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Bio-efficacy of Mandipropamid in the management of downy mildew of grapes in India

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Grape is an important commercial fruit crop cultivated around the world. Grapevine downy mildew, one of the most devastating diseases of the crop, is caused by the oomycetous fungus *Plasmopara viticola* in regions characterized by high precipitation rate and 28-30°C temperature, leading to crop losses ranging around 80-90%. For managing downy mildew, different fungicides with varied modes of action are used. Field trials were conducted to evaluate fungicide Mandipropamid (Carboxylic Acid Amide) at ten different locations of India i.e., Maharashtra (9) and Tamilnadu (1). Experimental results revealed that all the treatments significantly reduced the downy mildew disease severity over the untreated control. Mandipropamid 250 SC @ 0.8 ml/litre of water successfully reduced the disease at all the locations along with Cyazofamid 34.5% SC @ 0.2 ml/ Litre of water. Based on these findings, Mandipropamid 250 SC appears to be a reliable option for managing downy mildew, as there were no signs of resistance to the pathogen in the tested locations.

Keywords : Bio efficacy, downy mildew, fungicide, grapes, Mandipropamid

INTRODUCTION

Grape (*Vitis vinifera*) is an important commercial fruit crop of India that constitutes the highest foreign exchange among all fruit crops. In India, grape production is 2950 thousand MT from an average area of 175.93 thousand ha in the year 2023-24 (Anonymous, 2025). About 80% of the production comes from Maharashtra, followed by Karnataka and Tamil Nadu (Shinde, 2016; https://agriexchange.apeda.gov.in/Production/Indiacat/Index). Grape is attributed with many nutritional properties like high vitamins, minerals, lipids, fiber content, along with antioxidant, antimicrobial, anti-inflammatory, and anti-carcinogenic activities (Sabra *et al*. 2021). Among several biotic constraints, downy mildew is the major disease during the monsoon accompanied by cloudy conditions. *Plasmopara viticola*, the causal agent of grapevine downy mildew, is an oomycete phytopathogen that was introduced to Europe in the late 19th century.

The first symptom of the disease appears on the new flush as small light green patches on the upper surface of the leaves and a whitish downy growth on the corresponding lower surface. The downy growth of the pathogenic fungus spreads rapidly on the lower surface, turning the corresponding greenish patches on the upper surface yellowish and chlorotic (oil spots) with age (Ashraf, 2023). The disease causes a reduction in the sugar content, failure of several physiological processes in the crop plants, leaf drop, vine suppression, and poor ripening of shoots, resulting in poor establishment of the crop in the following year. Downy mildew can cause yield losses of up to 70% in some years if the disease develops epiphytically (Junior *et al.* 2020; Fontaine *et al.* 2021). Several fungicides like Propineb, Mancozeb, Fosetyl Al, Dimethomorph, Mandipropamid, and Cyazofamid were reported to control the disease (Ghule *et al* 2018). Continuous application of a fungicide generated fungicide-resistant strains. To overcome the disease caused by the resistant strains, there is a need for a large number of new effective molecules to be incorporated in the management schedule (Sawant *et al.* 2016). This

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necessitates the evolution of new molecules with unique modes of action. Mandipropamid is also proposed for use on leafy vegetables to manage downy mildew (*Bremia lactucae*) and blue mold (*Peronospora effuse*). Mandipropamid belongs to the mandelic acid amine sub-group of the carboxylic acid amide (CAA) fungicides chemical group, with the target site as cellulose synthase in cell wall biosynthesis of the pathogen (FRAC Pathogen Risk List 2024).

Mandipropamid is generally mixed with fungicides of different modes of action for the management of cucumber downy mildew and *Phytophthora infestans* (Cohen *et al*.,2007), and the proposal for such ready mixes to manage downy mildew in grapes is in process. Hence, it is necessary to understand the efficacy of mandipropamid as a solo fungicide across multiplications to bring out the best synergy in the ready mix.

MATERIAL AND METHODS

Field experiments were conducted to analyze the comparative bio-efficacy of Mandipropamid 250 SC against downy mildew of grapes at 10 locations in Pune (18.192082° N 73.986975° E), Nashik (20.0771° N, 74.1094° E), Sangli (17.0265° N 74.3743 E) and Pandharpur (17.6745° N 75.3237° E) district of Maharashtra in Thompson seedless variety, and Theni in Tamilnadu in a Black paneer-Black muscut variety during 2020-21 after fruit pruning (Table 1).

The test chemical Mandipropamid 250 SC (branded as Revus) was supplied by Syngenta Private Limited, India. Six test treatments comprising Mandipropamid 250 SC @ 800 ml/ ha, Iprovalicarb + Propineb @ 3000g/ha, Cyazofamid 34.5% SC @ 200 ml/ha, Dimethomorph 50 WP @ 1000 g/ha, Mancozeb 75% WP @ 1500 g/ha, and an untreated control were taken for the study. The experiment was laid out in a Randomized Block Design (RBD) with four replications, with a spacing of 3.05m x 1.83m on Y trellises. Fungicide application was commenced with the visibility of initial symptoms (35 days after fruit pruning) with a knapsack sprayer. Four number sprays, including one preventive spray, were applied. Water volume used for spray was calculated based on the requirement of 1000 l/ha at full canopy. Downy mildew incidence on leaves was recorded visually, adopting the 0-4 scale, where 0 = nil, 1 = trace to 25%, 2 = 26-50%, 3 = 51-75% and 4 = more than 75% leaf area infected (Horsfall and Heuberger 1942). Percent Disease Index (PDI) was calculated by the following formula of McKinney (1923): PDI = [(Sum of numerical ratings) / (Number of leaves observed × Maximum of rating scale) x 100]

The ratings on ten leaves were recorded on randomly selected canes. Ten such canes per vine were observed, and 100 disease observations were recorded per replicate. Four replications for each treatment were considered. Only actively growing downy mildew lesions were considered for recording ratings. The marketable yield from all the treatments was recorded at harvest and expressed in kg /vine and further extrapolated to yield in q/ha basis.
The PDI was calculated, and the percent disease control (PDC) was tabulated using the formula of Vincent (1947) viz., percent disease control = [(PDI in untreated control - PDI in fungicide treatment) / PDI in untreated control] x 100.

Statistical Analysis

The data of PDI was transformed by using arcsine transformation for leaves and analyzed statistically following a Randomized Block Design (RBD) using WASP 2.0 (ICAR Central Coastal Agricultural Research Institute). All data obtained were subsequently analyzed statistically.

RESULTS AND DISCUSSION

Field efficacy of Mandipropamid against downy mildew at ten locations

In ICAR-NRCG location (18.49’21" N, 73.98’69" E), Mandipropamid @ 0.8 ml/l showed lower PDI of 17.9 with a PDC of 52.0 as compared to Iprovalicarb + Propineb (5.5 + 61.25%) WP @ 3.0 g/l, which showed a PDI of 18.1 (Fig 1 and Table 2a) with a PDC of 51.7, Dimethomorph 50 WP @ 1.0 g/l and Mancozeb 75 WP @ 1.5 g/l, which showed a PDI of 18.3 and 19.0, respectively. Cyazofamid @ 0.2 ml/l exhibited the

Table 1: Details of locations of trials of Mandipropamid against downy mildew of grapes

State	District	Latitude	Longitude	Location
Maharashtra	Pune	18.49'21° N	73.98'69° E	ICAR-NRCG, Pune
		19.00'47° N	73.94'69° E	Manchar
		19.20'32° N	73.87'43° E	Narayangaon
	Nashik	20^0 14'57" N	73^0 52'15" E	Warkheda
		20^0 14'37" N	73^0 57'7" E	Khedgaon
		20^0 10"37" N	74^0 28' E	Ahirgaon
		20^0 13"58" N	74^0 24'4" E	Shirwdewani
	Sangli	17^0 8'5" N	74^0 33'37 E	Panmalewadi
	Pandharpur	17.68'06° N	75.31'55° E	Pandharpur
Tamil Nadu	Theni	10.00'79° N	77.47'35° E	Theni

Table. 2(a): Bio efficacy of Mandipropamid 250 SC against downy mildew of grapes during 2020-21

Tr. No.	Treatment	Formulation (g or ml)/l	ICAR-NRCG		Warkheda		Khedgaon		Ahirgaon		Shirwade wani	
			PDI	PDC	PDI	PDC	PDI	PDC	PDI	PDC	PDI	PDC
T_1	Mandipropamid 250 SC	0.8	9.5 (17.9)c	62.2 (52.0)b	13.44 (21.2)c	42.6 (40.7)bc	14.25 (22.1)c	47.5 (43.6)c	10.5 (18.9)c	52.1 (46.2)bc	13.1 (21.2)c	54.5 (47.6)b
T_2	Iprovalicarb + Propineb (5.5 + 61.25%) WP	3.0	9.6 (18.1)c	61.7 (51.7)b	13.2 (21.3)c	43.4 (41.2)b	14.0 (21.9)c	48.5 (44.1)b	10.3 (18.7)c	53.2 (46.86) b	13.0 (21.1)c	55.1 (47.9)b
T_3	Cyazofamid 34.5% SC	0.2	7.8 (16.2)d	67.6 (55.3)a	11.3 (19.6)d	51.7 (45.9)a	12.4 (20.6)d	54.2 (47.4)a	8.5 (17.0)d	61.2 (51.47) a	11.7 (20.0)d	59.4 (50.4)a
T_4	Dimethomorph 50 WP	1.0	9.8 (18.3)c	61.7 (51.7)b	13.6 (21.6)c	41.8 (40.3)bc	14.3 (22.2)c	47.1 (43.3)c	10.8 (19.1)c	51.0 (45.5)bc	13.3 (21.4)c	53.8 (47.2)b
T_5	Mancozeb 75 WP	1.5	10.6 (19.0)b	59.2 (50.3)c	15.0 (22.6)b	35.7 (36.6)c	16.9 (24.2)b	37.7 (37.8)d	12.2 (20.4)b	44.4 (41.8)c	14.8 (22.6)b	48.9 (44.3)c
T_6	Untreated control	-	25.31 (30.19) a	-	23.4 (28.9)a	-	27.1 (31.4)a	-	22.06 (28.0)a	-	29.00 (32.5)a	-
	CD (P = 0.05)		0.66	1.78	0.57	1.88	0.53	0.52	0.62	1.95	0.53	1.41

lowest PDI of 16.2 with a corresponding PDC of 55.3 (Fig 2).

In Nashik, the PDI of downy mildew was in the range of 8.5 to 29.0. At Ahirgaon (20^0 10"37" N, 74^0 28' E), PDI was less as compared to the other locations. Observations for PDI at all the four locations viz; Warkheda (20^0 14'57" N, 73^0 52'15" E), Khedgaon (20^0 14'37" N, 73^0 57'7" E), Ahirgaon (20^0 10"37" N, 74^0 28' E) and Shirwde wani (20^0 13"58" N, 74^0 24'4" E) various treatments, showed the same trend as above in managing the disease. Mandipropamid performed better than Mancozeb @ 2.0 g/l of water and in the untreated control. Iprovalicarb + Propineb and Dimethomorph were at par with Mandipropamid in managing the downy mildew.

The results from Manchar (19.00'47" N, 73.94'69" E) and Narayangaon (19.20'32" N, 73.87'43" E) showed that Mandipropamid had a PDI of 18.8 and 20.4 (fig 1) with PDC 53.4 and 59.6 (Fig. 2 and table 2b), respectively and it was at par with Iprovalicarb + Propineb (PDI of 19.0 and 20.1, respectively) and Dimethomorph, which had a PDI of 20.2 at both the locations. Cyazofamid performed best in managing downy mildew (PDI 17.3 and 18.4 with PDC 56.94 and 54.9,

Table. 2 (b): Bio efficacy of Mandipropamid 250 SC against downy mildew of grapes during 2020-21

Tr. No.	Treatments	Formulation (g or ml)/l	Manchar		Narayngaon		Panmale wadi		Pandharpur		Theni	
			PDI	PDC	PDI	PDC	PDI	PDC	PDI	PDC	PDI	PDC
T_1	Mandipropamid 250 SC	0.8	10.4 (18.8)d	65.0 (53.4)b	12.1 (20.4)c	59.6 (50.5)b	10.2 (18.6)c	63.1 (52.6)b	10.5 (18.9)c	63.5 (52.8)b	12.5 (20.6)c	58.5 (49.9)b
T_2	Iprovalicarb + Propineb (5.5 + 61.25%) WP	3.0	10.6 (19.0)d	64.3 (53.3)b	11.8 (20.1)c	60.7 (51.1)b	10.0 (18.4)c	64.0 (53.1)b	10.3 (18.7)c	64.2 (53.2)b	12.3 (20.5)c	59.2 (50.3)b
T_3	Cyazofamid 34.5% SC	0.2	8.8 (17.3)e	70.2 (56.94)a	10.0 (18.4)d	66.9 (54.9)a	9.1 (17.5)d	67.2 (55.0)a	8.5 (16.9)d	70.7 (57.2)a	9.1 (17.6)d	69.5 (56.5)a
T_4	Dimethomorph 50 WP	1.0	11.9 (20.2)c	59.9 (50.7)c	11.9 (20.2)c	60.5 (51.0)b	10.3 (18.7)c	62.7 (52.3)b	10.8 (19.1)c	62.7 (52.3)b	12.6 (20.8)c	57.9 (49.5)b
T_5	Mancozeb 75 WP	1.5	13.3 (21.3)b	55.3 (48.0)d	13.8 (21.8)b	54.0 (47.32)c	12.1 (20.3)b	56.4 (48.6)c	12.2 (20.4)b	57.7 (49.4)c	14.2 (22.1)b	52.8 (46.6)c
T_6	Untreated control	-	29.8 (33.0)a	-	30.1 (33.2)a	-	27.8 (31.8)a	-	29.0 (32.5)a	-	30.1 (33.3)a	-
	CD (P = 0.05)		0.58	1.38	0.55	1.36	0.69	1.63	0.73	1.67	0.62	1.48

Table. 2 (c): Effect of Mandipropamid 250 SC on yield of Grapes during 2020-21

Tr. No.	Treatments	Formulation (g or ml)/l	ICAR-NRCG	Warkheda	Khedgaon	Ahirgaon	Shirwade wani	Narayngaon-1	Narayngaon-2	Sangli	Pandharpur	Theni
T_1	Mandipropamid 250 SC	0.8	222.7b	215.6b	190.9b	197.0b	135.6b	162.1b	118.4b	144.8b	127.4b	180.2b
T_2	Iprovalicarb + Propineb (5.5 + 61.25%) WP	3.0	216.7b	203.0b	188.2b	193.8b	132.5b	158.0b	115.5b	141.7b	124.3b	174.1b
T_3	Cyazofamid 34.5% SC	0.2	255.4a	243.1a	233.4a	233.0a	171.5a	210.6a	143.7a	194.0a	157.4a	225.6a
T_4	Dimethomorph 50 WP	1.0	213.8b	205.0b	192.7b	199.9b	138.6b	156.2b	114.0b	139.4b	121.5b	174.4b
T_5	Mancozeb 75 WP	1.5	175.7c	160.3c	152.6c	170.1c	109.5c	116.4c	88.9c	104.8c	95.2c	139.3c
T_6	Untreated control	-	117.8d	113.5d	98.9d	131.2d	86.9d	100.1d	68.1d	83.5d	71.0d	107.5d
	CD (P = 0.05)		1.25	1.20	1.22	1.26	1.13	1.56	1.07	0.94	1.03	1.10

respectively) as compared to the other treatments.

At Sangli, Panmalewadi, (17^0 8'5" N, 74^0 33'37" E), Mandipropamid showed a lower PDC as compared to Cyazofamid but performed better than Mancozeb and the untreated control.

In case of Pandharpur (17.68'06" N 75.31'55" E), Mandipropamid showed a PDI of 18.9 with a PDC of 52.8 (Fig 1 and Table 2b), and it was followed by Iprovalicarb + Propineb, which exhibited a PDI of 18.7 with a PDC of 53.2 (Fig. 2 and Table 2b), and Dimethomorph (PDI of 19.1 and PDC of 52.3). Cyazofamid 34.5% SC was the most effective among the tested fungicides for reducing downy mildew (PDI 16.9; PDC 57.2). So, all the CAA fungicides were at par, but Cyazofamid is QoI (Quinone outside Inhibitor), being a relatively newer molecule, performed better than the CAA fungicides.

In Theni (10°0' 79^0 N, 77° 47'35" E), Mandipropamid showed a PDI of 20.6 with a PDC of 49.9, while Dimethomorph exhibited a PDI of 20.8 (fig 1) with a PDC of 49.9 (Fig. 2 and table 2b), and Mancozeb 75 WP had a PDI of 22.1 with a PDC of 46.6. The untreated control had the highest PDI of 33.3.

Effect of Mandipropamid 250 SC on harvestable yield of Grapes during 2020-21

In case of ICAR-NRCG, the harvestable yield of Mandipropamid @ 0.8 ml/l, Iprovalicarb + propineb @ 3 g/l, and Dimethomorph @ 1g/l recorded 222.7 q/ha, 216.7 q/ha, and 213.8 q/ha, (fig 3 and

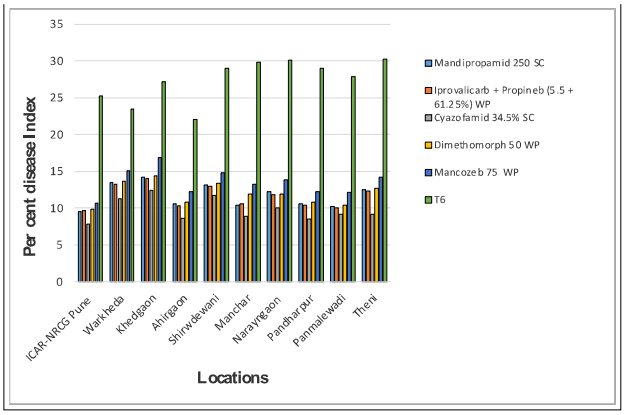

Fig. 1: PDI of Mandipropamid 250 SC against downy mildew of Grapes

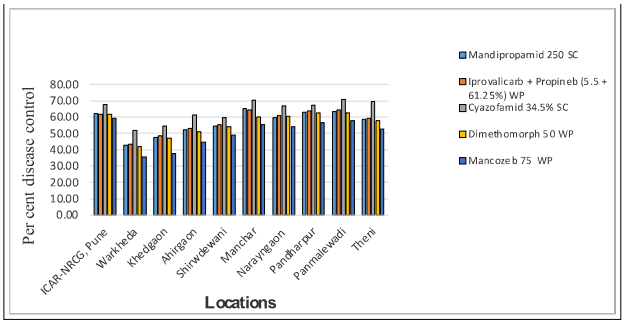

Fig. 2: PDC of Mandipropamid 250 SC against downy mildew of Grapes

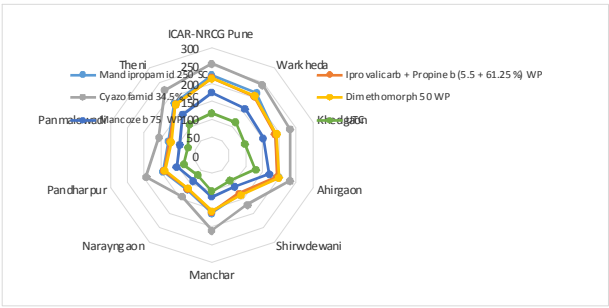

Fig. 3: Effect of Mandipropamid 250 SC on yield of Grapes during 2020-21

table 2c) respectively. Yield of Cyazofamid @ 0.2 ml/l (255.4 q/ha) was higher than the untreated control (117.8 q/ha) and all other fungicide treatments.

In Warkheda of Nashik, Mandipropamid (215.6 q/ha) recorded a higher yield than mancozeb (160.3 q/ha), and an untreated control (113.5 q/ha) followed by Iprovalicarb + propineb and Dimethomorph, which recorded harvestable yield of 203.0 q/ha and 205.0 q/ha, respectively. Among all the treatments, Cyazofamid resulted in the highest harvestable yield i.e., 243.18 q/ha. (fig 3 and table 2c) In case of Khedgaon of Nashik, Mandipropamid provided more harvestable yield i.e., 190.9 q/ha, and was at par with Iprovalicarb + propineb (188.2 q/ha), and Dimethomorph, but not more than Cyazofamid (233.4 q/ha) (Fig 3). At Ahirgaon and Shirwdewani (district Nashik), it was observed that Mandipropamid resulted in more harvestable yield (197.0 q/ha and 135.6 q/ha, respectively) than the rest of the fungicides, except Cyazofamid (233.0 q/ha and 171.5 q/ha).

In case of Narayangaon the same trend was observed in both the locations i.e., Manchar and Narayangaon. Mandipropamid, Iprovalicarb + propineb and Dimethomorph showed higher yield than the untreated control, but among all the treatments, Cyazofamid provided the highest marketable yield (210.6 q/ha and 143.7 q/ha, respectively).

In Sangli, Cyazofamid resulted in more marketable yield 194.00 q/ha than Mandipropamid (144.8 q/ha), Iprovalicarb + propineb (141.7 q/ha), and Dimethomorph (139.4 q/ha) (Fig. 3 and Table 2c).

At Pandharpur, it was observed that the yield of Cyazofamid (157.4 q/ha) was higher than the untreated control (71.0 q/ha) and all the other fungicide treatments. In case of Theni, Mandipropamid, Iprovalicarb + propineb, and Dimethomorph recorded a harvestable yield of 180.25 q/ha, 174.1 q/ha, and 139.39 q/ha. (Fig 3 and Table 2c).

A comparative analysis of bio-efficacy of Mandipropamid 250 SC and other fungicides registered against downy mildew, viz., Cyazofamid 34.5% SC, Dimethomorph 50 WP, Iprovalicarb + Propineb (5.5 + 61.25%) WP, and Mancozeb 75 WP was carried out. All the fungicides were significantly superior to the untreated control in managing downy mildew and exhibited enhancement in marketable yield. The fungicide Cyazofamid @ 0.2 ml/l exhibited the lowest PDI in all the ten locations, followed by Mandipropamid @ 0.8 ml/l and Iprovalicarb + Propineb (5.5 + 61.25%) WP @ 3.0 g/l. Standard check fungicides Dimethomorph 50 WP @ 1.0 g/l, and Mancozeb 75 WP @ 1.5 g/l were at par with each other and were less effective as compared to Mandipropamid @ 0.8 ml. The

untreated control exhibited the highest disease severity. Cohen *et al*. (2007) and Ekabote *et al*. (2019) studied the bio-efficacy of Mandipropamid against the oomycetes, and highlighted its efficacy against *Phytopthora infestans* and *Pseudoperonospora cubensis,* respectively. Huggenberger *et al*. (2005) studied the mode of action of Mandipropamid and highlighted the anti-sporulent, anti-mycelial nature of the molecule. It had a moderate amount of translaminar and acropetal systemicity and was the most effective when used as a protectant fungicide; however, it had some degree of post-infection activity as well (Stein and Kirk, 2003). After foliar application, a large amount of the active ingredient was absorbed in the cuticular wax layer, ensuring excellent rain fastness (Fanigliulo and Sacchetti, 2009). The efficacy of Cyazofamid 34.5% SC was in line with the findings of Gentile *et al.* (2002) who, stated that Cyazofamid had high preventive and good curative activity and it inhibits the mitochondrial complex III (syn. complex bc or ubiquinone c reductase). However, Cyazofamid is a new fungicide for the management of downy mildew in grapes and has limited systemic activity. Moreover, it was known to be resistant to *Phytophthora capsici* as well as *Plasmopara viticola* (Jackson *et al.* 2012; Cherrad *et al*. 2018; Fontaine *et al*. 2019). According to Siegenthaler *et al.* (2021) the isolates of *Phytophthora capsici* that showed resistance to Cyazofamid were sensitive to Mandipropamid. These findings were also supported by many workers (Kousik and Keinath, 2008; Jackson *et al*. 2012). Thus, Mandipropamid had a broader activity in the case of long-term durable efficacy as compared to cyazofamid, in the management of downy mildew of grape. The multi-location trials in the present study proved that Mandipropamid 250 SC @ 0.8 ml/l of water as foliar spray provided effective management of downy mildew on leaves and is a probable solution for managing downy mildew of grape, as well as mitigating fungicide resistance in viticulture.

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DECLARATION

Conflict of interest. Authors declare no conflict of interest.

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