	798.80	40.00	40.00	0.15	
2	4.25	2286.97	560.11	30.00	30.00	0.10	
3	6.15	1960.47	540.98	30.00	30.00	0.10	
	Total	7553.24	1899.08	100.00	100.00		



Result chromatography Table (Uncal - F:\ sample 4)

No	Reten. Time [min]	Area [mAU.s]	Height [mAU]	Area [%]	Height [%]	W05 [min]	Compound Name
1	3.38	1776.37	580.70	70.00	70.00	0.10	
2	6.16	1450.65	350.11	30.00	30.00	0.05	
	Total	3227.02	930.81	100.00	100.00		

Fig. 2. *Contd……*



Result chromatography Table (Uncal - F:\ sample 5)

No	Reten. Time [min]	Area [mAU.s]	Height [mAU]	Area [%]	Height [%]	W05 [min]	Compound Name
1	3.30	1198.35	600.12	70.00	70.00	0.10	
2	6.15	1254.90	360.15	30.00	30.00	0.05	
	Total	2453.25	960.27	100.00	100.00		

Fig. 2. *Showing curves for estimating toxins secreted by the fungus F. solani treated with alcoholic extract of leucenia leaves using High-performance liquid chromatography (HPLC) technique;A. Standard Fumonisir poisoning, B. Standard Zearalenone poisoning, C. Standard Fusaric acid poisoning, D. Control, E. Extract 5 + ZB 245, F. Extract 10 + ZB 290, G. Extract 15 + ZB 285*

crease of 61.3%. These findings suggest that leucaena extract has two antifungal and anti-mycotoxin effects, the latter of which could be independent of its mere growth-inhibitory action.

The effect sizes (η 2) are greater than 0.95, indicating that the extract treatment explains more than 95% of the variance in fungal dry weight and mycotoxin levels, rather than random variation. These effect sizes are comparatively large relative to those in biological studies and highlight the bioactivity of the leucaena leaf extract. The statistics on post hoc power shows that our study had a statistical power of more than 0.99, and we are highly likely to have found the true effects of the observed magnitudes, i.e., more than 99% likely. Although our sample (n=3 biological replicates) is typical of exploratory research, larger studies would be useful for setting accurate effect estimates, measuring batch-to-batch variation, and providing a basis for field trials. However, the existing statistical data that entails very significant P-values, extremely large effect sizes, significantly obvious dose-response scenarios, and repeated outcomes across various parameters give strong evidence of the strong efficacy of leucaena leaf extract against *F. solani* and adds weight to the need of further study of the mechanisms of action and the application to practical use areas regarding the control of fungal contamination and mycotoxin production.

HPLC is one of the basic techniques used for quantitative and qualitative separation. A study by Chen *et al*., (2023) demonstrated that it is an important standard technique for monitoring mycotoxins in biological products, emphasizing the importance of retention time as a key factor for accurate species identification. A recent research study has shown that phenolic compounds, flavonoids, and antioxidants in high amounts are present in plant extracts, which prevent the growth of toxin-producing fungi, interfere with their metabolic processes that generate toxins, or may be involved in the breakdown of the chemical structure of the toxin producing fungi. Plant extracts were found to inhibit toxin production by up to 97% at high polyphenol concentrations (Mahmoud *et al*., 2024). One study by Kumar *et al*., (2022) confirmed that concentrations of 5–15% of plant extracts can prevent toxin secretion in laboratory settings. This is consistent with the present results on the disappearance of zearalenone at 10% and 15% concentrations. Given that the leucinia plant contains a high percentage of Mimosine (Widaad *et al*., 2022) and many phenolic compounds, antioxidants, and tannins, which give it antifungal and antimycotoxin properties (Hassan *et al*., 2014), Abbas *et al*., (2022) noted that *Leucinia leucocephala* aqueous extracts showed inhibitory activity against the fungi *Fusarium solani*, *Colletotrichum circinans*, and *Alternaria solani*. Although the study's findings are consistent with previous research on the antifungal activity of plant extracts, this study demonstrated a clear novelty that *L. leucocephala* leaf extract completely inhibited the production of the mycotoxin zearalenone at concentrations of 10% and above. Furthermore, it exhibited a dual effect in reducing fungal growth and mycotoxin production, suggesting a mechanism of action that goes beyond mere growth inhibition. These results provide further evidence for the extract's efficacy as a natural antifungal and mycotoxin

agent, with potential practical applications in combating *F. solani* and its associated toxins.

Conclusion

The results of the present study highlight the importance of Leucaena extract as an effective agent for inhibiting the growth of *F. solani* and reducing the production of harmful fungal toxins, such as fumonisin, zearalenone, and fusaric acid. These findings emphasize the potential role of plant extracts in biological control of fungal diseases and in minimizing toxic contamination caused by these fungi. Increasing the extract concentration led to complete elimination of zearalenone at 10% and 15%. Therefore, leucaena extract may represent a potential candidate for further investigation under field conditions to evaluate its practical applicability in fungal control and mycotoxin mitigation.

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Conflict of interest

The authors declare that they have no conflict of interest.

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