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Research Article

Evaluation of Chemical Fungicides for Managing Chili Anthracnose Disease Caused by *Colletotrichum capsici*

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ABSTRACT

Chili anthracnose, caused by *Colletotrichum capsici*, is a major disease affecting chili production in Punjab, Pakistan, leading to significant yield losses. This study aimed to isolate and identify the pathogen and evaluate the efficacy of six fungicides at different concentrations (200, 400, 600 ppm) under *in-vitro, in vivo*, and field conditions. Pathogen isolation and pathogenicity were confirmed through morphological characterization and Koch's postulates. Fungicide evaluation revealed that Topsin M (thiophanate-methyl 70% w/w) was the most effective, reducing fungal growth to 5.05 mm in vitro and lesion sizes to 10.8 mm and 8.2 mm under greenhouse and field conditions, respectively, at 600 ppm. Fossil (mancozeb 50% w/w) followed closely in efficacy. Other fungicides showed moderate to low disease suppression. Disease severity increased over time, but Topsin M consistently maintained superior control. These findings underscore the potential of Topsin M as a key component in anthracnose management, while highlighting the need for integrated strategies combining chemical, resistant varieties, and biological controls for sustainable disease suppression. This research contributes valuable data for optimizing fungicide use and minimizing economic losses in chili production.

Keywords: Chemical control, *Colletotrichum capsici*, chili anthracnose, fungicide efficacy, integrated disease management.

INTRODUCTION

Chili, a valuable crop in the genus *Capsicum*, includes several cultivated species, with *Capsicum annuum* L. being the most widely farmed, producing both sweet (bell pepper) and spicy varieties (Kiran et al., 2020). Other domesticated species include *C. pubescens, C. frutescens,* and *C. baccatum.* Originating from tropical America, chili is among the oldest domesticated crops (Yang et al., 2018). Global chili production covers approximately 1.5 million hectares, yielding around 7 million tonnes annually. Pakistan produces 2 million tonnes, contributing 7.2% of global chili production, compared to China (4 million tonnes) and Mexico (3 million tonnes). India leads with 25% of production and exports. In Pakistan, red chili production reached 143.1 thousand tonnes from 64.2 thousand hectares, with an average yield of 1.7 tonnes per acre, accounting for 1.5% of the country's GDP. Sindh province is a major chili production hub, producing about 85% of Pakistan's red chili on 38.4 thousand hectares, yielding 53.7 thousand tonnes (Arin, 2019).

Chili peppers are rich in essential minerals, vitamins (A, B, B5, C, E), amino acids, and phytochemicals such as phenolics and flavonoids, which act as potent antioxidants preventing degenerative diseases. Green chili contains higher vitamin C levels than citrus fruits (Kiran et al., 2020) and also provides potassium, magnesium, iron, calcium, phosphorus, and antioxidants that support the immune system and reduce cholesterol, thus protecting against cancer and cardiovascular diseases. Nutritionally, chili contains per 100 g: 15.00 g protein, 6.25 g fat, 6.16 g minerals, 30.20 g fiber, and 31.64 g carbohydrates (Khan et al., 2019).

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Chili is a key ingredient in subtropical and tropical cuisines, commonly used in curries, pickles, salads, stuffings, and as a seasoning (Saxena et al., 2016). However, chili plants are susceptible to fungal, bacterial, and viral infections, causing 10–80% crop losses worldwide (Kiran et al., 2020). Infections spread through seeds, soil, water, and air, affecting aerial parts and mainly causing fruit rot in green and red stages, known as "chili ripe fruit rot" (Saxena et al., 2016). Chili anthracnose caused by *Colletotrichum capsici* is one of a critical disease that significantly reduces fruit yield, quality, and marketability, causing substantial economic losses in chili production worldwide.

The infection starts with conidia adhering to the host surface, followed by germination, appressoria formation, and penetration into the host epidermis, leading to fungal growth, colonization, and acervuli formation for spore spread (Oo et al., 2017). The pathogen can remain dormant in unripe fruit tissues and becomes active when fruits mature; a dendroid structure from the appressorium penetrates the host cuticle during infection (Suwannarat et al., 2017). Symptoms include concentric acervuli rings, sunken necrotic tissue, dark spots, stem dieback, damping off, seedling blight, and leaf spot. Infection reduces fruit dry weight, capsaicin, oleoresin content, and overall fruit quality (Kiran et al., 2020). Disease severity is influenced by leaf surface moisture, light, humidity, rainfall, crop geometry, inoculum dispersion, with optimum conditions around 27℃ and 80% relative humidity (Retnaningdyah et al., 2019).

Management strategies include chemical control, plant extracts, and resistant cultivars, with resistant/tolerant cultivars preferred. Varieties AVPP1004-B, AVPP0719, AVPP1102-B, AVPP027, AVPP0513 show good yield and anthracnose tolerance (Kiran et al., 2020). Additional resistant varieties include BS-28, Bhut jolokia, Punjab Lal, BS-20, BS-35 Lankamura Collection, Taiwan-2, Part C-1, and IC-383072 useful for breeding (Bhusnure et al., 2018).

Chemical fungicides such as copper compounds, dithiocarbonates, benzimidazole, and triazole are commonly recommended (Prommaa and Termsaithong, 2021). New strobilurin-based fungicides (azoxystrobin, pyraclostrobin) have shown limited large-field trial data (Saini et al., 2020). Controlling chili anthracnose is a real challenge for producers. Many control strategies have been developed and applied. Extensive research has been conducted on management techniques for *C. capsici* induced disease. However, the availability of effective commercial control treatments for anthracnose diseases remains highly limited. This present study aimed to isolate chili anthracnose associate pathogen found in Faisalabad and to test some new chemicals for the disease control.

MATERIAL AND METHODS

Survey

A systematic survey was conducted for collection of leaves samples showing typical disease symptoms from the field of Institute of Horticultural Sciences (IHS). Diseased samples were put in brown paper bags and brought to the laboratory for isolation and stored in the refrigerator at 4°C until further processing.

Isolation and purification and multiplication of the pathogen

Firstly, a sterilized beaker with a capacity of 1 liter was taken and 18 g of Potato Dextrose Agar (PDA) and 500 ml of distilled water were added in it and autoclaved the media at 121°C and 15 psi for 15 min using autoclave (Riaz et al., 2008). The media were then carefully poured into sterilized petri plates in a laminar flow chamber and placed for 15 min for solidification. Infected diseased portion was carefully cut with a small healthy portion and surface sterilized with 0.1% NaClO for 1 min followed by three sequential rinses with sterile distilled water (Ali et al., 2024). Samples were placed on blotter paper to eliminate moisture after surface sterilization. Following their placement on PDA media plates, these samples were wrapped in wrapping tape. After proper tagging, the plates were kept in the incubator for 36-48 h at 25±1°C. After 36-48 h, fungal spores around the samples on the PDA media plates were observed and hyphae of pure culture were placed onto new sterilized plates with PDA medium. After 36-48 h of incubation, pure colonies of fungus were observed.

Pathogenicity test

Confirmation of the fungal isolates was done by fulfilling Koch's postulates (Juhasz et al., 2013). For pathogenicity, ten pots with seedlings were employed and the inoculum was made by dissolving fungal spores in distilled water in a flask (the number of spores in the flask was adjusted to 1×10^6 spores/ml of H_2O by adding sterilized water to the flask) (Jaiganesh *et al*., 2019). The soil was infected and mixed with a fungal suspension that had been prepared. Control treatments were put up to prevent the growth of the investigated fungus and kept under supervision. The symptoms were recognized after 12-15 days. To confirm the fungus, the pathogen was re-isolated from these artificially inoculated plants.

Management of *Colletotrichum capsici* with chemicals

The assessment of three concentrations (200, 400, and 600 ppm) of six fungicides (Alext super, Contaf plus, Topsin-M, Score, Flint max, and Fossil) and control (distilled water) were conducted in the *In-vitro, In-vivo* and field condition. In order to achieve these concentrations, a sufficient amount of stock solution for all chemicals was prepared and working concentrations were adjusted using the formula $C_1V_1= C_2V_2$ by following the protocol provided by Rehman et al. (2015).

In-vitro evaluation of chili anthracnose through chemicals by using poisoned food technique

In-vitro evaluation of chili anthracnose through chemicals with a control were evaluated under using the poisoned food technique. The respective fungicide was mixed with PDA media in conical flasks, and the modified media was poured into 9 cm diameter petri plates under a laminar flow chamber. A 6 cm diameter hole was made in each plate using a sterilized cork borer, into which an 8-day-old active culture of *C. capsici* was placed; control plates contained only PDA media. Three replicates per treatment were arranged in a Completely Randomized Design (CRD) and incubated at approximately 25±1°C for 10 days. Colony growth was recorded at 4, 7, and 10 days (Parsa et al., 2013).

In-vivo evaluation of chili anthracnose through chemicals

For the *in-vivo* experiment, 15-day-old healthy chili seedlings grown in pots were inoculated by uniformly spraying an active spore suspension of *C. capsici* ($1×10^6$ spores/ml) prepared from an 8-day-old culture. Post-inoculation, seedlings were treated with foliar sprays of six fungicide solutions at concentrations of 200, 400, and 600 ppm, and control plants received distilled water only. Each treatment, including the control, was replicated three times in a CRD. Plants were maintained under controlled greenhouse conditions at 25±1°C and monitored for disease progression. Disease severity was assessed at 2, 3, and 4 days post-inoculation by measuring lesion diameters on leaves and fruits.

Field evaluation of chili anthracnose through chemicals

For the field experiment, soil was inoculated with a fungal suspension of *C. capsici* before sowing to create a sick field. A 400 m² area was sprayed twice at 15-day intervals with pure *C. capsici* culture prior to transplanting the most sensitive chili varieties (4828 and 10599). After sowing, 15-day-old chili seedlings grown in field were foliar sprayed with six fungicide solutions at concentrations of 200, 400, and 600 ppm, and controls were sprayed with distilled water only. Treatments were replicated three times in a Randomized Complete Block Design (RCBD). Disease severity was assessed at 2, 3, and 4 days post-inoculation by measuring lesion diameters on leaves and fruits.

Statistical analysis

Data was recorded for each experiment and statistically analyzed by using Statistics 8.1 software. CRD design was used for laboratory experiments and RCBD was used for field condition (Steel et al., 1997).

RESULTS

Collection and Isolation of pathogen

Disease samples were collected on the basis of characterized disease symptoms from the field of Institute of Horticultural Sciences (IHS). The collected samples were placed in the browns bags and brought to the laboratory for isolation and identification to process further studies Infected chili leaves were cut into 2-3 mm segments, surface sterilized with 0.1% NaClO for 2-3 minutes, rinsed thrice with distilled water, and inoculated on autoclaved PDA media. Plates were incubated at 25±1°C. Pure cultures of fungal isolate exhibited rapid growth with white cottony colonies that turned dark gray to black by day 5, reaching an average diameter of 7.5 cm. Morphology included septate, hyaline to light brown branched hyphae; smooth, cylindrical, falcate conidia (12-18 µm × 3-5 µm); and dark brown, lobed appressoria characteristic of *C. capsici.* Some isolates showed variable growth rates and sporulation densities but all matched diagnostic features of *C. capsici.*

Culture Preservation

After 7-8 days at 25°C, cultures on PDA slants were dense, fluffy, and darkened with age, indicating vigorous growth. Stored at 4°C, cultures remained viable and morphologically stable for over three months with no contamination or loss of pathogenic traits, demonstrating effective long-term preservation.

Pathogenicity Test

Chili seedlings inoculated with *C. capsici* spores developed typical anthracnose symptoms including small water-soaked lesions progressing to dark brown necrotic spots within 12-15 days. Lesions coalesced causing extensive tissue damage and fruit rot, similar to natural infections. Fungi were successfully re-isolated from symptomatic plants, fulfilling Koch's postulates.

Management of *Colletotrichum capsici* with chemicals

Among the tested fungicides at various concentrations, effective management of *C. capsici* was observed in the *In-vitro*, *In-vivo* and field condition, demonstrating significant inhibition of anthracnose disease on chili.

In-vitro evaluation of different chemicals against *Colletotrichum capsici*

The ANOVA table showed that the results of Treatment (T), Concentration (C), Days (D) and interaction between T × C, T × D, C × D and T × C × D were significant as shown in (Table 1). Among treatments, Topsin M showed minimum fungal growth (5.77) followed by Fossil (7.77), score (10.13), Contaf plus (16.237), Alext super (17.107), Flint max (19.048) mm as compared to control (Figure 1). The interaction between Treatments and Concentration (T × C) showed that minimum fungal growth was shown by Topsin M (6.5, 5.77, 5.05)mm @ 200ppm, 400 ppm and 600 ppm followed by Fossil (8.5, 7.77, 7.05), Score (10.88,10.38,9.11), Contaf plus (16.83, 16.22, 15.65), Alext super (17.67, 17.1,16.54), Flint max (19.58, 19.05, 18.5,)mm as compared to control (Figure. 2). The interaction between Treatments and Days (T × D) showed that minimum fungal growth was shown by Topsin M (7.44, 5.77, 4.11)mm after 2 days, 3 days and 4 days followed by Fossil (9.44, 7.77, 6.11), Score (13.22, 9.5, 7.66), Contaf plus (18.07, 16.24, 14.38), Alext super (19.16, 17.03, 15.12), Flint max (19.97, 19.02, 18.14)mm as compared to control (Figure 3).

Table 1: ANOVA for *in-vitro* evaluation of compounds against *Colletotrichum capsici* in laboratory conditions.

Source	**DF**	**SS**	**MS**	**F**	**P**
Treatment (T)	6	31160.1	5193.34	2686.43	0
Days(D)	2	112	56.02	28.98	0
Conc. (C)	2	431.6	215.81	111.63	0
T × D	12	75.7	6.31	3.26	0.0004
T × C	12	112.7	9.39	4.86	0
D × C	4	13	3.24	1.68	0.1594
T × D × C	24	91.3	3.8	1.97	0.0088
Error	126	243.6	1.93		
Total	188	32240			

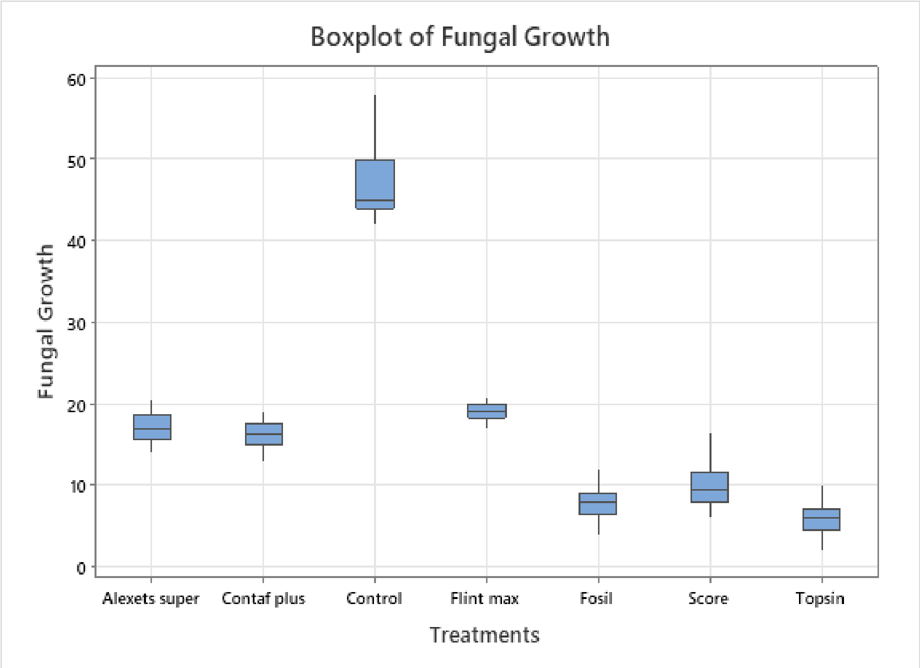

Figure 1. Effects of several treatments on *Colletotrichum capsici* fungal growth in the lab.

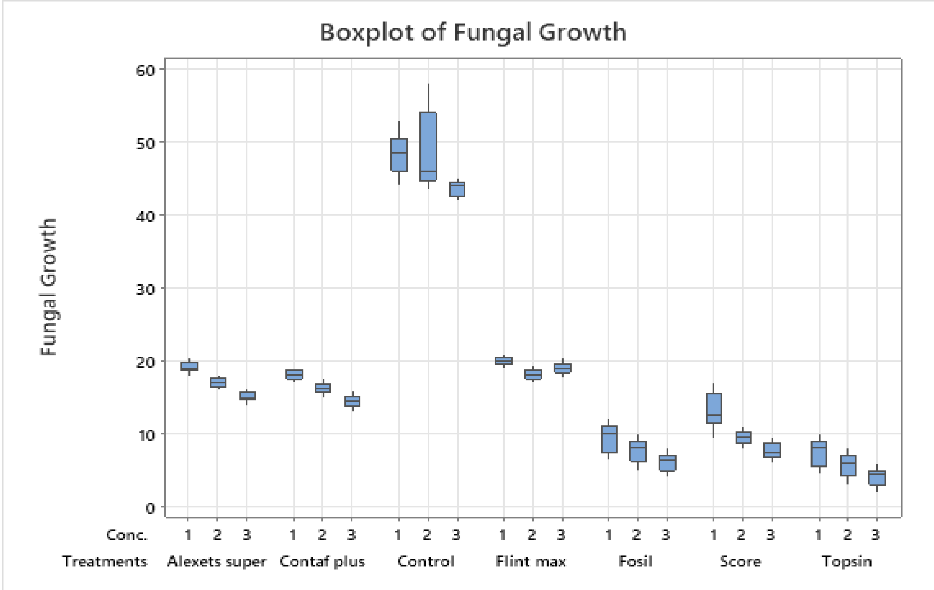

Figure 2. Under laboratory conditions, the impact of interactions between treatments and concentrations on *C. capsici* fungal growth is shown.

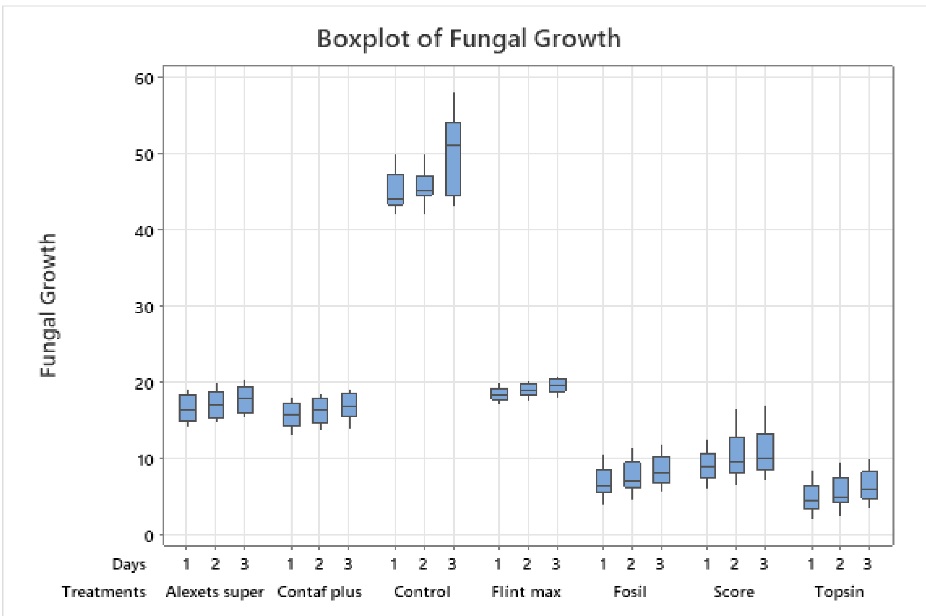

Figure 3. Under laboratory conditions, the impact of interactions between treatments and days on *C. capsici* fungal development

In-vivo management of Chili anthracnose in field circumstances using chemicals to reduce disease incidence

The efficacy of six fungicides was evaluated against *C. capsici* under controlled greenhouse conditions at three concentrations (200, 400, and 600 ppm). Data was subjected to ANOVA, and mean comparisons were conducted using LSD All-Pairwise Comparisons Test (Table 2). ANOVA results indicated that treatment (T), concentration (C), days post-application (D), and their interactions (T × C, T × D, C × D, and T × C × D) were statistically significant ($p < 0.05$), demonstrating that fungicide type, dosage, and time influenced disease control.

Table 2. ANOVA for *In-vivo* evaluation of compounds against *C. capsici* in Greenhouse conditions

Source	DF	SS	MS	F	P
Treatment (T)	6	15230.5	2538.42	1420.75	0.0001
Days (D)	2	85.4	42.7	23.89	0.0003

Concentration (C)	2	210.8	105.4	59.01	0.0001
T × D	12	45.3	3.78	2.12	0.025
T × C	12	68.9	5.74	3.23	0.004
D × C	4	9.1	2.28	1.28	0.28
T × D × C	24	55.7	2.32	1.31	0.07
Error	126	225.4	1.79		
Total	188	15740.1			

Among treatments, Topsin M, containing Thiophanate-methyl (70% w/w), demonstrated the highest efficacy by significantly reducing lesion diameter to an average of 12.5 mm. This was followed by Fossil (Mancozeb 250 g/l, 50% w/w), which resulted in a lesion size of 15.8 mm, indicating strong but slightly lower activity compared to Topsin M. Score (Difenoconazole 250 g/l, 51.24% w/w) also showed considerable disease control, with lesion diameters averaging 19.4 mm. In contrast, Contaf plus (Hexaconazole 51 g/l, 5% w/w), Alext super (Trifloxystrobin 50% w/w), and Flint max (Trifloxystrobin 500 g/kg, 250 g/kg) were less effective, with lesion sizes ranging from 28.7 mm to 32.5 mm, indicating moderate suppression of fungal growth. The untreated control plants exhibited the highest disease severity, with lesion diameters averaging 55.2 mm (Figure 4). Statistical analysis using LSD at the 0.05 significance level confirmed that Topsin M and Fossil were significantly more effective than the other treatments, while the latter three fungicides did not differ significantly from each other but were all superior to the control.

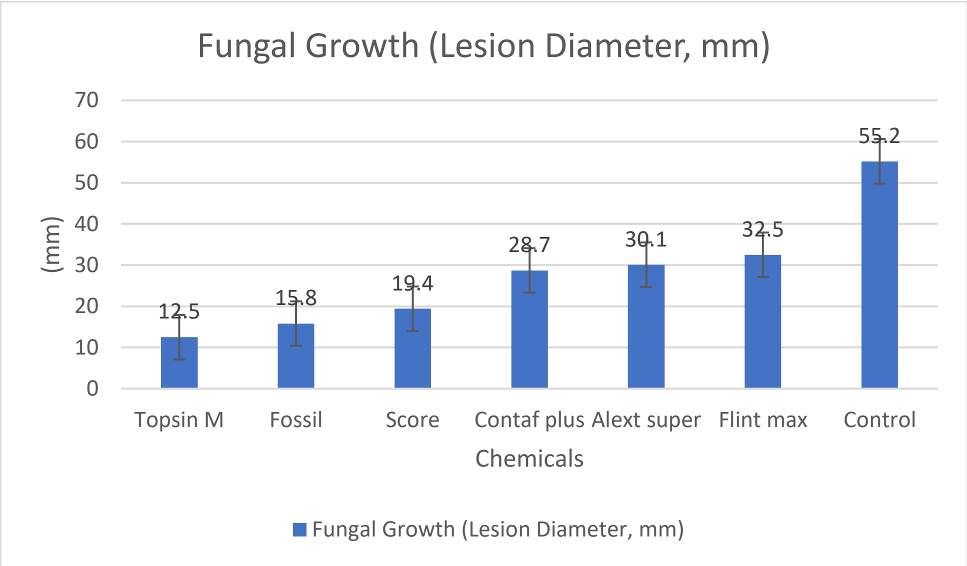

Figure 4. Effects of Various Treatments on *C. capsici* Disease Severity *in-vivo* Greenhouse Conditions

The interaction between fungicide treatments and their concentrations (T × C) had a marked impact on the severity of *C. capsici* infection *in-vivo*. At all tested concentrations (200, 400, and 600 ppm), Topsin M consistently provided the highest level of disease suppression, with lesion diameters decreasing from 15.8 mm at 200 ppm to just 10.8 mm at 600 ppm (Figure 5). Fossil also demonstrated strong efficacy, reducing lesion size from 19.5 mm at the lowest concentration to 13.9 mm at the highest. Score was moderately effective, with lesion diameters decreasing from 24.7 mm to 15.7 mm as concentration increased. In comparison, Contaf plus, Alext super, and Flint max were less effective, with lesion sizes remaining above 17 mm even at 600 ppm and exceeding 33 mm at the lowest concentration. The untreated control group consistently showed the largest lesions, ranging from 55.2 mm at 200 ppm to 52.05 mm at 600 ppm, underscoring the severity of disease without chemical intervention. The LSD value of 1.32 mm indicated that these differences were statistically significant.

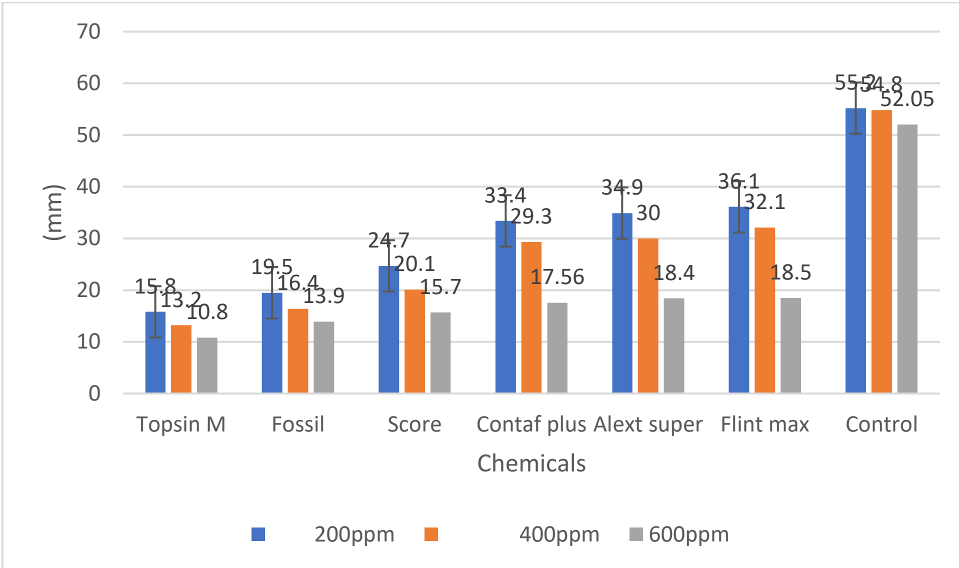

Figure 5. Effects of Interaction Between Treatments and Concentrations on *C. capsici* Disease Severity in *in-vivo*

The interaction between treatments and days (T × D) showed a gradual increase in lesion size over time in all treatments; however, Topsin M consistently demonstrated the strongest disease suppression, with lesion diameters decreasing from 15.8 mm after 48 hours to 11.2 mm after 96 hours, indicating sustained control of fungal growth. Fossil also showed notable efficacy, reducing lesion sizes from 18.9 mm at 48 hours to 13.8 mm at 96 hours. Score provided moderate disease control, with lesion diameters declining from 23.5 mm to 17.5 mm over the same period. In contrast, Contaf plus, Alext super, and Flint max exhibited less effective control, with lesion sizes remaining relatively high, ranging from approximately 31 to 34 mm at 48 hours and decreasing only slightly by 96 hours. The untreated control plants showed the most severe disease symptoms, with lesion diameters exceeding 50 mm throughout the observation period (Figure 6). The LSD value of 1.48 confirms that these differences among treatments were statistically significant.

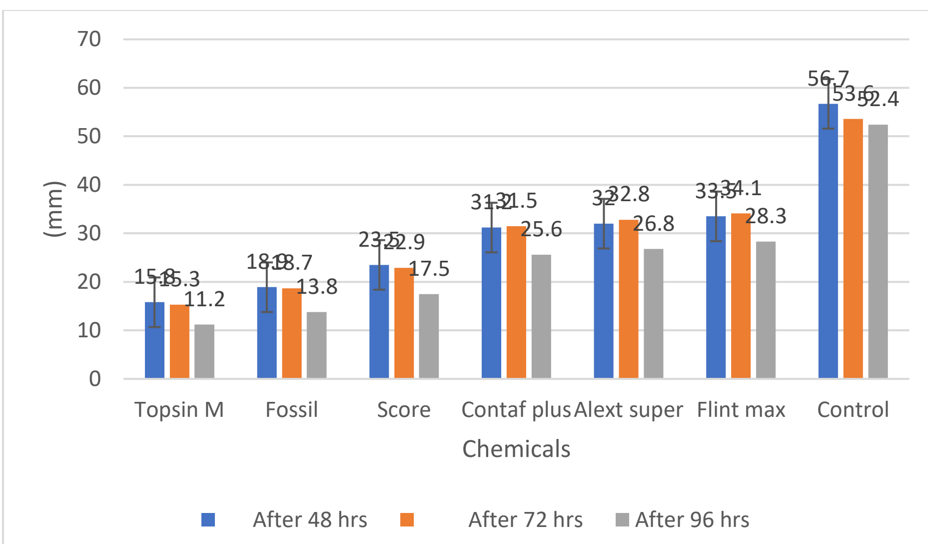

Figure 6. Effects of Interaction Between Treatments and Days on *C. capsici* Disease Severity in *in-vivo* Condition.

Evaluation of Different Chemicals Against *Colletotrichum capsica* in Field conditions

The data on the evaluation of fungicides and plant extracts under field conditions revealed significant variation in the reduction of *C. capsici* disease severity among treatments, concentrations, and time intervals. The results were statistically analyzed using ANOVA, and the mean comparisons were made through the LSD All-Pairwise Comparisons Test. Although all the fungicides were effective in reducing the disease compared to the control, the efficacy under in-vivo conditions was slightly lower than *in-vitro* conditions. Among the treatments, Topsin M remained the most effective with reduced fungal severity, followed by Fossil and Score, while Flint Max showed the least effectiveness among the fungicides tested. The control plots consistently recorded the highest disease severity. Figure 7 shows that Topsin M treatment reduced *C. capsici* disease severity to 9.44 mm, which is the lowest among all treatments. The control group exhibited the highest disease severity at 48.33 mm, indicating significant disease development without treatment.

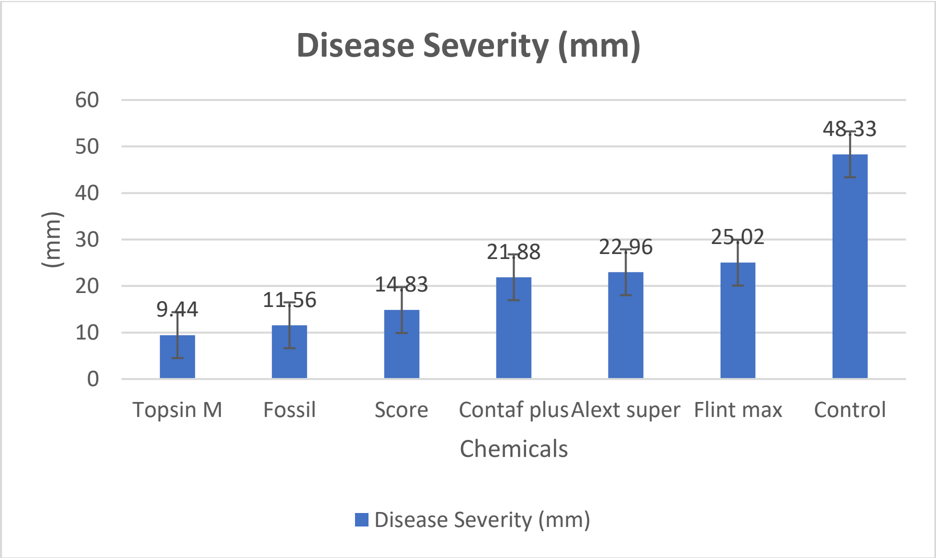

Figure 7. Effects of Various Treatments on *C. capsici* Disease Severity in Field Conditions

Further analysis of treatment efficacy at different concentrations (200, 400, and 600 ppm) is detailed in Table 4.14. Topsin M consistently provided superior disease suppression across all concentrations, with lesion diameters decreasing from 10.4 mm at 200 ppm to 8.5 mm at 600 ppm. Fossil followed a similar trend, with lesion sizes reducing from 12.8 mm to 10.4 mm as concentration increased. Score showed moderate efficacy, while Contaf Plus, Alexet Super, and Flint Max maintained higher lesion diameters even at the highest concentration. Control plants again showed the greatest disease severity, with lesion sizes remaining above 46 mm (Figure 8). The LSD of 1.49 indicates significant differences among treatments and concentrations.

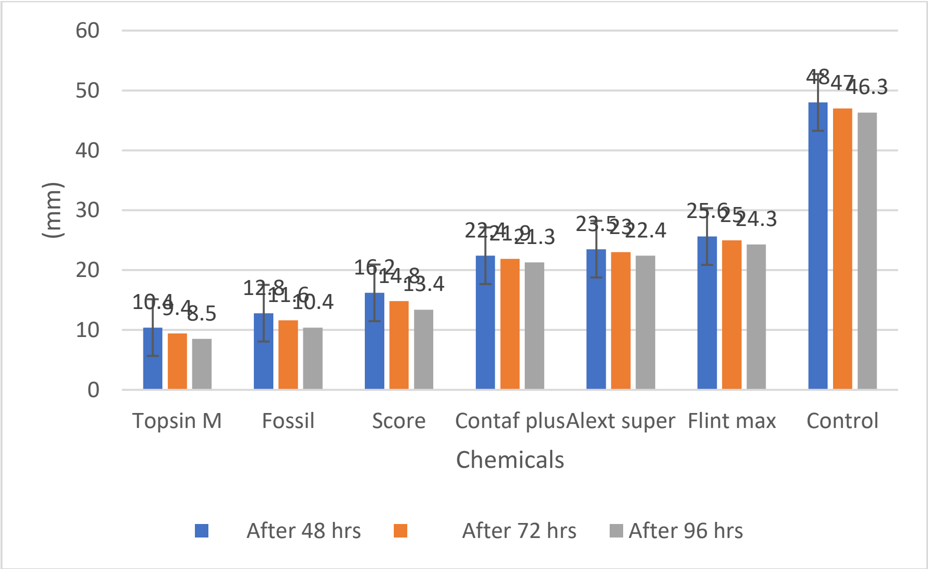

Figure 8. Effects of Interactions Between Treatments and Concentrations on *C. capsici* Disease Severity in Field Conditions

The temporal progression of disease severity post-treatment is presented in Figure 9. Topsin M maintained the lowest lesion diameters over time, decreasing from 10.7 mm at 48 hours to 8.2 mm at 96 hours, indicating sustained disease control. Fossil and Score also showed effective suppression with lesion sizes decreasing over time, whereas Contaf

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Plus, Alexet Super, and Flint Max exhibited less control, with lesion diameters remaining relatively high throughout the observation period. Control plants showed consistently severe disease symptoms with lesion sizes above 46 mm at all time points. The LSD value of 1.52 confirms the statistical significance of these observations.

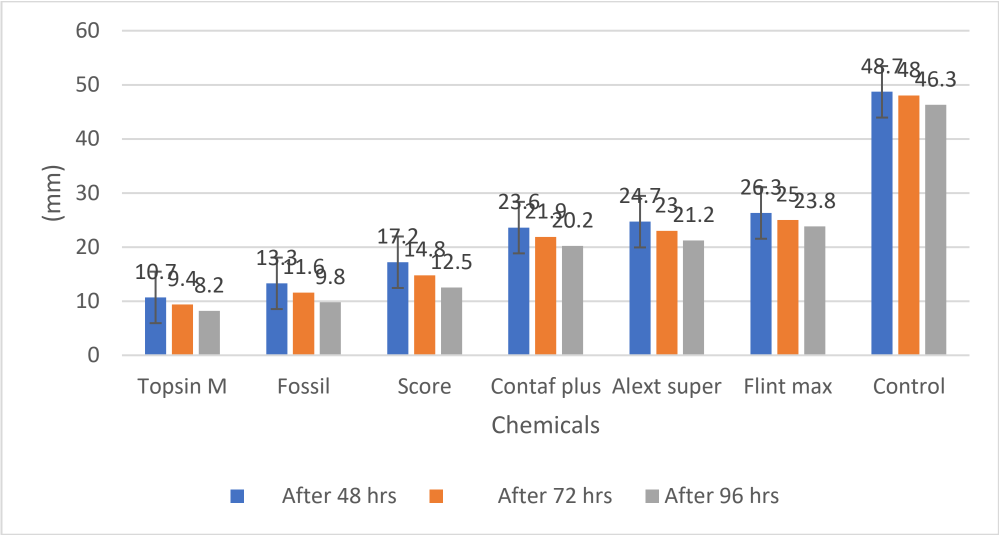

Figure 9. Effects of Interactions Between Treatments and Days on *C. capsici* Disease Severity in Field Conditions

The field trials corroborated laboratory findings but showed reduced fungicidal performance, which is expected due to the influence of weather, soil, and host resistance. Topsin M, followed by Fossil and Score, were effective in reducing the disease severity of chili anthracnose even under natural conditions. The interaction effects indicate that higher concentrations and longer durations generally resulted in better control of the disease. However, no treatment matched the effectiveness levels seen under controlled lab conditions.

DISUCSSION

Chili (*Capsicum annuum* L.), a valuable and economically significant crop of the *Solanaceae* family, ranks as the fourth major crop worldwide and is a staple in subtropical and tropical cuisines (Walker and Morey, 1999). Globally, over 400 chili varieties are cultivated for uses ranging from vegetables to spices and condiments, with diverse fruit shapes, sizes, colors, and pungency. In Pakistan, chili cultivation is widespread with Sindh contributing 89.7% of production, followed by Punjab (6.3%), Baluchistan (3.4%), and KPK (0.6%) (Khokhar, 2013). Major producing districts include Multan, Sheikhupura, Okara (Punjab), Hyderabad, Mirpurkhas (Sindh), Khuzdar (Baluchistan), and Bajour (KPK).

Anthracnose caused by *C. capsici* severely affects chili, especially during the fruiting stage, where even minor lesions significantly reduce market value and farmer profitability (Manandhar et al., 1995). The disease is transmitted through seed, soil, water, and air, and can damage seedlings as well as aerial parts of the plant. Several Colletotrichum species, mainly *C. capsici, C. acutatum,* and *C. gloeosporioides*, have been implicated in chili anthracnose globally, with *C. capsici* causing major damage at the ripe fruit stage (Ranathunge et al., 2012; Saxena et al., 2014). These species can attack chili at various developmental stages, though leaf and stem infections are less common. Chemical control using fungicides has proven effective when applied during the critical developmental stages of chili—targeting expanding fruits, leaves, and flowers—to prevent pathogen penetration (Wharton and Diieguez-Uribeondo, 2004). However, concerns over farmer health, economic burden, and environmental toxicity due to fungicide overuse are prominent, particularly in developing countries, warranting the careful and judicious use of such chemicals (Voorrips et al., 2004).

This study identified Topsin M (thiophanate-methyl) and Fossil (mancozeb) as the most effective fungicides against *C. capsici* in both greenhouse and field conditions, significantly reducing anthracnose severity compared to other fungicides and untreated controls, consistent with previous findings (Than et al., 2008; Mannaa et al., 2017). Their broad-spectrum activity likely contributes to their efficacy across variable environmental conditions. Fungicide concentration played a critical role, with Topsin M at 600 ppm showing the lowest lesion diameters *in-vivo* and field trials, indicating its strong resilience. However, fungicide effectiveness was generally lower under field and *in-vivo* conditions than *in-vitro*, likely due to abiotic factors (temperature, humidity, UV exposure) and biotic factors (plant physiology, microbial competition) impacting fungicide persistence and uptake (Hameed et al., 2024).

Other fungicides, including Contaf Plus (hexaconazole), Alexet Super, and Flint Max (both trifloxystrobin), demonstrated moderate to insignificant control, highlighting the need for integrated disease management strategies. Previous studies report that strobilurin and azole fungicides may be limited by rapid degradation and resistance development in pathogen populations (Shcherbakova, 2019). Therefore, rotating fungicides with different modes of action alongside cultural and biological controls is recommended to sustain long-term disease suppression and minimize resistance risk.

Overall, Topsin M and Fossil remain reliable components in managing anthracnose in chili; however, reduced efficacy in field settings underscores the importance of optimizing application timing, dosage, and combining chemical control with non-chemical approaches. Future research should focus on integrating these fungicides with resistant chili varieties and beneficial microbiota, while assessing environmental impacts and resistance potential (Islam et al., 2024). Such integrated management is essential for sustainable control of *C. capsici* across agroecosystems.

CONCLUSIONS

The present study successfully isolated and characterized *C. capsici* from chili fields in Punjab, confirming its pathogenicity through Koch's postulates. Evaluation of six fungicides at 200, 400, and 600 ppm concentrations demonstrated that Topsin M (thiophanate-methyl 70% w/w) was the most effective, reducing lesion diameter significantly to 5.05 mm *in-vitro*, 10.8 mm *in-vivo*, and 8.2 mm in field conditions at the highest concentration. Fossil (mancozeb 50% w/w) also showed strong disease suppression, followed by Score (difenoconazole). Other fungicides exhibited moderate to low efficacy, with control plants showing lesion sizes up to 55.2 mm. Disease severity increased over time, but Topsin M maintained consistent suppression. Field results mirrored laboratory findings but with reduced effectiveness likely due to environmental factors. Future research should focus on integrating Topsin M with resistant chili varieties and biological controls to develop sustainable, environmentally safe anthracnose management strategies, while monitoring for fungicide resistance development and environmental impacts to ensure long-term disease control.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

All the authors actively participated in finalizing the manuscript. All authors reviewed and approved the final version of the manuscript for publication.

COMPETING OF INTEREST

No potential conflict of interest was reported by the authors.

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