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Integrative Management of Anthracnose in Mungbean Using Carbendazim Seed Treatment and Botanical Foliar Sprays

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Abstract: This study investigates the synergistic approach for managing anthracnose in mungbean (*Vigna radiata* (L.) R. Wilczek) by integrating carbendazim seed treatment with botanical foliar sprays. The research was conducted to evaluate the efficacy of various botanicals and their combination with carbendazim seed treatment in controlling mungbean anthracnose caused by *Colletotrichum truncatum*. *In vitro* tests were performed using neem (*Azadirachta indica*) oil, neem leaf extract, tulsi (*Ocimum tenuiflorum*) leaf extract, lemon grass (*Cymbopogon citratus*) oil, and moringa (*Moringa oleifera*) leaf extract. Field trials were conducted at Punjab Agricultural University, Ludhiana, and its Regional Research Station, Gurdaspur. Results indicated that among all the botanicals tested, neem oil at 20% concentration exhibited the highest mycelial growth inhibition *in vitro*. In field conditions, neem oil, when combined with carbendazim seed treatment, significantly reduced disease severity and improved yield compared to untreated controls. These findings suggest that integrating carbendazim seed treatment with botanical foliar sprays can effectively manage anthracnose in mungbean, providing an effective and sustainable disease management strategy.

Keywords: Anthracnose, Mungbean, Carbendazim, Botanical extracts, Neem oil, Foliar spray, Disease management

Mungbean (*Vigna radiata* (L.) R. Wilczek) is an important legume crop known for its ecological benefits such as nitrogen fixation, phosphorus mobilization, and improvement of soil health (Tivoli et al 2006), besides nutritional value. In addition to these ecological benefits, it also plays a key role in crop rotation and thus offers a viable option for crop diversification (Pandey et al 2023). However, its cultivation is hindered by diseases like anthracnose, caused by *Colletotrichum truncatum* and/or *Colletotrichum lindemuthianum*, which appears at all the growth stages of the crop, significantly reducing its yield and quality (Lima et al 2023). Traditional management practices primarily rely on chemical fungicides, which pose environmental and health risks. This study explores a more sustainable approach by integrating seed treatment with carbendazim and foliar applications of botanical extracts for the management of anthracnose disease. Previous studies have highlighted the efficacy of botanicals like neem, tulsi, and lemon grass in managing various plant diseases. Not only the crude leaf extract, but also the essential oil derivatives and seed extract have been studied for their disease management potential (Amadioha and Obi 1998, Uddin et al 2013). Besides the foliar application of botanicals, few studies also highlighted the integration of seed treatment and foliar sprays for management of anthracnose of mungbean (Amin et al 2014, Chaudhari and Gohel 2016). Therefore, this research aimed to evaluate the combined effect of carbendazim seed treatment and different botanical foliar sprays on anthracnose in mungbean.

MATERIAL AND METHODS

Study area and experimental design: Field trials were conducted in the year 2022-23 at two different locations, *viz*. Experimental Area, Department of Plant Pathology, Punjab Agricultural University (PAU), Ludhiana (30.898, 75.797 Decimal Degrees) and Regional Research Station (RRS) of Punjab Agricultural University situated at Gurdaspur, Punjab (32.050, 75.423 Decimal Degrees). The experiments were laid out in a randomized complete block design with three replications.

Preparation and evaluation of botanical extracts: Healthy leaves of neem (*Azadirachta indica*), tulsi (*Ocimum tenuiflorum*), curry patta (*Murraya koenigii*), and moringa (*Moringa oleifera*) as depicted in Table 1 were collected, washed, and ground. Extracts were prepared by mixing 100 grams of leaves with 200 ml of distilled water, filtering through muslin cloth, followed by hot water bath treatment and filter sterilization and diluting this stock concentration to desired concentrations (1%, 5%, 10%, 15%, and 20%). Commercial neem and lemon grass (*Cymbopogon citratus*) oil formulations were procured and diluted accordingly, considering the 3000-ppm commercial formulation as 100 per cent stock solution.

Efficacy of botanicals was evaluated in the laboratory using poison food assay (Nene and Thapliyal 1979) on double strength potato dextrose agar (PDA) medium against the pathogen. Required quantity of botanical was mixed with the cooled PDA medium and poured in Petri plates under aseptic conditions. Circular bit (5mm) of actively growing pathogen was inoculated in the centre of Petri plates. Three replications were maintained for each concentration. Medium without any botanical was taken as control and propiconazole 25EC was taken as chemical check. Inoculated Petri plates were incubated at 25±2ºC. The growth of the pathogen in poisoned plates was measured when the control plate exhibited full radial growth (90mm). Per cent growth inhibition was calculated by using the formula given by Vincent (1947):

$$\text{Per cent mycelial growth inhibition} = \frac{C-T}{C} \times 100$$

Where,

C = Radial mycelial growth in un-amended plate (mm)

T = Radial growth in treatment (mm)

Likewise, effect of different botanicals on pathogen's spore production at similar concentrations was worked out by scrapping the mycelial growth from each Petri plate in 1ml of autoclaved distilled water and transferring the mixture into a test tube. This mixture was shaken well so as to dislodge conidia. After mixing, the number of spores was counted with the help of a haemocytometer under the light microscope. The spore count was multiplied with factor 10^4 to calculate the total number of spores/ml.

Table 1. Botanicals used to test *in vitro* efficacy against the pathogen

Botanical (s)	Scientific name
Neem (leaves), Neem oil	*Azadirachta indica*
Tulsi (leaves)	*Ocimum tenuiflorum*
Curry patta (leaves)	*Murraya koenigii*
Lemon grass oil	*Cymbopogon citratus*
Arjuna (leaves)	*Terminalia arjuna*
Sohanjana (leaves)	*Moringa oelifera*

Further, mungbean cultivar ML2056 was used for *in vivo* evaluation of promising botanicals against anthracnose disease in randomized complete block design with three replications in 3×3 m² plots each. Botanicals (neem oil, neem leaves, lemon grass oil, tulsi leaves and sohanjana leaves) that exhibited significant antifungal activity under *in vitro* assays were further evaluated under field conditions at 40 per cent of the stock concentration. The observations were also compared with standard chemical check (0.05% propiconazole 25EC). Two sets of treatments were established *viz*. Set-I: without carbendazim seed treatment and Set-II: with carbendazim-treated seeds (@ 2 g/kg seed). Both the sets were simultaneously given subsequent botanical foliar spray treatments at 40 per cent of stock concentration. The first spray of botanicals was done 14 days before inoculation of the pathogen and the second spray 14 days after pathogen inoculation. Disease severity was recorded 1,2,3,4,5 and 6 weeks after disease appearance using the disease rating scale given by Mayee and Datar (1986) as given in Table 2 and expressed as Per cent Disease Index (PDI).

Per cent Disease Index was calculated using the formula given by McKinney (1923).

$$\text{Per cent Disease Index} = \frac{\text{Sum of numerical ratings}}{\text{Total number of plants observed} \times \text{Maximum rating}} \times 100$$

Further, the Area Under Disease Progress Curve (AUDPC) was calculated for each treatment from PDI using the formula given by Roelfs et al (1992) as given:

$$\text{AUDPC} = \sum_{i=1}^{n-1} \frac{(X_{i+1} + X_i)/2}{t_{i+1} - t_i}$$

Where,

X_{i+1} = PDI at the i+1thobservation

X_i = PDI at the ithobservation

t_{i+1} = Time after inoculation (day) at the i+1thobservation

t_i = Time after inoculation (day) at the ithobservation,

n = Total number of observations

Table 2. Disease rating scale for anthracnose of mungbean (Mayee and Datar 1986)

Scale	Description
0	No symptoms on leaves
1	Small size lesions covering 1% or less of the leaf area
3	Small size lesions covering 1-10% of the leaf area
5	Lesions size big but not coalescing, covering 11-25% of the leaf area
7	Lesions on leaves covering 26-50% of leaf area. Cankers on stem and pod infection
9	Lesions on leaves cover 51% or more of leaf area. Defoliation of leaves, deep cankers on stem and pods, blighting of plant occurs

The apparent rate of disease development was computed using the formula given by Van der Plank (1963):

$$r = \frac{2.303}{(t2-t1)} \log 10 \frac{x2(1-x1)}{x1(1-x2)}$$

Where,

r = Apparent infection rate /unit/day,

t1 = Date of first observation,

t2 = Date of second observation,

x1 = Per cent disease incidence at time t1,

x2 = Per cent disease incidence at time t2

Statistical analysis: Data were statistically analysed using RStudio. Factorial ANOVA was worked out and means were compared using the least significant difference (LSD) test at $p \leq 0.05$.

RESULTS AND DISCUSSION

***In vitro* evaluation of botanicals against anthracnose pathogen, *Colletotrichum truncatum*:** The botanicals evaluated against anthracnose pathogen depicted differential response at different concentrations *viz*. 1, 5, 10, 15 and 20 per cent against *Colletotrichum truncatum*. The botanicals significantly restricted the growth of *Colletotrichum truncatum* under *in vitro* conditions (Table 3). The maximum mycelial growth inhibition (50.46%) was in neem oil @20 per cent concentration followed by neem leaf extract @20 per cent . neem oil @15 per cent , tulsi leaf extract @20 per cent, neem leaf extract @15 per cent . Among all the botanicals, neem oil was the most effective antifungal treatment against *C. truncatum* followed by neem leaf, tulsi leaf extract, lemon grass oil and moringa leaf extract. The arjuna leaf extract proved to be least effective with 28.70% growth inhibition at 20 per cent concentration.

The data presented in Table 4 indicate that the botanicals significantly inhibited the conidial count of *C. truncatum* under *in vitro* conditions. Highest mean conidial count (19.2×10^4 spores/ml) was recorded in arjuna leaf extract followed by curry patta leaf extract (18.87×10^4 spores/ml), moringa leaf extract (17.4×10^4 spores /ml) and lemon grass oil (14.34×10^4 spores/ml). Neem oil was found to be the most effective treatment which resulted in the lowest mean conidial count (10.34×10^4 spores/ml), demonstrating significant antifungal activity. Notably, the mean conidial count in the control was (27.00×10^4spores/ml).

Based on *in vitro* evaluation of different botanicals against anthracnose pathogen, the neem oil-based formulation was found to be the most effective botanical in restricting the fungal growth followed by neem leaf extract.

Field evaluation of promising botanicals against anthracnose of mungbean: The field evaluation conducted at PAU, Ludhiana revealed significant variation in the disease severity of anthracnose of mungbean among the botanicals in both sets of treatments (Table 5). In the first set (no seed

Table 3. *In vitro* efficacy of different botanicals against *Colletotrichum truncatum*

Botanical (A)	Radial growth at different concentrations (mm)					Mean	Per cent growth inhibition at different concentrations					Mean
	1%	5%	10%	15%	20%		1%	5%	10%	15%	20%	
T1 -Neem oil (*Azadirachta indica)*	71.25	63.66	57.16	50.41	44.58	57.41^{f}	20.83 (27.12)	29.26 (32.73)	36.48 (37.13)	43.98 (41.52)	50.46 (45.25)	36.20 (36.75)^{a}
T2-Lemon grass oil (*Cymbopogon citratus)*	76.00	73.08	67.75	64.00	59.83	68.13^{c}	15.55 (23.20)	18.79 (25.67))	24.72 (29.80)	28.89 (32.49)	33.52 (35.36)	24.29 (29.30)^{d}
T3-Neem leaf extract*(Azadirachta indica)*	74.08	66.91	61.58	56.17	49.16	61.58^{e}	17.68 (24.85)	25.65 (30.41)	31.57 (34.16)	37.59 (37.79)	45.37 (42.32)	31.57 (33.90)^{b}
T4-Tulsi leaf extract (*Ocimum tenuiflorum*)	76.25	67.33	66.50	59.42	55.82	65.06^{d}	15.27 (22.98)	25.18 (30.06)	26.11 (30.71)	33.99 (35.63)	37.96 (38.01)	27.70 (31.48)^{c}
T5-Curry patta leaf extract (*Murraya koenigii*)	79.83	76.66	71.00	66.67	62.66	71.36^{b}	11.29 (19.62)	14.81 (22.62)	21.11 (27.33)	25.93 (30.59)	30.37 (33.42)	20.70 (26.72)^{e}
T6-Moringa leaf (*Moringa oelifera)*	77.17	72.16	68.83	65.17	61.33	68.93^{c}	14.25 (22.17)	19.81 (26.41)	23.51 (29.00)	27.59 (31.67)	31.85 (34.34)	23.40 (28.72)^{d}
T 7-Arjuna leaf extract (*Terminalia arjuna*)	80.33	76.33	71.83	68.50	64.16	72.23^{b}	10.74 (19.12)	15.18 (22.92)	20.18 (26.68)	23.88 (29.24)	28.70 (32.38)	19.74 (26.07)^{e}
T 8-Control	90	90	90	90	90	90^{a}	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)^{f}
Mean	76.41^{a}	70.88^{b}	66.38^{c}	61.47^{d}	56.79^{e}		15.09 (22.72)^{e}	21.24 (27.26)^{d}	26.24 (30.69)^{c}	31.69 (34.13)^{b}	36.89 (37.30)^{a}	
	A		B		A×B		A		B		A×B	
CD (p≤0.05)	1.10		0.93		2.46		0.77		0.65		1.73	

Values in the parentheses indicate the arc sine (angular) transformed values,
Different alphabetical letters are significantly different at p<0.05,
A=Botanicals, B=Concentrations

treatment), maximum disease control (55.56%) was from neem oil among botanicals followed by neem leaf extract , tulsi leaf extract , lemon grass oil , and moringa leaf extract . In second set (carbendazim seed treatment), highest disease control (59.73%) among botanicals was in neem oil followed by neem leaf extract, tulsi leaf extract , lemon grass oil and moringa leaf extract when compared to inoculated control. The treatments in second set (carbendazim treated seed) were superior than first set in controlling the disease due to effect of seed treatment with carbendazim which exhibited significantly lowered mean per cent disease index as compared to first set that had no carbendazim seed treatment. However, for both sets, the maximum per cent disease control was for propiconazole 25EC i.e. 74.08 and 75.85 per cent for set I (untreated seed) and set II (carbendazim treated seed), respectively. The observation

Table 4. *In vitro* efficacy of different botanicals on conidial count of *Colletotrichum truncatum*

Botanical (A)	Conidial count at different concentrations (10^4 conidia/ml)					Mean
	1%	5%	10%	15%	20%	
T1 -Neem oil (*Azadirachta indica)*	15.00 (3.93)	11.67 (3.49)	10.34 (3.30)	8.67 (3.03)	6.00 (2.55)	10.34 (3.25)^{g}
T2-Lemon grass oil (*Cymbopogon citratus)*	19.00 (4.41)	16.34 (4.10)	14.67 (3.89)	11.34 (3.45)	10.34 (3.30)	14.34 (3.82)^{d}
T3-Neem leaf extract*(Azadirachta indica)*	17.00 (4.18)	14.34 (3.86)	11.67 (3.49)	9.00 (3.09)	6.67 (2.68)	11.74 (3.45)^{f}
T4-Tulsi leaf extract (*Ocimum tenuiflorum*)	17.67 (4.26)	15.67 (4.02)	13.00 (3.68)	11.34 (3.45)	9.34 (3.14)	13.40 (3.71)^{e}
T5-Curry patta leaf extract (*Murraya koenigii*)	21.67 (4.70)	20.67 (4.61)	18.67 (4.37)	17.67 (4.26)	15.67 (4.02)	18.87 (4.39)^{b}
T6-Moringa leaf (*Moringa oelifera)*	20.67 (4.60)	19.67 (4.49)	18.00 (4.30)	15.34 (3.97)	13.34 (3.73)	17.40 (4.21)^{c}
T 7-Arjuna leaf extract (*Terminalia arjuna*)	22.00 (4.74)	20.67 (4.60)	19.00 (4.41)	18.00 (4.30)	16.34 (4.10)	19.20 (4.43)^{b}
T 8-Control	27.00 (5.24)	27.00 (5.24)	27.00 (5.24)	27.00 (5.24)	27.00 (5.24)	27.00 (5.24)^{a}
Mean	20 (4.51)^{a}	18.25 (4.30)^{b}	16.54 (4.08)^{c}	14.79 (3.80)^{d}	13.09 (3.59)^{e}	
	A		B		A×B	
CD (p≤0.05)	0.1		0.059		0.167	

Values in the parentheses indicate the square root (√x+0.5) transformed values
Different alphabetical letters are significantly different at p<0.05
A=Botanicals, B=Concentrations

Table 5. Evaluation of promising botanicals against anthracnose of mungbean during *Kharif* 2022 under field conditions at PAU, Ludhiana

Treatment*	Set-I Seeds not treated with carbendazim		Set-II Seeds treated with carbendazim		Yield (kg/acre)	
	Per cent disease index	Per cent disease control**	Per cent disease index	Per cent disease control**	Seeds not treated with carbendazim	Seeds treated with carbendazim
Lemon grass oil **(***Cymbopogon citratus)*	32.22 (34.54)	35.56	27.78 (31.79)	32.90	364.30	372.00
Neem leaf extract (*Azadirachta indica*)	28.89 (32.49)	42.22	24.08 (29.37)	41.84	395.30	402.34
Tulsi leaf extract (*Ocimum tenuiflorum*)	30.37 (33.42)	39.26	26.66 (31.06)	35.60	374.70	382.67
Moringa leaf extract (Moringa *oelifera*)	35.56 (36.58)	28.88	30.00 (33.17)	27.54	323.30	340.00
Neem oil (*Azadirachta indica*)	22.22 (28.07)	55.56	16.67 (24.06)	59.73	421.70	438.00
Inoculated control ©	50.00 (44.98)	0.00	41.40 (40.07)	0.00	233.30	250.67
Propiconazole 25EC 0.05%	12.96 (21.08)	74.08	10.00 (18.36)	75.85	475.00	480.00
Mean	29.49 (33.02)^{a}		24.56 (29.70)^{b}		369.67^{b}	380.80^{a}
	A	B	A×B	A	B	A×B
CD (p≤0.05)	2.616	0.901	4.27	13.033	4.48	21.28

*40 per cent of stock concentration, A=Treatment, B=Carbendazim/no carbendazim seed treatment
Different alphabetical letters are significantly different at p<0.05
Values in the parentheses are arc sine transformed values **Per cent disease control = [Inoculated Control (C) – Treatment (T) /Inoculated Control (C)] × 100
[Note: The values of per cent disease control in set II (seed treated with carbendazim) appear to be lower than set I for treatment (Sr. No. 1 to 4). This apparent reduction is due to decreased per cent disease index in the inoculated control (C) (Sr. No. 6), attributed to the exclusive effect of carbendazim seed treatment]

on yield data also exhibited significant difference amongst the treatments under both sets. In first set, maximum yield (475.00 kg/acre) was in propiconazole 25EC followed by neem oil (421.70 kg/acre), neem leaf extract and tulsi leaf extract. In the second set, maximum yield (480.00 kg/acre) was in propiconazole. Among the botanicals, neem oil reported highest yield (438.00 kg/acre) followed by neem leaf extract, tulsi leaf extract and lemon grass oil.

Similarly, in field trials conducted at RRS, Gurdaspur statistically significant variation was observed in efficacy. There was significant variation in the per cent disease control among the botanicals in both sets. In the first set, highest disease control (70.44%) was in propiconazole 25EC followed by neem oil , neem leaf extract and tulsi leaf extract (Table 6). Similarly, in the second set same trend for disease control was observed with propiconazole 25EC recording maximum disease control (70.26%) followed by neem oil, neem leaf extract and tulsi leaf extract . Among botanicals, neem oil was most effective. The yield in first set was maximum in propiconazole 25EC (443.67 kg/acre) followed by neem oil, neem leaf extract and tulsi leaf extract. Similar trend was seen in second set with propiconazole 25EC recording maximum yield (471.00 kg/acre). The neem oil was the most effective among botanicals (435.00 kg/acre).

Similarly, AUDPC and apparent infection rate (r-value) at PAU, Ludhiana also varied significantly among treatments (Table 7). In the first set, maximum AUDPC (933.67) was observed in inoculated control followed by moringa leaf extract , lemon grass oil and neem leaf extract. However, lowest AUDPC (262.91) was observed in propiconazole 25EC treatment. Similarly in second set, maximum AUDPC (787.16) was reported in inoculated control followed by moringa leaf extract, lemon grass oil, tulsi leaf extract and neem leaf extract whereas lowest AUDPC (244.61) was observed in propiconazole 25EC. In the first set, at PAU, Ludhiana, the highest apparent infection rate (0.056) was reported from moringa leaf extract among botanicals followed by lemon grass oil (0.051). Lowest r-value (0.046) was observed in neem oil among botanicals. Similarly, in second set, maximum r- value (0.049) among botanicals was observed in moringa leaf extract followed by lemon grass oil (0.047) and tulsi leaf extract (0.047) whereas, minimum r-value (0.040) was observed in neem oil treatment among botanicals.

Likewise, AUDPC and apparent infection rate (r-value) at RRS, Gurdaspur, also varied significantly among the treatments. In first set, maximum AUDPC (1064.00) was in inoculated control followed by moringa leaf extract and lemon grass oil. Least AUDPC (293.98) was observed in propiconazole 25EC. In second set, same trend was seen

Table 6. Evaluation of promising botanicals against anthracnose of mungbean during *Kharif*, 2022 under field conditions at RRS, Gurdaspur

Treatment*	Seeds not treated with carbendazim		Seeds treated with carbendazim		Yield (kg/acre)	
	Per cent disease index	Per cent disease control**	Per cent disease index	Per cent disease control**	Seeds not treated with carbendazim	Seeds treated with carbendazim
Lemon grass oil **(***Cymbopogon citratus)*	32.23 (34.5)	34.08	30.74 (33.65)	25.24	353.00	369.67
Neem leaf extract (*Azadirachta indica*)	28.89 (32.51)	40.91	27.76 (31.77)	32.49	371.67	404.34
Tulsi leaf extract (*Ocimum tenuiflorum*)	30.37 (33.42)	37.88	29.26 (32.72)	28.84	357.34	378.00
Moringa leaf extract (Moringa *oelifera*)	37.74 (37.88)	22.81	33.34 (35.24)	18.92	318.34	348.67
Neem oil (*Azadirachta indica*)	23.34 (28.86)	52.26	20.00 (26.8)	51.36	415.67	435.00
Inoculated control ©	48.89 (46.05)	0.00	41.12 (41.14)	0.00	225.67	260.33
Propiconazole 25EC 0.05%	14.45 (20.44)	70.44	12.23 (18.4)	70.26	443.67	471.00
Mean	30.90 (33.39)[a]		27.80 (31.39)[b]		355.04[b]	381.04[a]
	A	B	A×B	A	B	A×B
CD (p≤0.05)	1.18	0.63	1.676	10.8	5.791	15.3

*40 per cent of stock concentration, A=Treatment, B=Carbendazim/no carbendazim seed treatment
Different alphabetical letters are significantly different at p<0.05
Values in the parentheses are arc sine transformed values
**Per cent disease control = [Inoculated Control (C) – Treatment (T) /Inoculated Control (C)] × 100
[Note: The values of per cent disease control in set II (seed treated with carbendazim) appear to be lower than set I for treatment (Sr. No. 1 to 5). This apparent reduction is due to decreased per cent disease index in the inoculated control (C) (Sr. No. 6), attributed to the exclusive effect of carbendazim seed treatment]

Table 7. Effect of botanicals on the progression of anthracnose of mungbean (AUDPC and apparent infection rate) at PAU, Ludhiana and RRS, Gurdaspur

Treatment*	PAU, Ludhiana				RRS, Gurdaspur			
	AUDPC		Apparent infection rate (r-value)		AUDPC		Apparent infection rate (r-value)	
	Seeds not treated with carbendazim	Seeds treated with carbendazim	Seeds not treated with carbendazim	Seeds treated with carbendazim	Seeds not treated with carbendazim	Seeds treated with carbendazim	Seeds not treated with carbendazim	Seeds treated with carbendazim
Lemon grass oil **(***Cymbopogon citratus)*	672.86	550.27	0.051	0.047	725.12	608.61	0.049	0.049
Neem leaf extract (*Azadirachta indica*)	583.72	522.82	0.048	0.042	618.34	552.13	0.045	0.043
Tulsi leaf extract (*Ocimum tenuiflorum*)	579.84	533.63	0.049	0.047	680.55	602.78	0.046	0.046
Moringa leaf extract (Moringa *oelifera*)	725.13	658.98	0.056	0.049	813.55	711.64	0.051	0.051
Neem oil (*Azadirachta indica*)	439.03	348.02	0.046	0.040	528.89	397.39	0.041	0.040
Inoculated control (C)	933.67	787.16	0.058	0.057	1064.00	894.37	0.056	0.054
Propiconazole 25EC 0.05%	262.91	244.61	0.037	0.029	293.98	260.78	0.038	0.037

*40 per cent of stock concentration

with propiconazole 25EC recording minimum AUDPC (260.78) and inoculated control recording highest AUDPC (894.37). Among botanicals, neem oil recorded lowest AUDPC (397.39). At RRS, Gurdaspur, highest apparent infection rate (0.056) was in inoculated control and lowest apparent infection rate (0.038) was in propiconazole 25EC treatment. Among botanicals, neem oil recorded lowest r-value (0.041). Similar trend was seen in second set with inoculated control recording highest r-value (0.054) followed by moringa leaf extract (0.051). Among botanicals neem oil recorded minimum infection rate (0.040).

The overall results were in conformity with several findings reported previously. Laxman (2006) reported that garlic, neem and eucalyptus oil were effective in managing mungbean anthracnose caused by *C. truncatum*. Uddin et al (2013) reported lowest disease incidence (7.33%) in neem leaf extract treatment at 60 days after sowing, besides giving yield advantage (1.26 t per ha), and higher 1000 seeds weight (27.33g) followed by garlic cloves extract as compared to untreated control. Kulkarni (2019) also reported 10 per cent azadirachtin to be most effective in inhibiting the mycelial growth of *C. truncatum* followed by eucalyptus oil, garlic and neem seed kernel extract.

CONCLUSION

This study highlights the potential of integrating fungicidal seed treatment with botanical foliar sprays, specifically neem oil, neem leaf extract, and tulsi leaf extract, for managing anthracnose in mungbean. The *in vitro* and *in vivo* evaluations revealed that certain botanicals effectively inhibited the growth of *Colletotrichum truncatum* and significantly reduced disease severity in field conditions, particularly in integration with fungicidal seed treatment. Neem oil was the most effective, leading to substantial reductions in Per cent Disease Index (PDI) and Area Under Disease Progress Curve (AUDPC) values, and subsequently, improved yield outcomes. The integrated approach of combining fungicidal (*viz*. carbendazim) seed treatment with botanical foliar applications not only enhances disease control but also promotes sustainable agricultural practices by reducing sole reliance on chemical fungicides. The findings demonstrate potential benefits, as evidenced by higher yields compared to untreated controls, highlighting the practical application and sustainability of this strategy. Future research should explore the synergistic effects of combining botanical extracts with other biocontrol agents and assess their long-term impacts on soil health and crop productivity,

more particularly under organic farming setup. Overall, the integration of carbendazim seed treatment with botanical foliar sprays provides an eco-friendly, effective, and sustainable disease management strategy, aligning with the principles of sustainable agriculture and offering a viable alternative to conventional total chemical-based methods.

AUTHOR CONTRIBUTIONS

All authors made significant contributions to the conception and design of the study. SS and YB were involved in conducting the *in vitro* and *in vivo* experiments, analyzing the data, and drafting the manuscript. YB and VKS provided expertise in statistical analysis and contributed to the interpretation of the results. SK assisted with the outstation field trials and the collection of yield data. VKS and AS reviewed and revised the manuscript ensuring its rigor and clarity.

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