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Fungicides for cost-effective management of white rust-downy mildew disease complex of mustard

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Abstract
White rust-downy mildew disease complex caused by *Albugo candida* and *Hyaloperonospora parasitica* has been affecting rapeseed-mustard crop globally and in India, and causing severe losses over the last few years. The study aimed to evaluate the efficacy of fungicides and their combinations for cost-effective management of this disease complex. In pooled data (2022-23 & 2023-24) among various fungicides, the combination of Metalaxyl @ 0.1% + (Metalaxyl 4% + Mancozeb 64%) @ 0.2% showed significantly minimum disease index and highest yield (14.17% and 25.74 q/ha), followed by Metalaxyl @ 0.2% (15.83% and 24.07 q/ha) and were statistically at par with each other but significantly different from other treatments and untreated control (44.17% and 16.22 q/ha) respectively. The highest net return over control (Rs. 44,976/ha) was recorded in Metalaxyl @ 0.1% + (Metalaxyl 4% + Mancozeb 64%) @ 0.2% followed by Metalaxyl @ 0.2% (Rs.37827/ha) and standard check-Metalaxyl 4% + Mancozeb 64% @ 0.2% (Rs.36898/ha). However, maximum benefit-cost ratio of 2.87 was recorded in Azoxystrobin 8.3%+Mancozeb 66.7% WG @ 0.1%, followed by Azoxystrobin 11% + Tebuconazole 18.3% w/w SC @ 0.1 (2.86) and standard check (2.85). These findings highlight the potential of fungicidal combinations for cost-effective management of white rust-downy mildew disease complex.

Keywords: White rust-downy disease complex, mustard, fungicides, disease severity

Introduction
Oilseed crops constitute a significant component of global agriculture, accounting for approximately 22% of the world's arable land. Among these, rapeseed-mustard is a widely cultivated oilseed, grown extensively across 60 countries. It ranks as the world's second most important oilseed crop after soybean, and holds the premier position among India's oilseed crops (Anonymous, 2024) [2]. India plays a significant role in global rapeseed-mustard production, ranking fourth in terms of both cultivated area and production, after Canada, the European Union, and China (Anonymous, 2024) [2]. It belongs to the *Brassicaceae* family, which includes species like *Brassica juncea* (Indian, Mustard), *B. rapa*, *B. napus*, *B. carinata* (Rapeseed), *Sinapis alba*, and *Eruca sativa*. In India, *B. juncea* dominates, covering over 90% of the mustard cultivation area, primarily in marginal and sub-marginal lands. It is mainly cultivated as a pure crop or intercrop in the eastern, northern, and western regions, where cool, damp winters favour its growth. However, Indian *Brassica* crops face threats from over 30 diseases, which reduce seed quality and oil content.

White rust (*Albugo candida*) and downy mildew (*Hyaloperonospora parasitica*) are among the most damaging diseases of rapeseed-mustard, particularly when they occur in association (Kolte, 1985; Borhan *et al*., 2001; Singh *et al*., 2002) [6, 5, 13]. White rust first appears as small, creamy-white pustules on the lower leaf surface, often with chlorosis on the upper leaf surface. When combined with downy mildew, a dirty, cottony growth also appears around the white rust pustules on the lower surface with a yellow halo on the upper surface (Pandey *et al*., 2024) [8]. On malformed floral parts, *A. candida* pustules are later covered by *H. parasitica* mycelium, spreading over the inflorescence (Saharan *et al*., 2017) [9]. Mixed infections can reduce silique formation by 37-47% and seed yield by 17-32% (Bains and Jhooty, 1979) [3]. In the absence of resistant cultivars, chemical intervention remains the principal strategy for disease management. Field studies across multiple agroecological zones in India have demonstrated the efficacy of several fungicides against the white rust and downy mildew pathogens in mustard.

Captafol, Mancozeb, and Metalaxyl have shown consistent suppression of both pathogens (Saharan *et al*., 2017) [9]. More recently, newer formulations including Fluopicolide + Fosetyl Al and Azoxystrobin were also effective against downy mildew and white rust diseases of mustard (Singh *et al*., 2025; Basavaraj *et al*., 2020) [13, 4].

Notably, these studies have primarily focused on the management of the pathogen in isolation, despite their frequent co-occurrence under field conditions. Given the substantial economic losses caused by the white rust-downy mildew disease complex on Indian mustard, the lack of systematic research on its fungicidal control highlights a critical gap. This underscores the need for the present study on "Fungicides for cost-effective management of white rust-downy mildew disease complex of mustard".

Materials and methods

The field study was carried out in two successive years (2022-23 & 2023-24) to evaluate the efficacy of fungicides and their combinations for the management of white rust-downy mildew disease complex. Varuna, a variety of mustard, was sown on 2nd Nov. in plot size of 3 x 1.5 m^2 with three replications. Seed treatment was done with Metalaxyl @ 2g/kg seed. Two foliar sprays of each fungicide were applied 1st at 55 DAS and 2nd at 70 DAS. The plots without fungicide application served as control. The details of treatments used in the study are given in Table 1.

Table 1: Details of treatments

S.N.	Fungicide		Concentration (%)
	Common name	Trade Name	
1.	Amisulbrom 20% SC	Kirari	0.05
2.	Azoxystrobin 23%SC	Amistar	0.05
3.	Azoxystrobin 8.3% + Mancozeb 66.7% WG	Avancer	0.10
4.	Azoxystrobin 11% + Tebuconazole 18.3% w/w SC	Spectrum	0.10
5.	Metalaxyl @ 0.1%+ (Metalaxyl 4% + Mancozeb 64%) @ 0.2%	Ridomet 35 + Ridomil Gold	0.30
6.	Metalaxyl 35% WS	Ridomet 35	0.20
7.	Metalaxyl 4% + Mancozeb 64% (standard check)	Ridomil Gold	0.20
8.	Untreated check	-	-

The observations of leaf area covered in each treatment were recorded at 70, 80, and 90 DAS using 0-9 rating scale given by AICRP-RM, 2010 (Table 2) and percent disease index was calculated using the following formula:

$$\text{PDI (\%)} = \frac{\text{Sum of all disease rating (Number of selected plants x Disease rating scale)}}{\text{Total number of plants X Maximum disease rating}} \text{ X } 100$$

Table 2: 0-9 Rating scale (AICRP-RM, 2010)

Rating score	Leaf area covered (%)
0	No symptoms
1	1-5
3	6-10
5	11-25
7	26-50
9	>50

Statistical Analysis

The field experiment was laid out in a Randomized Block Design (RBD) with a single-factor treatment structure and three replications, ensuring statistical rigor and minimizing experimental error. Disease impact was quantified by calculating the Percent Disease Index (PDI) for each treatment. The collected data were subjected to analysis of variance (ANOVA) to determine the significance of treatment effects. Critical Differences (CD) at the 5% probability level ($p \leq 0.05$) were computed to separate the treatment means and identify statistically significant differences. For statistical analyses, SPSS software, OPSTAT, and WASP 2.0 were employed.

Results & Discussion

In the year 2022-23, the treatment comprising Metalaxyl @ 0.1% combined with (Metalaxyl 4% + Mancozeb 64%) @ 0.2% exhibited the lowest disease index (13.33%), maximum disease reduction (70.38%) at 90 DAS and highest yield (25.56 q/ha) followed by Metalaxyl @ 0.2% with disease index of 15%, disease reduction of 66.67% and yield of 24.07 q/ha and standard check (16.67% DI, 62.95% disease reduction and yield 24.07 q/ha) (Table 3, 4 & Figure 1, 2).

In the year 2023-24, Metalaxyl @ 0.1% combined with (Metalaxyl 4% + Mancozeb 64%) @ 0.2% was again found most effective, showing the lowest disease index (15.00%), maximum disease reduction (65.38%) at 90 DAS and highest yield (25.93 q/ha) followed by Metalaxyl @ 0.2% and the standard check (Metalaxyl 4% + Mancozeb 64% @ 0.2%) both showing disease index of 16.67%, disease reduction of 61.53% at 90 DAS while yield of 24.07 and 23.33 q/ha respectively (Table 3, 4 & Figure 1, 2).

In pooled data (2022-23 & 2023-24), Metalaxyl @ 0.1% + (Metalaxyl 4% + Mancozeb 64%) @ 0.2% consistently recorded the lowest disease index (14.17%), highest disease reduction (67.92%) at 90 DAS, and the highest yield (25.74 q/ha) followed by Metalaxyl @ 0.2% with disease index of 15.83%), disease reduction of 64.16% and yield of 24.07 q/ha and were at par with each other but statistically significant over all other treatments, standard check and untreated check (Table 3, 4 & Figure 1, 2).

The present findings align with earlier reports highlighting the efficacy of Metalaxyl-based fungicides against downy mildew and white rust. While earlier findings predominantly focused on either white rust or downy mildew in isolation. Meena *et al.* (2013) [7] found seed treatment with Apron (Metalaxyl) highly effective in reducing downy mildew incidence in Indian mustard. Singh *et al.* (2025) [12] reported significantly minimum disease incidence of 12.40% (2021-22) and 18.30% (2022-23) in broccoli with two sprays of Metalaxyl + Mancozeb (0.25%). Salunke (2018) [10] observed the lowest disease severity (9.26%) with seed

treatment (Apron 35 SD), followed by a Metalaxyl spray. Similarly, Sharma *et al.* (2025) [11] reported minimum disease severity (7.71%), staghead incidence (9.61%), and highest yield (30.03 q/ha) with foliar application of Metalaxyl 8% + Mancozeb 64%. In the present findings, the combination of Metalaxyl + (Metalaxyl + Mancozeb) was found most effective in managing white rust-downy mildew disease complex. However, no research reports are available on the management of the white rust-downy mildew disease complex using fungicides. Before recommending any fungicide for disease management, assessing its cost-effectiveness is crucial to ensure economic viability. An economic analysis was thus performed using pooled data from both years for all the treatments (Table 5 & Figure 3). Among all the treatments maximum net return of Rs.112485/ha and net return over control of Rs.44976/ha was obtained in Metalaxyl @ 0.1% + (Metalaxyl 4% + Mancozeb 64%) @ 0.2%. This was followed by Metalaxyl @ 0.2% with Rs.105336/ha and Rs.37827/ha and standard check Metalaxyl 4% + Mancozeb 64% @ 0.2% with Rs.104407/ha and ₹36898/ha net return and net return over control, respectively. The highest benefit cost ratio of 2.87 was obtained in Azoxystrobin 8.3%+Mancozeb 66.7% WG @ 0.1, followed by Azoxystrobin 11% + Tebuconazole 18.3% w/w SC @ 0.1 and standard check @ 0.2%) with B:C ratios of 2.86 and 2.85, respectively.

Table 3: Efficacy of fungicides for the management of white rust-downy mildew disease complex under field conditions

Fungicide	Conc. (%)	Disease Index (%)											
		2022-23				2023-24				Pooled data (2022-23 & 2023-24)			
		Days after sowing			Disease reduction (%)	Days after sowing			Disease reduction (%)	Days after sowing			Disease reduction (%)
		70	80	90		70	80	90		70	80	90	
Amisulbrom 20% SC	0.05	6.67 (14.92)	16.67 (24.08)	23.33 (28.87)	48.15	5.00 (12.91)	15.00 (22.77)	21.67 (27.72)	49.99	5.84 (13.98)	15.84 (23.44)	22.50 (28.31)	49.06
Azoxystrobin 23%SC	0.05	6.67 (14.96)	11.67 (19.96)	20.00 (26.54)	55.55	8.33 (16.76)	10.00 (18.40)	23.33 (28.87)	46.16	7.50 (15.89)	10.84 (19.21)	21.67 (27.73)	50.94
Azoxystrobin 8.3% + Mancozeb 66.7% WG	0.1	5.00 (12.92)	10.00 (18.42)	20.00 (26.55)	55.55	5.00 (12.91)	13.33 (21.41)	18.33 (25.34)	57.70	5.00 (12.92)	11.67 (19.96)	19.17 (25.95)	56.60
Azoxystrobin 11% + Tebuconazole 18.3% w/w SC	0.1	5.00 (12.86)	10.00 (18.43)	16.67 (24.7)	62.95	5.00 (12.92)	10.00 (18.41)	18.33 (25.34)	57.70	5.00 (12.92)	10.00 (18.43)	17.50 (24.72)	60.38
Metalaxyl @ 0.1%+ (Metalaxyl 4% + Mancozeb 64%) @ 0.2%	0.3	5.00 (12.87)	6.70 (14.95)	13.33 (21.39)	70.38	3.33 (10.50)	8.33 (16.75)	15.00 (22.77)	65.38	4.17 (11.77)	7.50 (15.89)	14.17 (22.10)	67.92
Metalaxyl 35% WS	0.2	5.00 (12.92)	8.33 (16.77)	15.00 (22.76)	66.67	5.00 (12.87)	10.00 (18.41)	16.67 (24.07)	61.53	5.00 (12.92)	9.17 (17.62)	15.83 (23.44)	64.16
Metalaxyl 4% + Mancozeb 64% (standard check)	0.2	6.67 (14.96)	8.33 (16.76)	16.67 (24.08)	62.95	3.33 (10.49)	8.33 (16.77)	16.67 (24.08)	61.53	5.00 (12.92)	8.33 (16.77)	16.67 (24.08)	62.26
Untreated Check	-	18.33 (25.34)	28.33 (32.14)	45.00 (42.11)	-	23.33 (28.87)	33.33 (35.25)	43.33 (41.15)	-	20.83 (27.14)	30.83 (33.72)	44.17 (41.63)	-
CD (5%)		1.24 (1.53)	1.49 (1.23)	2.52 (1.91)	-	1.25 (1.43)	1.27 (1.13)	2.80 (1.87)	-	0.82 (0.91)	1.00 (0.80)	1.93 (1.37)	-
SE(m)		0.40 (0.50)	0.49 (0.40)	0.82 (0.62)	-	0.41 (0.47)	0.41 (0.37)	0.91 (0.61)	-	0.27 (0.30)	0.33 (0.26)	0.63 (0.45)	-
C.V.		9.60 (5.70)	6.72 (3.46)	6.72 (4.00)	-	9.72 (5.49)	5.28 (3.03)	7.31 (3.87)	-	6.34 (3.42)	4.33 (2.20)	5.09 (2.85)	-

*All values are the average of three replications
*Angular transformed values are given in parentheses

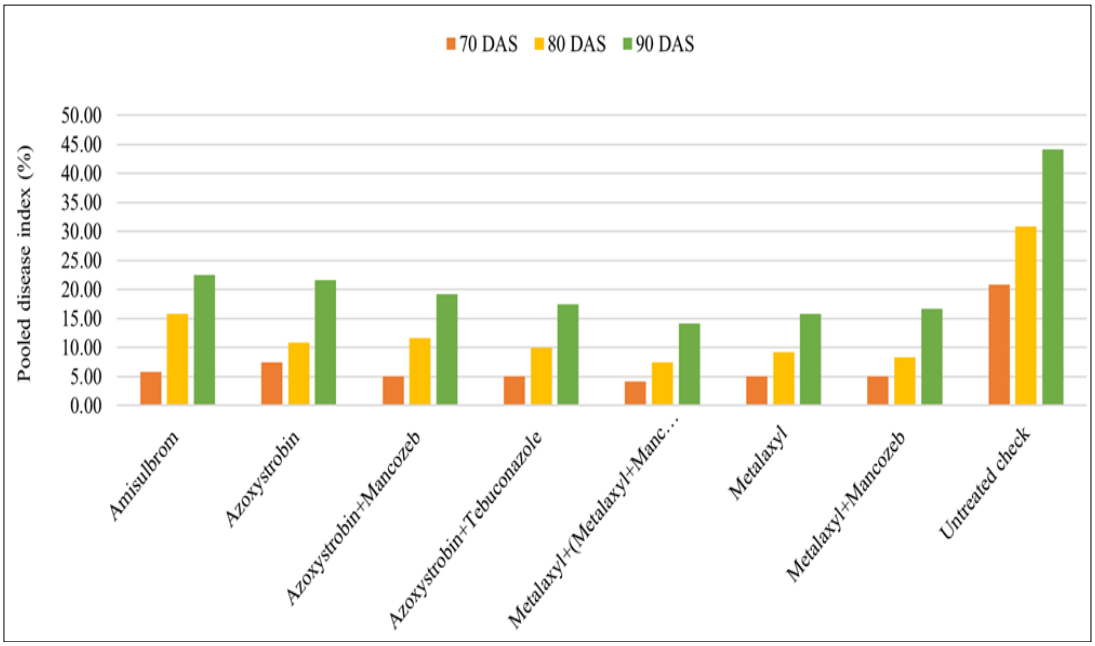

Fig 1: Efficacy of fungicides for the management of white rust-downy mildew disease complex under field conditions (2022-23 & 2023-24)

Table 4: Efficacy of fungicides on mustard yield

Treatment	Conc. (%)	Yield (2022-23)		Yield (2023-24)		Pooled yield (2022-23 & 2023-24)		Increase in yield
		kg/4.5m^2	q/ha	kg/4.5m^2	q/ha	kg/4.5m^2	q/ha	%
Amisulbrom 20% SC	0.05	0.90	20.00	0.86	19.04	0.88	19.52	20.34
Azoxystrobin 23%SC	0.05	0.97	21.48	0.92	20.37	0.94	20.93	29.04
Azoxystrobin 8.3% + Mancozeb 66.7% WG	0.1	0.95	21.11	0.99	22.07	0.97	21.59	33.11
Azoxystrobin 11% + Tebuconazole 18.3% w/w SC	0.1	1.06	23.48	1.02	22.59	1.04	23.04	42.05
Metalaxyl @ 0.1%+ (Metalaxyl 4% + Mancozeb 64%) @ 0.2%	0.3	1.15	25.56	1.17	25.93	1.16	25.74	58.69
Metalaxyl 35% WS	0.2	1.08	24.07	1.08	24.07	1.08	24.07	48.39
Metalaxyl 4% + Mancozeb 64% (Std. Check)	0.2	1.08	24.07	1.07	23.33	1.08	23.70	46.12
Untreated Check	-	0.76	16.89	0.70	15.56	0.73	16.22	-
CD (5%)		0.11	2.47	0.15	3.33	0.09	1.94	-
SE(m)		0.04	0.81	0.05	1.09	0.03	0.63	-
C.V.		6.27	6.27	8.60	8.60	4.96	4.95	-

*All values are the average of three replications

Table 5: Cost-benefit ratio of fungicides against white rust-downy mildew disease complex (Pooled 2022-23 & 2023-24)

Treatment	Dose (ml or g/ha)	Cost of protection/ha					Cost of cultivation (Rs. /ha)	Protection & cultivation cost (Rs/ha)	Gross return		Cost-benefit ratio		
		Cost of fungicide /kg or lit (Rs.)	Cost of fungicide for 1 spray (Rs.)	Cost of fungicide for 2 sprays (Rs.)	Labour cost for 2 sprays (Rs.)	Total cost			Yield (q/ha)	Total income (yield x price/q) (Rs.)	Net return (Rs.)	Net return over control (Rs.)	B:C
		1	2	3	4	5 (3+4)	6	7 (5+6)	8	9	10 (9-7)		11 (10/7)
Amisulbrom 20% SC @ 0.05	375	12200	4575	9150	800	9950	29000	38950	19.52	116134	77184	9675	1.98
Azoxystrobin 23%SC @ 0.05	375	7738	2901	5802	800	6602	29000	35602	20.93	124504	88902	21393	2.50
Azoxystrobin 8.3%+Mancozeb 66.7% WG @ 0.1	750	2260	1695	3390	800	4190	29000	33190	21.59	128470	95280	27771	2.87
Azoxystrobin 11% + Tebuconazole 18.3% w/w SC @0.1	750	3832	2874	5748	800	6548	29000	35548	23.04	137068	101520	34011	2.86
Metalaxyl @ 0.1%+(Metalaxyl 4%+Mancozeb 64%) @ 0.2%	750+1500	2700+2276	5439	10878	800	11678	29000	40678	25.74	153163	112485	44976	2.77
Metalaxyl 35% WS @ 0.2%	1500	2700	4050	8100	800	8900	29000	37900	24.07	143236	105336	37827	2.78
Metalaxyl 4%+Mancozeb 64% (Std. Check) @ 0.2%	1500	2276	3414	6828	800	7628	29000	36628	23.70	141035	104407	36898	2.85
Untreated Check	-	-	-	-	-	-	29000	29000	16.22	96509	67509	-	2.33

* Labour charge: Rs. 400 per spray
*Market price of mustard grain: Rs. 5950 per quintal
*Water used for 1 foliar spray: 750 lit/ha

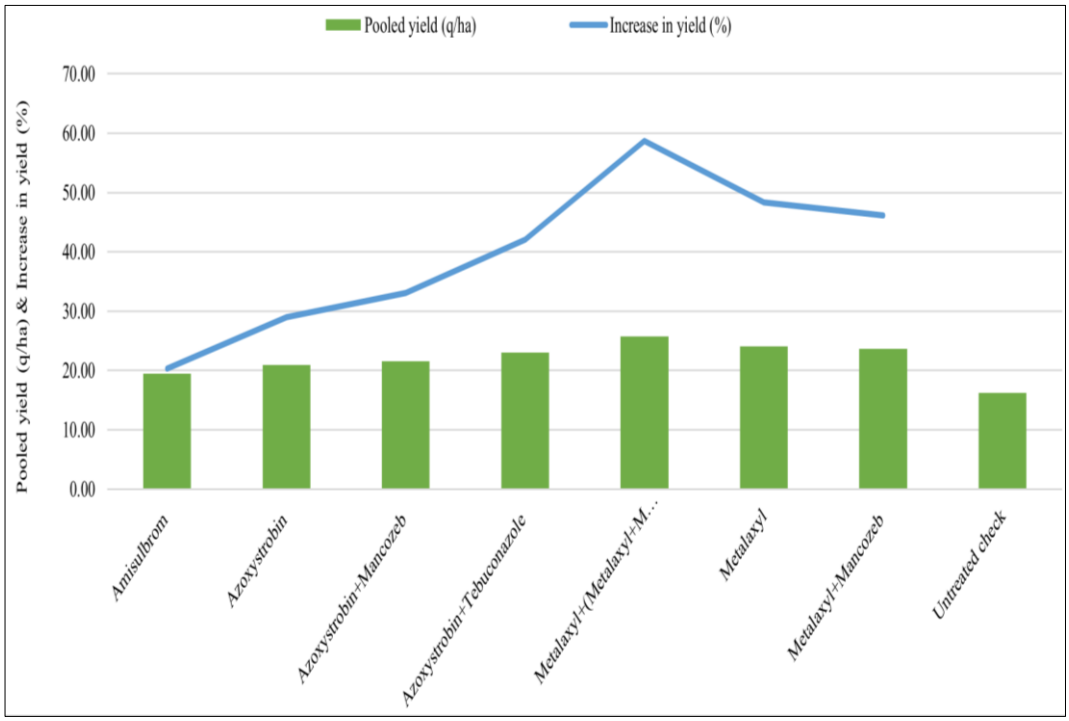

Fig 2: Efficacy of fungicides on grain yield of mustard (2022-23 & 2023-24)

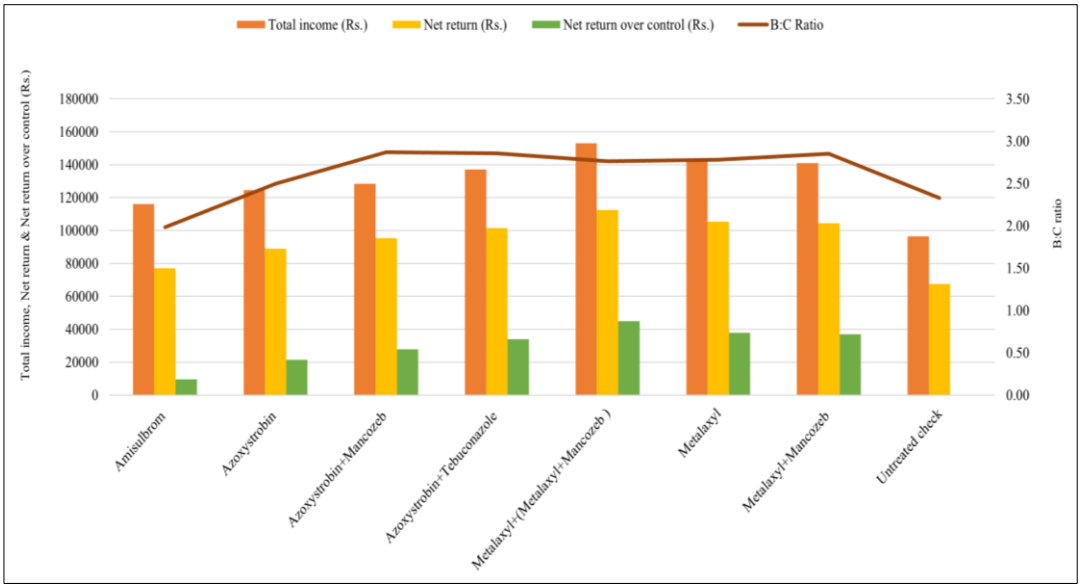

Fig 3: Cost-benefit ratio of fungicides against white rust-downy mildew disease complex (Pooled 2022-23 & 2023-24)

Conclusion

White rust-downy mildew disease complex continues to pose a serious challenge to mustard production, since last few years particularly under favourable environmental conditions for disease development. This study demonstrated that Metalaxyl @ 0.1% in combination with Metalaxyl 4% + Mancozeb 64% @ 0.2%, applied at 55 and 70 DAS, provided the most effective disease control across two growing seasons. This treatment not only minimized disease index but also resulted in the highest and most consistent grain yield and net return over control followed by Metalaxyl @ 0.25% and standard check (Metalaxyl 4% + Mancozeb 64%) @ 0.2%. Economic analysis further validated the practicality of the combined treatment, proving it both agronomically and economically superior. The study underscores the importance of targeting co-infection of white rust and downy mildew with combination of fungicides. It also demonstrated that increasing the proportion of Metalaxyl specifically by applying Metalaxyl @ 0.1% in combination with Metalaxyl 4% + Mancozeb 64% @ 0.2% significantly enhanced disease control. This highlights the critical role of fungicide formulation for effective disease management. These findings can guide farmers and policymakers toward adopting efficient and cost-effective disease management strategies, ultimately improving the productivity and sustainability of mustard cultivation in India.

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