Journal of Underutilised Crops Research
ISSN: (Online) 2958-0994, (Print) 3105-4277

Management of *Alternaria* species diseases on *Cleome gynandra* in Zimbabwe

Check for updates

Authors:
Joyce R. Kaliyati[1,2]
Nyamande Mapope[1]
Walter Manyangarirwa[3]

Affiliations:
[1]Department of Crop Science, Faculty of Plant and Animal Sciences Technology, Marondera University of Agricultural Sciences and Technology, Marondera, Zimbabwe

[2]Department of Science, Zimuto High School, Masvingo, Zimbabwe

[3]Department of Agricultural Sciences, Faculty of Agriculture, Africa University, Mutare, Zimbabwe

Corresponding author:
Joyce Kaliyati,
m200128a@muast.ac.zw

Dates:
Received: 05 Sept. 2025
Accepted: 21 Apr. 2026
Published: 25 May 2026

How to cite this article:
Kaliyati, J.R., Mapope, N. & Manyangarirwa, W., 2026, 'Management of *Alternaria* species diseases on *Cleome gynandra* in Zimbabwe', *Journal of Underutilised Crops Research* 5(1), a42. https://doi.org/10.4102/jucr.v5i1.42

Copyright:
© 2026. The Authors. Licensee: AOSIS. This work is licensed under the Creative Commons Attribution 4.0 International (CC BY 4.0) license (https://creativecommons.org/licenses/by/4.0/).

Read online:
Scan this QR code with your smart phone or mobile device to read online.

Background: Angular leaf spot and blight, caused by fungi of the genus *Alternaria*, known as most destructive diseases affecting *Cleome gynandra*, a potential Indigenous African vegetable, being promoted in Zimbabwe. Information on its disease management is scanty.

Aim: To isolate, evaluate and propose potential management options against the diseases caused by *Alternaria alternata* and *Alternaria senecionicola*, obtained and identified from Marondera University of Agricultural Sciences and Technology, Agro Industrial Park (MUAST AIP) and Premier areas of Zimbabwe.

Setting: Efficacy of fungicides, in a CRD (6*2 factorial experiment), Biological Control Agents (3*2 factorial experiment) and organic agent (2*2 factorial experiment), was evaluated against these species on *C. gynandra*, with three replications.

Methods: Fifteen cm plants under greenhouse conditions at MUAST AIP were inoculated and monitored. Data on incidence and severity were collected every week for 3 weeks.

Results: *A. alternata* and *A. senecionicola* Area Under Disease Progress (AUDPs) and disease incidence were effectively suppressed by all test fungicides (p = 0.02) on days 7–14 and AUDPCs on days 14–21 and had no interactions (p = 0.07). There was interaction between *Alternaria* species and fungicides for % disease incidence for day 7 (p = 0.009), day 14 (p = 0.04) and day 21 (p = 0.04). Biological control using *Trichoderma harzianum* (T77) and *Saccharomyces cerevisiae* was effective in reducing disease severity and incidence. There were no interactions on AUDPCs days 7–14 (p = 0.6), but noted on days 14–21 (p = 0.02). The cattle bile was effective, and it was noted without interactive effects on AUDPCs days 7–14 (p = 0.2) and days 14–21 (p = 0.4). % disease incidences lack interactive effects on day 7 (p = 0.3), and noted on day 14 (p = 0.001). There was no interaction on day 21 (p = 0.08).

Conclusion: Two *Alternaria* species can be managed by fungicides, BCAs and organic agents.

Contribution: Diseases were controlled.

Keywords: fungicides; biological control; agent; organic control; *Alternaria*.

Introduction

Angular leaf spot and blight, caused by fungi of the genus *Alternaria,* are one of the most destructive diseases affecting *Cleome gynandra*, a potential African Indigenous Vegetable crop, being promoted in Zimbabwe. Information about their disease management is scanty. *Alternaria* genus is a fungal genus that has been divided into 24 sections based on molecular and morphological data (Woudenberg et al. 2014), hence more species can be found to cause diseases on *C. gynandra,* which requires more research on their prevalence and management. *Alternaria* species cause leaf spot diseases in many different plant species, and they cause diseases in aerial plant parts (Agrios 2005; Alalade et al. 2017). *Alternaria alternata* produces mycotoxins, which are responsible for causing the leaf spot disease in plants, and diseases in postharvest in crops (Troncos-Rojas & Tiznado-Hernandez 2014) and in humans, causing asthma.

C. gynandra has become a weed of importance with its demand increasing, being used in different areas, including pharmaceuticals, culinary and traditional medicine, besides being a nutritious traditional leafy vegetable. *C. gynandra's* increase in demand has raised interest in working on the diseases that affect its growth, and the need to do commercial production of the plant in provinces of Zimbabwe, a new area of research to ensure its availability and reduce crop loss to diseases. *Alternaria* species has been identified through morphological, physiological and molecular characterisation during research at MUAST AIP Laboratory to identify pathogens that affect *C. gynandra* during the 2021–2022 cropping season in Zimbabwe. Four areas were assessed.

They included three provinces, that is, Mashonaland East Province's Marondera University of Agricultural Sciences and Technology, Dozmery area, Manicaland Province's Premier and Mutanda 2 areas, and Masvingo Province's Zimuto area. Differences in morphology, physiology and biochemical characteristics have shown that *Alternaria* has many species that are pathogenic to *C. gynandra* accessions in Zimbabwe. The effect of the pathogens on *C. gynandra* plants has not been evaluated and controlled, hence this research.

Quality and quantity of feed, food and fibre produced by farmers in the world need to be maintained by controlling plant diseases (Cwalina-Amboziak, Damszel & Glosek-Sobieraj 2015). The use of chemical control methods was very effective in the past 100 years, but due to their residual effect in the environment causing pollution, the methods are being replaced by alternatives that are environmentally friendly, such as biological control (Cwalina-Amboziak et al. 2015; Pal & McSpadden Gardener 2006; Pandit et al. 2022). Biological control agencies (BCA) have been used to manage pathogens that cause diseases on plants, and they are cheaper and environmentally friendly because they are available in the environment (Chandrashekara et al. 2012).

Alternaria species have been considered an important fungal species that is known to cause early blight disease. The management of pathogens that has been done before, where different plant pathogens have been controlled using Integrated Pest Management (IPM) options, has been successful (Kaliyati, Mapope & Manyangarirwa 2023; Razdan, Gupta & Peshin 2009). Diseases associated with *Alternaria* species have been managed effectively with the use of chemicals and biological control agents (Grondona et al. 1997). *Alternaria* leaf spot management has been noted to have low efficacy when using fungicides (Scheufele 2013), hence the need to use different control methods in this research. This research is new in Zimbabwe, and it deployed synthetic fungicides, BCAs and organic control methods to control pathogens affecting *C. gynandra*. The use of BCAs has gained widespread acceptance as an alternative to the use of pesticides and pesticide resistance in the control of pathogens (Loona et al. 2024; Pandit et al. 2022), though there is still much to be done on their interaction with natural and societal functions to ensure their sustainable development and deployment of the approach for its endorsement (Loona et al. 2024). Biological control agents can control pathogens, though they fail to permanently eradicate the pathogen (Chandrashekara et al. 2012; Mahr, Whitaker & Ridgway 2008). There are natural BCAs that survive in the plant and soil environment, which produce antibiotics (Alalade et al. 2017; Pal & McSpadden Gardener 2006). Sudden disease appearance under greenhouse conditions, leaving little or no room for farmers to take control action, leads to only the use of fungicides as a control measure (Scheufele 2013). The use of Metalaxyl in combination with Dithiocarbamates was shown to be an effective combination that can regulate the growth of fungi in plants (Panek, Helmer & Ali 2022). The management of early blight diseases caused by *Alternaria* species has been shown to be low, around 60% – 70% under field conditions (Kaliyati et al. 2023). Acylalanine has been shown *in vitro* to reduce mycelial growth of *A. alternata* when applied at a rate of 2 kg/ha and had an efficacy rate of 49%, while Dithiocarbamate at a rate of 2 kg/ha had 100%. A combination of Mancozeb + carbedazim (0.2%) was used on seed treatment and then foliar application and proved to be most effective in reducing disease intensity (Meena et al. 2022). Terbuconazole, a Triazole fungicide, was also found to be effective in controlling *Alternaria* leaf blight both in *in vitro* and *in vivo* by inhibiting mycelial growth (100%) and conidial germination (90.7%), on Radish plants (Razdan et al. 2009). A combination of terbuconazole and azoxystrobin was found to be effective in controlling Alternaria pori at 0.1%, followed by pyraclostrobin + epoxiconazole at the same rate (Mushrif et al. 2023). Biological control is one of the solutions that are now being researched as an alternative pathogen control (Alalade et al. 2017; Torres et al. 2017). *Trichoderma,* a BCA, has been widely used due to its ability to control pathogen growth and populations in crop production (Pandit et al. 2022). *Trichoderma harzianum* was noted to reduce the incidence and seed infection of *Alternaria* species on *Brassica* seeds, thereby increasing seed emergence and decreasing leaf infections (Scheufele 2013).

The aim of this research was to isolate, evaluate and propose potential management options against the diseases caused by *Alternaria alternata* and *Alternaria senecionicola,* obtained and identified from Marondera University of Agricultural Sciences and Technology, Agro Industrial Park (MUAST AIP) and Premier areas, after a research that was conducted from three provinces of Zimbabwe, that is, Mashonaland East Province, MUAST AIP area, Manicaland Province Premier and Mutanda 2 areas, and Masvingo Province's Zimuto area. This research is new in Zimbabwe.

Research methods and design

Site

These trials were run in a greenhouse in Marondera at MUAST AIP.

Biological material

Fungi used in this research were isolated from three provinces of Zimbabwe during a survey to identify pathogens that affect *C. gynandra*. Mashonaland East Province MUAST AIP, Masvingo Province, Zimuto area, Manicaland Premier area and Mutanda area during the 2020/22 growing season. *In vitro* cultures of *Alternaria alternata* and *Alternaria senecionicola* were done on potato dextrose agar (PDA) and were placed in an incubator for 7 days at 25 °C + –2 °C. The grown fungi were diluted to a concentration of 1×10^{-6} and used to inoculate 6-week-old greenhouse plants at a height of 15 cm.

In vivo experiments

In vitro experiments were conducted to test the efficacy of fungicides, BCAs and organic control agents against fungal

isolates found to be pathogenic to *C. gynandra* accessions. The different concentrations were used to determine the minimum inhibitory concentrations that were later used in *in vivo* experiments under greenhouse conditions to control the effect of *A. alternata* and *A. senecionicola*.

Three trials were conducted in the greenhouse using fungicide concentrations that effectively controlled fungal growth on *C. gynandra in vitro.* The 6*2 factorial experiment was laid out in a CRD, with three replications. The main plot had a chemical being tested, for example, triazole, against a pathogen inoculated on *C. gynandra* plants. 3 m × 1 m plots were used as the main plots with the same fungicide being applied on different isolates, each being replicated three times. The experiments were run in a greenhouse where a double layer of nap liner was used to block each main plot to prevent the drifting of chemicals to other plots.

The first trial was a 6*2 factorial experiment laid out in a CRD, with three replications. The six factors consisted of chemical control agents at rates of 3760 ppm Triazole, 10 000 ppm Acylalanine, 2000 ppm Methyl Benzimidazol Carbamate (MBC), 8520 ppm Dithiocarbamate and 520 ppm Triadimenol, and 3760 ppm Pyraclostrobin+epoxiconazole, as indicated in Table 1, whereas the two factors consisted of the two fungal pathogens, *Alternaria alternata* and *Alternaria senecionicola.* Plants inoculated with the two pathogens at a rate of 1×10^{-6} were sprayed with the fungicide from the day of inoculation. The second trial was a 3*2 factorial (BCAs that included *Trichoderma harzanium* (T77) and *Saccharomyces cerevisiae* that were used at rates of 240 ppm and 11 000 ppm, as indicated in Table 2 and acylalanine control at 10 000 ppm on plants inoculated separately with *A. alternata* and *A. senecionicola*) experiment laid out in a CRD. Plants inoculated with the two pathogens at a rate of 1×10^{-6} were sprayed with the fungicide from the day of inoculation. The third trial was a 2*2 factorial (Cattle bile was used at a rate of 5000 ppm as indicated in Table 3 and Acylalanine control at 10 000 ppm on plants inoculated separately with *A. alternata* and *A. senecionicola*) experiment laid in a CRD. Plants inoculated with the two pathogens at a rate of 1×10^{-6} were sprayed with the fungicide from the day of inoculation.

Data collection

In planta experiment

After inoculation and spraying, data were collected every 7 days for 21 days, with disease incidence and severity scores being recorded for every inoculated plant.

Data analysis

Normality tests were conducted on incidence and severity scores using the Shapiro-Wilk test through SPSS. The data that did not fit normality were Log10(x + 1) transformed (Malato 2023) before subjecting them to analysis of variance using GenStat version 18. Severity data collected were used to calculate Area Under Disease Progress Curve (AUDPC) using Excel formula (day7 + day14)*7/2 for all the weeks, disease incidence data collected were Arc SIN transformed using Excel, and the data were subjected to a two-way analysis of variance using GenStat 18th edition at 5% significance.

Ethical considerations

This article followed all ethical standards for research without direct contact with human or animal subjects.

TABLE 1: Fungicide groups used in *in vivo* experiments.

FRAC group code	Group name	Chemical name	Common name	Dosage
1	Methyl benzimidazol carbamate (MBC)	-	Benomyl	2000 ppm
3	Demethylation inhibitor (DMI): SBI Class 1	Triazole	Terbuconazole	3700 ppm
M03	Dithiocarbamate	Dithiocarbamate	Mancozeb	8520 ppm
M03+ 4	Phenylamide-Acylamide + Dithiocarbamate	Acylalanine	Mancozeb + metalaxyl	10 000 ppm
	Triadimenol	-	Shavit	570 ppm
11	Methoxy-carbamate	Pyraclostrobin + epoxiconazole	Opera	3760 ppm

Source: Adopted from Fungicide Resistance Action Committee (FRAC), 2023, *FRAC Code List, 2023: Fungal control agents sorted by cross-resistance pattern and mode of action (including coding for FRAC Groups on product labels)*, Scribd, pp. 1–18, viewed n.d., from https://www.scribd.com/document/696613793/frac-code-list-2023-final.

FRAC, Fungicide resistance action committee.

TABLE 2: Biological control agents used in *in vivo* experiments.

FRAC group code	Group name	Chemical name	Common name	Dosage
BM02	Biological agent (BAC)	Fungal	*Trichoderma harzanium*	240 ppm
P06, BM02	Biological agent (BCA)	Fungal	*Saccharomyces cerevisiae* (Yeast)	11 000 ppm

Source: Adopted from Fungicide Resistance Action Committee (FRAC), 2023, *FRAC Code List, 2023: Fungal control agents sorted by cross-resistance pattern and mode of action (including coding for FRAC Groups on product labels)*, Scribd, pp. 1–18, viewed n.d., from https://www.scribd.com/document/696613793/frac-code-list-2023-final.

FRAC, Fungicide resistance action committee; BCA, biological control agencies.

TABLE 3: Biopesticide agent used in *in vivo* experiments.

Group code	Chemical ingredient	Group name	Chemical name	Common name	Dosage
NC	Bile salts	Bio pesticide	Organic	Cattle bile	5000 ppm

Source: Adopted from Fungicide Resistance Action Committee (FRAC), 2023, *FRAC Code List, 2023: Fungal control agents sorted by cross-resistance pattern and mode of action (including coding for FRAC Groups on product labels)*, Scribd, pp. 1–18, viewed n.d., from https://www.scribd.com/document/696613793/frac-code-list-2023-final.

FRAC, Fungicide resistance action committee.

Results

Table 4 presents results with AUDPCs and % disease incidence scores that did not fit normality tests, hence were transformed accordingly. On analysis of variance, there was a significant interaction between fungicide and fungal pathogens on AUDPC on day 7–14 interactions $p < 0.02$, while there was no significant interaction on day 14–21 $p = 0.07$. There were significant interactions on % disease incidences for day 7, with $p = 0.009$, day 14, $p = 0.04$, and day 21, $p = 0.04$.

On mean separation, there were significant differences on fungicide action on controlling the pathogens on days 7–14 AUDPCs $p < 0.001$, where Diathiocarbamate and the control were having the highest AUDPC = 7.9 (70% disease severity) against the rest of the fungicides that are not significantly different from each other, where Pyraclostroblin + epoxyconazole and Triazole had AUDPC = 7.1 (10% disease severity) and MBC had AUDPC = 7.2 (15% disease severity), and both Acylalanine (control) and Triademenol had AUDPC = 7.3 (20% disease severity).

Days 14–21, fungicide action was significant, with $p < 0.001$. Pyroclostrobin + epoxiconazole, Triazole and MBC were not significantly different, with AUDPCs of 7.1 (10% disease severity), 7.1 (10% disease severity), and 7.2 (15% disease severity), respectively, whilst both Acylalanine (control) and Triademinol had AUDPCs of 7.5 (35% disease severity) and were not significantly different. Dithiocarbamate and the control had the highest AUDPC of 7.8 (60% disease severity) and 7.9 (70% disease severity), respectively, and they were significantly different from the rest of the fungicides.

On % disease incidences, the fungicides were significantly different, with $p < 0.001$, where Pyraclostrobin + epoxiconazole, Triazole, Acylalanine (control) and Triademinol had 5.7% (0% disease incidence), followed by Diathiocarbamate being equal to 6.3%, which was significantly different, and lastly MBC and the control had the highest incidence of 7.3% (100% disease incidence). On day 14, the % disease incidence was significantly different, with $p < 0.001$, where Pyraclostrobin + epoxiconazole and Triazole were not significantly different from each other, at had 6% and 6.3%, respectively, whilst Triazole, MBC, Acylalanine (control), Triademinol, Dithiocarbamate and control were not significantly different, with % incidences of 6.3%, 7.1%, 7.3%, 7.3%, 6.8% and 7.3%, respectively.

On day 21, there was a significant difference, with $p < 0.001$. Pyraclostrobin+epoxiconazole, Triazole and Dithiocarbamate had the least % disease incidences of 6.3%, 6% and 6.3%, respectively, whilst MBC, Acylalanine (control), Triademenol, and control had no significant difference, with disease incidences of 7.3%, 7.1%, 7.3% and 7.3%, respectively (Figure 1).

Fungal pathogens' response to fungicide treatment was only significant on days 7–14 AUDPCs, with *A. alternat*a being the least, with 7.2 (15% disease severity), and *A. senecionicola* had a higher AUDPC of 7.4 (20% disease severity). % disease incidences were not significant throughout the research period.

Table 5 results had the AUDPCs and disease incidence scores not fitting normality tests, hence were transformed accordingly. On analysis of variance, there were no significant interactions between BCAs and fungal pathogens on AUDPCs days 7–14, with $p = 0.6$ and on days 14–21 $p = 0.2$.

On disease incidences, there was no significance during the research on day 7 $p = 0$, day 14 $p = 0.1$, and day 21, $p = 0.3$. On mean separation there were significant differences on AUDPCs on days 7–14, with $p < 0.001$, where *S. cerevisiae* and Acylalanine control were not significantly different,

TABLE 4: Response on disease severity as area under disease progress curve for chemical control (fungicides) on isolated pathogens on *Cleome gynandra* plants.

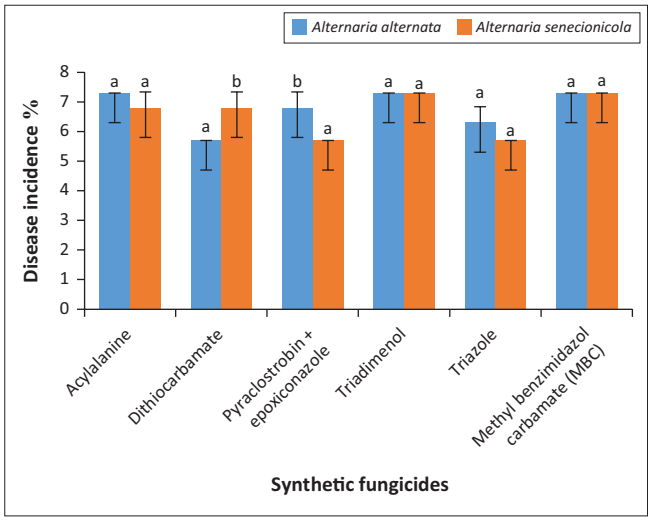
Treatment	AUDPC day 7–14	AUDPC day 14–21	% disease incidence day 7	% disease incidence day 14	% disease incidence day 21
Fungicide					
Pyraclostrobin + epoxiconazole	7.1 (1.8)[a]	7.1 (1.8)[a]	5.7 (0.0)[a]	6 (9.0)[a]	6.3 (16.4)[a]
Triazole	7.1 (1.8)[a]	7.1 (1.8)[a]	5.7 (0.0)[a]	6.3 (16.4)[ab]	6 (9.0)[a]
Methyl benzimidazol carbamate (MBC)	7.2 (3.5)[a]	7.2 (3.5)[a]	7.3 (35.0)[c]	7.1 (29.9)[b]	7.3 (35.0)[b]
Acylalanine (control)	7.3 (7.0)[a]	7.5 (14.0)[b]	5.7 (0.0)[a]	7.3 (35.0)[b]	7.1 (29.9)[b]
Triadimenol	7.3 (7.0)[a]	7.5 (14.0)[b]	5.7 (0.0)[a]	7.3 (35.0)[b]	7.3 (35.0)[b]
Dithiocarbamate	7.9 (22.8)[b]	7.8 (21.0)[c]	6.3 (16.4)[b]	6.8 (23.3)[b]	6.3 (16.4)[a]
Control	7.9 (22.8)[b]	7.9 (22.8)[c]	7.3 (35.0)[c]	7.3 (35.0)[b]	7.3 (35.0)[b]
Chemical *p*-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
LSD chemical	0.2	0.2	0.3	0.6	0.6
Species					
Alternaria alternata	7.2 (3.5)[a]	7.3 (7.0)[a]	6.8 (23.3)[a]	6.7 (22.0)[a]	6.8 (23.3)[a]
Alternaria senecionicola	7.4 (10.5)[b]	7.4 (10.5)[a]	6.8 (23.3)[a]	6.9 (26.6)[a]	6.6 (20.6)[a]
Pathogen *p*-value	0.006	0.070	0.060	0.300	0.300
LSD pathogen	0.1	0.1	0.2	0.4	0.4
Chemical*pathogen (*p*-value)	0.020	0.070	0.009	0.040	0.040
CV%	2.0	2.4	4.4	7.9	8.0
Grand mean	7.3	7.4	6.1	6.8	6.7

Note: Means denoted by same letters are not significantly different at ($p < 0.05$). Log10(x+1) or arcsine transformed means are not in brackets.
AUDPC, area under disease progress curve; LSD, least significant difference; CV, coefficient of variation.

with 7 (0% disease severity) and 7.1 (10% disease severity), respectively, whilst *T. harzianum* (T77) had a higher AUDPC of 7.4 (30% disease severity), followed by the control with 7.9 (70% disease severity).

On days 14–21, there was no significant difference for all the BCAs and the control. On % disease incidence for day 7, 14, and 21, there was no significant difference, with $p = 0$, 0.1 and 0.05, respectively. Fungal pathogen responses on AUDPCs were not significantly different for days 7–14 evaluations, whilst significance was noted on days 14–21, with $p = 0.003$ and *A. alternata* having an AUDPC of 7.1 (10% disease severity), whilst *A. senecionicola* had a higher AUDPC of 7.4 (30% disease severity).

On % disease incidence, there was no significance throughout the research for days 7, 14 and 21, with $p = 0$, 0.1, 0.3, respectively.



Note: Means denoted by the same letters are not significantly different, and means denoted by different letters are significantly different at ($p < 0.05$).

AIP, Agro Industrial Park; MUAST, Marondera University of Agricultural Sciences and Technology.

FIGURE 1: Interactive effect of Synthetic fungicides and *Alternaria* species on disease incidence (%) day 21 at Agro Industrial Park, Marondera University of Agricultural Sciences and Technology 2023.

From Table 6, the AUDPCs and % disease incidence scores did not fit normality tests, hence were transformed accordingly. On analysis of variance, there were no significant interactions between organic control and fungal pathogens on AUDPCs days 7–14, with $p = 0.2$ and days 14–21 $p = 0.4$.

On disease incidences, there was no significance during the research on day 7 $p = 0.3$, and there was significance on day 14 $p = 0.001$, and no significance on day 21, $p = 0.08$. On mean separation, there were no significant differences on AUDPCs on days 7–14, with $p = 0.4$. On days 14–21, there was no significant difference $p = 0.05$. On % disease incidence for days 7, 14 and 21, there was no significant difference, with $p = 0.3$, 0.3 and 0.08, respectively.

Fungal pathogen responses on AUDPCs were not significantly different for days 7–14 and 14–21 evaluations, with $p = 0.4$ and 0.7. On % disease incidence, there was no significance throughout the research for days 7, 14 and 21, with $p = 0.3$, 0.3, 0.08, respectively.

Discussion

Alternaria species has been considered an important fungal species that is known to cause early blight disease (He et al. 2021). The control of pathogens that has been done before involved different plant pathogens that have been controlled using IPM options, and the control has been successful (He et al. 2021). This was observed to complement the results obtained during this research, where the trials (fungicide, BCAs, and organic) were successful in controlling the isolates on *C. gynandra*. Observations made during this research have shown that chemical treatments were able to control the two pathogens from the two provinces of Zimbabwe. *Alternaria alternata* and *Alternaria senecionicola*, which have been found to affect *C. gynandra* were successfully controlled by Triazole, Triademinol, Pyraclostrobin+epoxiconazole, and MBC. Acylalanine was able to control the pathogen establishment on the *C. gynandra* plants by keeping disease severity low, below

TABLE 5: Response to disease severity as area under disease progress curve for Biological Control Agents against a chemical control on isolated pathogens on *Cleome gynandra* plants.

Treatment	AUDPC day 7–14	AUDPC day 14–21	% disease incidence day 7	% disease incidence day 14	% disease incidence day 21
BCAs					
Saccharomyces cerevisiae	7 (0.0)[a]	7 (0.0)[a]	5.7 (0.0)[a]	6.3 (16.4)[a]	5.7 (0.0)[a]
Acylalanine (control)	7.1 (1.8)[a]	7.2 (3.5)[a]	5.7 (0.0)[a]	6.5 (19.2)[a]	6.3 (16.4)[a]
Trichoderma harzianum (T77)	7.4 (10.5)[b]	7.5 (14.0)[a]	6.5 (19.2)[a]	7.1 (29.9)[a]	6.8 (23.3)[a]
Control	7.9 (22.8)[b]	7.9 (22.8)[a]	7.3 (35.0)[a]	7.3 (35.0)[a]	7.3 (35.0)[a]
p-value chemical	< 0.001	0.100	0.000	0.100	0.050
LSD chemical	0.1	0.3	0.0	0.7	0.7
Species					
Alternaria alternate	7.2 (3.5)[a]	7.1 (1.8)[a]	6.3 (16.4)[a]	6.3 (16.4)[a]	6.1 (12.0)[a]
Alternaria senecionicola	7.2 (3.5)[a]	7.4 (10.5)[b]	5.7 (0.0)[a]	7.1 (29.9)[b]	6.5 (19.2)[a]
Pathogen *p*-value	0.200	0.003	0.000	0.100	0.300
LSD Pathogen	0.1	0.2	0.0	0.7	0.7
Chemical*Pathogen (*p*-value)	0.600	0.200	0.000	0.100	0.300
CV%	1.6	2.8	0.0	9.9	10.4
Grand mean	7.2	7.3	6.0	6.6	6.3

Note: Means denoted by same letters are not significantly different at ($p < 0.05$). Log10(x+1) or arcsine transformed means are not in brackets.

AUDPC, area under disease progress curve; BCA, Biological control agencies; LSD, least significant difference; CV, coefficient of variation.

TABLE 6: Response to disease severity as area under the disease progress curve for cattle bile against a chemical control on isolated pathogens on *Cleome gynandra* plants.

Treatment	AUDPC day 7–14	AUDPC day 14–21	% disease incidence day 7	% disease incidence day 14	% disease incidence day 21
Organic control agents					
Acylalanine (control)	7.3 (7.0)[a]	7.5 (14.0)[a]	5.7 (0.0)[a]	6.5 (19.5)[a]	6.3 (16.4)[a]
Cattle bile	7.2 (3.5)[a]	7.2 (3.5)[a]	6 (9.0)[a]	6.8 (23.3)[a]	5.7 (0.0)[a]
Control	7.9 (22.8)[a]	7.9 (22.8)[a]	7.3 (35.0)[a]	7.3 (35.0)[a]	7.3 (35.0)[a]
p-value chemical	0.40	0.05	0.30	0.30	0.08
LSD chemical	0.3	0.3	0.6	0.6	0.6
Species					
Alternaria alternate	7.3 (7.0)[a]	7.4 (10.5)[a]	6 (9.0)[a]	6.5 (19.2)[a]	5.7 (0.0)[a]
Alternaria senecionicola	7.2 (3.5)[a]	7.3 (7.0)[a]	5.7 (0.0)[a]	6.8 (23.3)[a]	6.3 (16.4)[a]
Pathogen *p*-value	0.400	0.700	0.300	0.300	0.080
LSD pathogen	0.3	0.3	0.6	0.6	0.6
Chemical*pathogen (*p*-value)	0.200	0.400	0.300	0.001	0.080
CV%	2.8	3.3	7.9	6.9	7.7
Grand mean	7.2	7.3	5.9	6.7	6.0

Note: Means denoted by same letters are not significantly different at ($p < 0.05$). Log10(x+1) or arcsine transformed means are not in brackets.
AUDPC, area under disease progress curve; LSD, least significant difference; CV, coefficient of variation.

30%. Dithiocarbamate was used and was found not to be very effective, having a disease severity of 80%. Triazole, Triademinol, Pyroclostrobin+epoxiconazole, MBC are the most effective in the control of *Alternaria alternata* by keeping the pathogen below 10% of the disease severity. In another research, a combination of terbuconazole and azoxystrobin was found to be effective in controlling *Alternaria* pori at 0.1%, followed by pyraclostrobin + epoxiconazole at the same rate (Mushrif et al. 2023). Terbuconazole, a triazole fungicide, was also found to be effective in controlling *Alternaria* leaf blight both in *in vitro* and *in vivo* by inhibiting mycelial growth (100%) and conidial germination (90.7%) (Razdan et al. 2009), which approves the results found in this research. The use of metalaxyl in combination with Dithiocarbamates was shown to be an effective combination that can regulate the growth of fungi in plants (Panek et al. 2022). In this research, Acylalanine is a combination of Phenylamide-Acylamide + Dithiocarbamate, which is traded as Mancozeb and Metalaxyl. The management of early blight diseases caused by *Alternaria* species has been shown to be low, around 60% – 70% under field conditions (He et al. 2021). In this study, Acylalanine had a similar suppressive ability of the two species of the *C. gynandra* plants. Similarly, Acylalanine, which has been shown to reduce mycelial growth of *A. alternata* when applied at a rate of 2 kg/ha, had an efficacy rate of 49%, while Dithiocarbamate at a rate of 2 kg/ha had 100% effectiveness, yet in this research it was observed that both treatments that were managed under Acylalanine and Dithiocarbamate had some instances where there was total eradication and in some it was not complete. Observations of unsatisfactory fungicide efficacy are attributed to application of less efficient products, their late application and maybe composition of *Alternaria* populations in different regions (He et al. 2021).

Dithiocarbamate is a protectant fungicide which prevents the establishment of the pathogen under natural conditions. In this research, it has proved to be ineffective since the application of the fungicide and inoculation were done at the same time. Therefore, the fungi were able to successfully establish on the *C. gynandra* plants.

Application of *Trichoderma harzianum* (T77) and *Saccharomyces cerevisiae* may have suppressed disease incidence and AUDPCs through antagonistic and exclusion means (Grondona et al. 1997). *T. harzianum* and *S. cerevicae* were noted to control *A. alternata* as a biological control on lemon fruits as a pathogen of post-harvest rot (Troncos-Rojas & Tiznado-Hernandez 2014). The effect of different species of *T. harzianum* proved to be very effective in the management of the targeted fungi (He et al. 2021). *Trichoderma harzianum* was noted to reduce the incidence and seed infection of *Alternaria* species on *Brassica* seeds, thereby increasing seed emergence and decreasing leaf infections (Scheufele 2013). This agrees with the results obtained in this research, where the targeted fungal pathogens have been controlled by *T. harzianum* (T77), as it has antagonistic action and exclusion on the growth of the fungi.

Organic control success was found in the use of cattle bile, which inhibited the growth of the *Alternaria* species. Organic control using cattle bile has been effective in the control of the *Alternaria* species, as it has been observed to have been without significant difference to the effect of Acylalanine, a fungicide which is well known to be effective in the management of the *Alternaria* species (Kaliyati et al. 2023) throughout the evaluation period.

Conclusion

In this new research conducted in Zimbabwe, *Alternaria alternata* and *Alternaria senecionicola*, which have been found to affect *C. gynandra,* were successfully controlled by Triazole, Acylalanine, Triademinol, Pyraclostrobin+epoxiconazole, and MBC, which were significantly superior in controlling the pathogens, followed by Dithiocarbamate. Biological control was successful with the use of *Trichoderma harzanium* (T77) and *Saccharomyces cerevisiae,* and they were found to be competitive as the control Acylalanine in their performance. Organic control success was found in the use of cattle bile, which was significant as acylalanine, which was used as the control during the research. Integrated pest management will be beneficial in the control of pathogens to reduce resistance due to the continual use of chemical fungicides. *C. gynandra*

production will be managed at least with the control of pathogens to ensure success in the expected yield. Research should be ongoing to establish the presence of more different *Alternaria* species and more control treatments that can manage the current pathogens and many more in the production of *C. gynandra*.

Acknowledgements

I acknowledge the funding I received from the Government of Zimbabwe through the Ministry of Higher and Tertiary Education to conduct my research to fulfil my PhD studies at the Marondera University of Agricultural Sciences and Technology.

This article is based on research originally conducted as part of Joyce R. Kaliyati's doctoral thesis titled 'Fungal disease management in Cleome gynandra', submitted to the Department of Crop Science, Faculty of Plant and Animal Sciences Technology, Marondera University of Agricultural Sciences and Technology in 2026. The thesis is currently unpublished and not publicly available. The thesis was supervised by Nyamande Mapope and Walter Manyangarirwa. The thesis was reworked, revised and adapted into a journal article for publication. The author confirms that the content has not been previously published or disseminated and complies with ethical standards for original publication.

This article is based on data from a larger study. Another article was published from the same thesis. The article focuses on A review of Disease Management in *Cleome gynandra, which* has been published in the *International Journal of Innovative Science and Research Technology*, Volume 8, Issue 7. This article is accessible here: https://doi.org/10.5281/zenodo.8304414

Competing interests

The author reported that they received funding from the Ministry of Higher and Tertiary Education, Innovation, Science and Technology Development, Zimbabwe, which may be affected by the research reported in the enclosed publication. The author has disclosed those interests fully and has implemented an approved plan for managing any potential conflicts arising from their involvement. The terms of these funding arrangements have been reviewed and approved by the affiliated University in accordance with its policy on objectivity in research.

CRediT authorship contribution

Joyce R. Kaliyati: Conceptualisation, Methodology, Formal analysis, Investigation, Writing – original draft, Visualisation, Project administration, Software, Data curation, Resources, Writing – review & editing, Funding acquisition. Nyamande Mapope: Formal analysis, Writing – original draft, Visualisation, Project administration, Writing – review & editing, Supervision. Walter Manyangarirwa: Formal analysis, Visualisation, Project administration, Software, Writing – review & editing, Supervision. All authors reviewed the article, contributed to the discussion of results, approved the final version for submission and publication, and take responsibility for the integrity of its findings.

Funding information

The research was funded by the Ministry of Higher and Tertiary Education, Innovation, Science and Technology Development, Zimbabwe, under grant Ref: AIV/2020/03.

Data availability

The authors confirm that the data supporting the findings of this study are available within the article.

Disclaimer

The views and opinions expressed in this article are those of the authors and are the product of professional research. They do not necessarily reflect the official policy or position of any affiliated institution, funder, agency, or that of the publisher. The authors are responsible for this article's results, findings, and content.

References

Agrios, G., 2005, *Plant pathology*, 5th edn., Elsevier Inc, Oxford.

Alalade, O.A., Matanmi, B., Olaoye, I., Adegoke, B. & Olaitan, T., 2017, 'Assessment of pests control methods and its perceived effect on agricultural production among famers in Kwara State, Nigeria', *Agro-Science* 16(1), 42–47. https://doi.org/10.4314/as.v16i1.8

Chandrashekara, K.N., Manivannan, S., Chandrashekara, C. & Chakaravarthi, M., 2012, 'Biological control of plant diseases', in *Eco-friendly innovative approaches in plant disease management*, pp. 148–167, viewed 22 October 2023, from, https://www.researchgate.net/publication/233119112

Cwalina-Amboziak, B., Damszel, M.M. & Glosek-Sobieraj, M., 2015, 'The effect of biological and chemical control agents on the health status of the very early potato cultivar Rosara', *Journal of Plant Protection Research* 55(4), 389–395. https://doi.org/10.1515/jppr-2015-0052

Fungicide Resistance Action Committee (FRAC), 2023, *FRAC Code List, 2023: Fungal control agents sorted by cross-resistance pattern and mode of action (including coding for FRAC Groups on product labels)*, Scribd, pp. 1–18, viewed n.d., from https://www.scribd.com/document/696613793/frac-code-list-2023-final.

Grondona, I., Hermosa, R., Tejada, M., Gomis, M.D., Mateos, P.F., Bridge, P.D. et al., 1997, 'Physiological and biochemical characterization of trichoderma harzianum, a biological control agent against soilborne fungal plant pathogens', *Applied and Environmental Microbiology* 63(8), 3189–3198. https://doi.org/10.1128/aem.63.8.3189-3198.1997

He, D.-C., He, M.-H., Amalin, D.M., Liu, W., Alvindia, D.G. & Zhan, J., 2021, 'Biological control of plant diseases: An evolutionary and eco-economic consideration', *Pathogens* 10(10), 1311. https://doi.org/10.3390/pathogens10101311

Kaliyati, J.R., Mapope, N. & Manyangarirwa, W., 2023, 'Disease management in cleome gynandra: A review', *International Journal of Innovative Science and Research Technology* 8(7), 3307–3313. https://doi.org/10.5281/zenodo.8304414

Kapsa, J., 2009, 'Effectiveness of some fungicides in control of *Alternaria alternata* and *Alternaria solani*', *Eleventh Euroblight workshop Hamar (Norway)* 13, 127–134.

Loona, D., Singh, R., Chittaragi, A. & Patil, B., 2024, '*In-vitro* and field evaluation of foliar fungicides for the management of Alternaria leaf blight in Radish (*Raphanus sativus* L.)', *Crop protection* 187(2), 1006967. https://doi.org/10.1016/j.cropro.2024.106967

Mahr, D.L., Whitaker, P. & Ridgway, N., 2008, 'Biological control of insects and mites: An introduction to beneficial natural enemies and their use in pest management', *Biological Control of Insects and Mites*, pp. 1–60, University of Wisconsin–Extension, Madison, WI.

Malato, G., 2023, *An introduction to the Shapiro-Wilk test for normality*, Built In Data Science, Chicago, viewed n.d., from https://builtin.com/data-science/shapiro-wilk-test.

Meena, S., Gobika, S., Ghasolia, R.P., Sumitra, Nitharwal, N. & Kardam, V.K., 2022, 'Management of Alternaria blight disease (*Alternaria brassicae*) of mustard through plant extracts and fungicides', *The Pharma Innovation Journal* 11(1), 58–67, viewed n.d., from https://www.thepharmajournal.com/archives/2022/vol11issue1/PartA/11-1-331-372.pdf.

Mushrif, S., Venkat, D., Reddy, M. & Sood, M., 2023, 'Bio efficacy of fungicides against *Alternaria porri* causing the purple blotch disease of onion', *Biological Forum – An International Journal* 15(9), 623–630.

Pal, K.K. & McSpadden Gardener, B., 2006, 'Biological control of plant pathogens', *The Plant Health Instructor.* https://doi.org/10.1094/PHI-A-2006-1117-02

Pandit, M.A., Kumar, J., Gulati, S., Bhandari, N., Mehta, P., Katyal, R. et al., 2022, 'Major biological control strategies for plant pathogens', *Pathogens* 11(2), 273. https://doi.org/10.3390/pathogens11020273

Panek, M., Helmer, Š. & Ali, A., 2022, 'Use of metalaxyl against some soil plant pathogens of the class Peronosporomycetes – A review and two case studies', *Plant Protection Science* 58(2), 92–109. https://doi.org/10.17221/42/2021-PPS

Razdan, V.K., Gupta, S.R. & Peshin, A.K., 2009, 'Integrated disease management: Concepts and practices', in A.K. Dhawan (ed.), *Integrated pest management: Innovation-development process*, pp. 369–370, Chapter 15, Springer Science + Business Media B.V. https://doi.org/10.1007/978-1-4020-8992-3_15

Scheufele, S.B., 2013, 'Alternaria leaf spot of brassica crops: Disease incidence and sustainable management', MSc thesis, Cornell University.

Torres, D.E., Rojas-Martínez, R.I., Zavaleta-Mejía, E., Guevara-Fefer, P., Márquez-Guzmán, G.J. & Pérez-Martínez, C., 2017, 'Cladosporium cladosporioides and Cladosporium pseudocladosporioides as potential new fungal antagonists of Puccinia horiana Henn., the causal agent of chrysanthemum white rust', *PLoS One* 12(1), e0170782. https://doi.org/10.1371/journal.pone.0170782

Troncoso-Rojas, R. & Tiznado-Hernández, M.E., 2014, 'Alternaria alternata (Black rot, black spot)', in S. Bautista-Baños (ed.), *Postharvest decay: Control strategies*, pp. 147–187, Academic Press, San Diego, CA.

Woudenberg, J.H.C., Truter, M., Greenewald, J.Z. & Gous, P.W., 2014, 'Large-Spored Alternaria pathogens in section porri disentangled', *Studies in Mycology* 79(1), 1–47. https://doi.org/10.1016/j.simyco.2014.07.003