

EVALUATION OF TRANSLAMINAR FUNGICIDES AND THEIR TANK MIXED APPLICATION WITH ECONOMICS FOR MANAGEMENT OF LATE BLIGHT OF POTATO (*PHYTOPHTHORA INFESTANS*) IN SUBTROPICAL PLAINS OF INDIA

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ABSTRACT: Late blight, incited by *Phytophthora infestans* (Mont.) de Bary is the major disease of potato under the class of foliar diseases. Chemical methods are being used for the effective management of late blight. However, this pathogen is more vulnerable against specific mode of chemicals (systemic fungicides), which may develop resistant. The field efficacy of translaminar fungicides and their tank mixed application with economics were evaluated in two different experiments for managing late blight of potato during three consecutive years. In first experiment it was observed that dimethomorph 50%WP @ 0.2% showed least average terminal disease severity (14.54%) with highest disease controlled (84.15%) followed by ametoctradin 27% + dimethomorph 20.27% SC @ 0.2% and cymoxanil 8 + mancozeb 64%WP @ 0.3%. In second experiment, under the tank-mixed application dimethomorph 50%WP @ 0.1% + mancozeb 75%WP @ 0.2% showed less average terminal disease severity (22.67%) with highest disease controlled (75.97%) along with highest tuber yield (40.70 t/ha) and highest B:C ratio (2.16) followed dimethomorph 50%WP @ 0.1% + chlorothalonil 75% WP @ 0.2%, which was statistically significant. These treatments are also least affected by environmental factors like rainfall. These new fungicides and their tank-mixed sprays were found effective for managing the disease and moreover these tank-mixed sprays can be used to avoid development of resistance against pathogen.

KEYWORDS: Potato, Late blight, Fungicides, Spraying, Management

INTRODUCTION

Late blight incited by an oomycetes' *Phytophthora infestans* (Mont.) de Bary is the dreadful disease of potato in both fields and storage condition (Fry and Goodwin 1997). *P. infestans* has short asexual life cycle and sporulating foliar lesions develop in very short duration (3 to 7 days) after post infection under favorable weather conditions (Maltese *et al.*, 1995) causes quickly defoliation of plants in the field and can infect potato tubers under high disease pressure. In India, potato yield loss due to late blight disease was expected up to 10-15% during 2020 (Anonymous, 2020).

The yield losses and cost for management of late blight of potato amounted up to 10.00 billion US dollar (Suo-Meng & Shao-qun, 2022).

Various management measures are being used for controlling the late blight disease. The cultural practices can be used to minimize the pathogen populations by decreasing its survivability, dispersal and reproduction. The resistant cultivars are the best option for economically and eco-friendly management of the disease (Lal *et al.*, 2018). However, whenever the resistant varieties became more widely adopted and

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prevailing of highly diverse virulence nature of *P. infestans*, the host resistance breakdown occurred due to pathogen adaptation within a decade resulting in the emergence of new highly virulent strains (Fry 2008). Therefore, the last better option is remained the use of suitable fungicides for controlling the disease. Characterization and proper evaluation of fungicides are crucial steps for understanding better use of a new fungicide in effective late blight management program. Furthermore, successful disease management requires regular application of fungicides at high doses with short time intervals throughout the crop growing season (Lal *et al.*, 2015).

On the basis of mobility, late blight fungicides can be classified into three groups *i.e.* contact, translaminar and systemic. The contact fungicides are remained on surface of the plant while systemic fungicides moved inside the plant system, well known for plant disease management. In case of translaminar, fungicides enter into plant but not circulating in the plant and can cross the leaf surface thickness. The translaminar fungicides are more effective than contact fungicides and possess better tenacity on the plant surface, are being applied as combination with contact fungicides so that development of resistance can be avoid in pathogen. After introduction of metalaxyl (Phenylamide), within thirty-six months metalaxyl resistant isolates of *P. infestans* were observed on field grown potatoes in Ireland, The Netherlands and Switzerland (Gisi and Cohen 1996). The three fungicides *viz.*, mandipropamid, cymoxanil and mefenoxam were showed insensitivity against *P. infestans* clonal lineages of US11 and US8 (Saville *et al.*, 2015). During late 1980's for experimental purpose, metalaxyl based fungicides were introduced in India for management of late blight. However, its commercial application was started since

1994-95 and more than a decade developed high level of resistance against *P. infestans* thereby it failed to save the potato crop from the late blight in temperate highlands (Bhat *et al.*, 2009; Singh and Bhat 2007). The new fungicides with different mode of actions need to be evaluated regularly (Kamel *et al.*, 2024) and pre-mixed two or more fungicides with different modes of action or tank mixed fungicides to be applied for management of late blight diseases, so that these modes of fungicides application can avoid to development of resistance in the *P. infestans*. Therefore, the aim of this study was to evaluate the translaminar fungicides and their tank-mixed applications along with economics against late blight to obtain maximum benefit from potatoes production.

MATERIALS AND METHODS

Two field experiments were conducted at ICAR-Central Potato Research Institute, Regional Station, Meerut, Uttar Pradesh during *rabi* season of the years 2015-16, 2016-17 and 2017-18. For each experiment seed tubers of *cv.* Kufri Bahar (Highly Susceptible) were planted in randomize block design (RBD) in 3×3 m² plot size and maintain 60×20 cm row to plant distance. The crop was planted in each year during second week of November. The crop was raised with the application of 180kg N, 80kg P₂O₅ and 100 kg K₂O/ha and other practices were followed as per recommendations for the region (Lal *et al.*, 2022). In experiment 1, eight treatments consist with translaminar and systemic fungicides and in experiment 2; six treatments with tank mixed application of translaminar & contact fungicides were included. In each treatment three sprays were scheduled for both the experiments. The first sprays were initiated just at the appearance of late blight disease and second and third sprays at 7-10

days interval after the first spraying. The treatments details are as follows:

Experiment 1

T1: Cymoxanil 8 + Mancozeb 64% WP @ 0.3%

T2: Mandipropamid 23.4 % SC @ 0.1%

T3: Dimethomorph 50% WP @ 0.2%

T4: Phenomidon 10 + Mancozeb 50% WDG @ 0.3%

T5: Ametoctradin 27% + Dimethomorph 20.27 % SC @ 0.2%

T6: Metalaxyl- M 3.3% + Chlorothalonil 33% SC @ 0.1%

T7: Captan 70% + Hexaconazole 5% WP @ 0.2%

T8: Azoxystrobin 11% + Tebuconazole 18.3% WS @ 0.1%

T9: Control

Tank mixed application of translaminar fungicides (Experiment 2):

T1: Dimethomorph 50% WP @ 0.1% + Mancozeb 75% WP @ 0.2%

T2: Dimethomorph 50% WP @ 0.1% + Chlorothalonil 75% WP @ 0.2%

T3: Dimethomorph 50% WP @ 0.1% + Propineb 70% WP @ 0.2%

T4: Mandipropamid 23.4 SC @ 0.1% + Mancozeb 75% WP @ 0.2%

T5: Mandipropamid 23.4 SC @ 0.1% + Chlorothalonil 75% WP @ 0.2%

T6: Azoxystrobin 23 SC @ 0.1% + Mancozeb 75% WP @ 0.2%

T7: Control

Disease and yield assessment

The terminal disease severity was recorded as per method of Henfling (1987) after 10 days of final spray. The recorded experimental data was statistically analyzed using IRRISTAT software (version 4.4.20030719).

The percentage disease control and yield (t/ha) were recorded at harvesting. The cost of fungicides (Rupees per Kg or L) and their spraying cost were calculated. The rate of harvested potato tubers (Rupees per ton) was taken as prevailing rate in the markets. Net return over the control and Benefit-Cost ratio (B: C) were calculated for each treatment.

Weather parameters

Weather parameters *i.e.* temperature, relative humidity and rainfall were recorded during all three cropping season years. In each year, cropping season was started from November to February. During these period weather parameters was recorded and calculated average weekly for each month.

RESULTS AND DISCUSSION

In experiment 1 it was recorded that on mean basis (63.30 - 84.15% disease controlled) all treatments were found effective against control (91.78% disease severity). The results revealed that treatment T3 showed least average terminal disease severity (14.54%) with highest average disease controlled (84.15%). The second best treatment was T5 with average terminal disease severity (17.35%) with disease controlled (81.10%) followed by T1 with 20.01% terminal disease severity along with disease controlled 78.20% (**Table 1**). These treatments were statistically at par to each other and significantly differed from the treatments T6 and T8. The lowest average field efficacy (63.30% disease controlled) was observed with treatment T7 when first sprays were initiated just at the appearance of late blight disease and second and third sprays at 7-10 days interval after first spraying. All treatments showed higher yield compared to control treatment (T9). The highest average tuber yield (39.95 t/ha) was recorded with T1 followed by T3 with 39.91 t/ha. The yield of both the treatments was statistically at par. The lowest average yield

Table 1. Evaluation of new fungicides for management of late blight of potato during 2015-16, 2016-17 and 2017-18.

Treatments	2015-16			2016-17			2017-18			Average		
	Terminal disease severity (%)	Disease controlled (%)	Yield (T/ha)	Terminal disease severity (%)	Disease controlled (%)	Yield (T/ha)	Terminal disease severity (%)	Disease controlled (%)	Yield (T/ha)	Terminal disease severity (%)	Disease controlled (%)	Yield (T/ha)
T1	10.70	86.67	43.76	26.00	72.54	33.68	23.33	75.95	42.40	20.01	78.20	39.95
T2	24.30	69.58	41.77	30.00	68.47	32.84	22.00	77.32	42.97	25.43	72.29	39.19
T3	8.30	89.58	42.98	23.00	75.59	33.42	12.33	87.29	43.34	14.54	84.15	39.91
T4	27.70	65.42	41.86	31.00	67.46	32.54	23.00	76.29	42.04	27.23	70.33	38.81
T5	10.70	86.67	43.00	26.67	71.86	33.22	14.67	84.88	43.24	17.35	81.10	39.82
T6	30.00	62.50	41.02	34.33	64.07	31.51	29.00	70.10	41.02	31.11	66.10	37.85
T7	32.70	59.17	41.02	36.67	61.69	31.44	31.67	67.35	41.30	33.68	63.30	37.92
T8	34.00	57.50	40.44	40.00	58.30	30.88	21.33	78.01	42.48	31.78	65.38	37.93
T9	80.00	0.00	38.44	98.33	0.00	29.39	97.00	0.00	37.64	91.78	0.00	35.16
CD (P 0.05)	8.05	–	0.99	4.64	–	1.45	3.24	–	1.68	9.50	–	0.86
SE	2.48		0.33	1.60		0.48	1.08		0.56	3.18		0.28

(37.85 t/ha) was observed with treatment T6 against control treatment (35.16 t/ha).

In experiment 2, three translaminar fungicides *viz.* Dimethmorph 50% WP, Mandipropamid 23.4 % SC, and Azoxystrobin 23%SC were evaluated as tank-mixed fungicides with three contact fungicides *i.e.* Mancozeb 75%WP, Chlorothalonil 75%WP & Propineb 70%WP, which are frequently used as prophylactic in late blight management. All

treatments were found effective for managing the late blight. However, treatment T1 showed less average terminal disease severity (22.67%) with highest disease controlled (75.97%), which was significantly differed the T2 with average terminal disease severity of 30.83% along with disease controlled 67.31% as against control average terminal disease severity (94.33%). The next best tank-mixed spray was T3 which was statistically at par with T5 (**Table 2**). The

Table 2. Evaluation of tank mixed fungicides for management of late blight of potato during 2015-16, 2016-17 and 2017-18.

Treatments	2015-16		2016-17		2017-18		Average	
	Terminal disease severity (%)	Disease controlled (%)	Terminal disease severity (%)	Disease controlled (%)	Terminal disease severity (%)	Disease controlled (%)	Terminal disease severity (%)	Disease controlled (%)
T1	22.0	75.6	22.5	77.04	23.5	75.26	22.67	75.97
T2	35.0	61.1	27.5	71.94	30.0	68.42	30.83	67.31
T3	40.0	55.6	37.5	61.73	33.0	65.26	36.83	60.95
T4	42.5	52.8	40.0	59.18	32.5	65.79	38.33	59.36
T5	40.0	55.6	42.5	56.63	31.0	67.37	37.83	59.89
T6	55.0	38.9	47.5	51.53	36.0	62.11	46.17	51.06
T7	90.0	0.0	98.0	0.0	95.0	0.0	94.33	0.0
CD (P 0.05)	2.32	–	4.00	–	1.70	–	1.71	–
SE	0.75		1.40		0.55		0.55	

maximum average terminal disease severity (46.17%) was observed with treatment T6 when first spray was initiated just at the appearance of disease and second and third sprays at 7-10 days interval after first spraying. The maximum average tuber yield (40.70 t/ha) was recorded with treatment T1 followed by T2 with 38.10 t/ha. Both treatments T1 & T2 were significantly differed from each other. The next best treatment was T5 which was statistically at par with T3 (**Table 3**). Among the treatments lowest average yield (35.50 t/ha) was recorded in the treatment T6 against control (29.80 t/ha). Economics of the tank mixed fungicide were calculated and it was observed that treatment T1 gave 10.90 t/ha additional yield with Rs. 63,220.0 gross return and net return (Rs. 43,190.0) over control. The next best treatment was T2 that gave Rs. 22,830.0 net return over control. The highest B:C ratio (2.16) was calculated with treatment T1 followed by treatment T4. The least B:C ratio (1.91) was calculated in treatment T6 (1.90) against control.

During cropping season average weekly weather parameters *i.e.* temperature and relative humidity were varied within month. In the year 2015-16 the average weekly minimum temperature ranged from 6.0-16.93°C and maximum temperature ranged from 14.50 to 27.0°C. The average weekly minimum relative humidity ranged from 48.75 -76.57% and maximum relative humidity 82.71-91.43%. The total rainfall was only 7.95 mm (Fig.1a). During 2016-17, the average weekly minimum temperature ranged from 5.14 -14.00°C and maximum temperature ranged was 18.29 to 28.86°C. The average weekly minimum relative humidity ranged from 34.29 -60.57% and maximum relative humidity 77.33-91.86%. The total rainfall was 73.50 mm (Fig.1b). In 2017-18, the average weekly minimum temperature ranged from 4.71 -14.57°C and maximum temperature ranged was 15.14 to 29.43°C. The

average weekly minimum relative humidity ranged from 26.86 -61.57% and maximum relative humidity 77.14-91.00%. The total rainfall was 11.50 mm (Fig.1c).

Management of late blight is an important aspect for high quality potato production. Application of fungicides can be an important option for integrated crop management because resistant cultivars may be severely

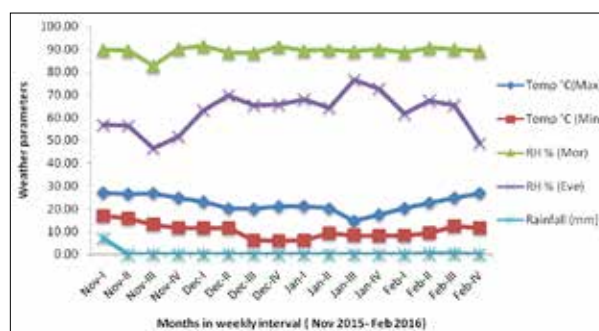


Fig.1a. Weather parameters during crop season 2015-16

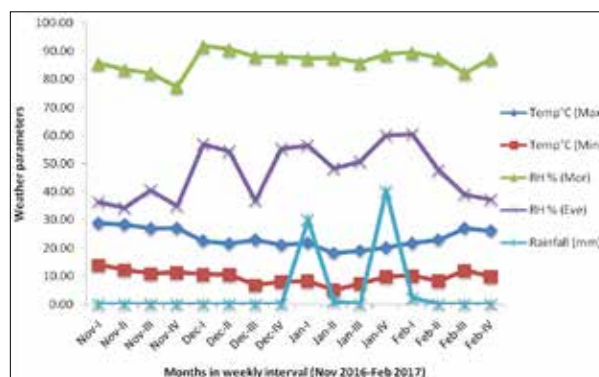


Fig.1b. Weather parameters during crop season 2016-17

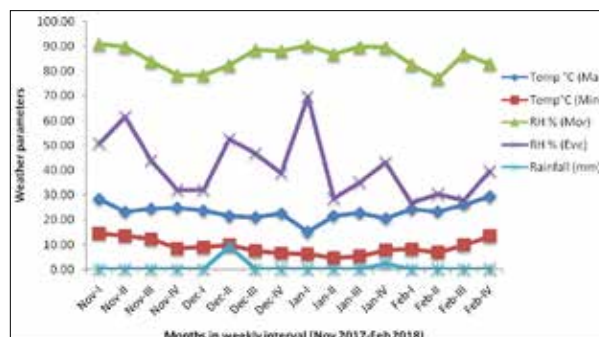


Fig.1c. Weather parameters during crop season 2017-18

Table 3. Economics of tank mixed fungicides for management of late blight of potato during 2015-16, 2016-17 and 2017-18.

Treatments	Yield (T/ha)			Average yield (T/ha)	Additional yield over control (T/ha)	Gross return (Rs/ha)	*Cost of treatment (Rs/ha)	Net return over control (Rs/ha)	B:C
	2015- 16	2016- 17	2017- 18						
T1	44.13	32.77	45.20	40.70	10.90	63220.0	20030.0	43190.0	2.16
T2	41.41	31.50	41.39	38.10	8.30	48140.0	25310.0	22830.0	1.93
T3	40.92	30.62	40.56	37.37	7.57	43906.0	22310.0	21596.0	1.94
T4	40.84	30.44	38.31	36.53	6.73	39034.0	18830.0	20204.0	1.96
T5	41.14	30.76	40.47	37.46	7.66	44428.0	24110.0	20318.0	1.92
T6	39.49	29.01	37.99	35.50	5.70	33060.0	18530.0	14530.0	1.91
T7	30.8	28.18	30.43	29.80	0.00	0.00	0.00	0.00	1.90
CD (P 0.05)	1.72	1.49	1.06	1.06					
SE	0.56	0.48	0.34	0.34					

*Includes cost of fungicides, labour and other cost. Tubers yield @ Rs 5080.0/T, Mancozeb 75% WP @ Rs 380.0/kg, Chlorothalonil 75% @ Rs 1260.0/kg, Propineb 70% WP @ Rs 760.0/ kg, Azoxystrobin 23 % SC @ Rs 680.0/L, Mandipropamid 23.4% SC @ Rs 4500.0/L and Dimethmorph 50% WP @ Rs 4900.0/kg.

affected under high congenial climatic condition (Nelson, 2020). Although, various management strategies are also available for managing the late blight disease but their efficacy is not effective as chemical management. In India, about 44 molecules (fungicides) have been registered on CIB& RC (Central Insecticides Board and Registration Committee) for late blight management. Among them 23 are in as single and 21 are in combinations of two groups of fungicides (Subhash *et al.*, 2025). In these fungicides, some of the fungicides were registered for both late blight and early blight diseases. In this study, Cymoxanil 8% + Mancozeb 64% @ 0.3%, Dimethmorph 50% @ 0.1% and Ametoctradin 27% + Dimethomorph 20.27% SC @ 0.2% found highly effective against *P. infestans*. The application of cymoxanil or dimethomorph based fungicides @ 0.3% at the early appearance of the disease along with one prophylactic and one post application spray of mancozeb, was found effective, these chemicals were also effective in sequential application as alone (Chakraborty and Mazumdar, 2012; Islam *et al.*, 2022). Using a mixture of narrow specific and widely specific fungicides for managing late blight is one of the strategy

(Ivanov *et al.*, 2021). The new fungicides *i.e.* Dimethmorph 50% WP @ 0.1%, Ametoctradin 27% + Dimethomorph 20.27% SC @ 0.2%, Azoxystrobin 11% + Tebuconazole 18.3% WS @ 0.1%, Mandipropamid 23.4% SC @ 0.1% and Metalaxyl- M 3.3% + Chlorothalonil 33% SC @ 0.1% can be included at farmer practices for controlling the late blight. Among them few fungicides have dual mode of action that will avoid resistance development in *P. infestans* than single mode of action fungicides. Ametoctradin 27% + dimethomorph 20.27% SC found effective against late blight @ 0.08 & 0.1% (Lal *et al.*, 2017). The mixed formulations of fungicides were found effective in controlling late blight (Jha *et al.*, 2017) and spray schedules of contact fungicides followed by systemic/translaminar + contact reduced late blight disease in Tripura (Dey *et al.*, 2024). Recently, the Azoxystrobin 11% + Tebuconazole 18.3% WS registered for late blight management. The application of tank-mixed fungicides was better than the rotational application of fungicides for managing *Botrytis* fruit rot of strawberry (Amiri *et al.*, 2019). In this study, the tank-mixed of Dimethmorph 50%WP @ 0.1% + Mancozeb 75% WP @ 0.2% and Dimethmorph 50%WP @ 0.1% + Chlorothalonil 75%WP @

0.2% were found highly effective. Because both translaminar and contact fungicides have synergistically actions to control the disease. Mancozeb and Chlorothalonil are well known to act as multisite activity and have less chance to develop resistance against *P. infestans* (Perez *et al.*, 2022). The assessment of benefit cost ratio (B: C) tells about economic benefit of the treatments at farmers' field, therefore, it is an important parameter for recommendation of any treatment for successful management of the disease. It is well known that severity of late blight disease is affected weather conditions. In this study, during year 2016-17 disease severity in control was higher than that of the other cropping years. This may be due to high rain fall and other weather factors during that year. Low temperature and higher relative humidity are the main climatic conditions responsible for appearance and spreading the disease. Further, rainfall is the crucial factor at management point of view, because it affects the efficacy of fungicides, spraying interval and disease severity. The fungicides efficacy is affected by intensity of rainfall in downy mildew of onion (Araújo *et al.*, 2020).

Therefore, it is better to select rainfastness fungicides which have attribute to resist against rain. The contact fungicides are easily washed due to rain water than the systemic/translaminar. In this context, present study used translaminar fungicides *i.e.* Dimethomorph, Madipropamid, Cymoxnil and Fenamidone having rainfastness quality which can be more helpful in managing late blight disease of potato.

CONCLUSION

The new fungicides *i.e.* Dimethomorph 50% WP @ 0.1%, Ametoctradin 27% + Dimethomorph 20.27% SC @ 0.2%, Azoxystrobin 11% + Tebuconazole 18.3% WS @ 0.1%, Mandipropamid 23.4% SC @ 0.1% and

Metalaxyl-M 3.3% + Chlorothalonil 33% SC @ 0.1%, can be included at farmer practices for managing the late blight disease. The tank mixed of Dimethomorph 50% WP @ 0.1% + Mancozeb 75% WP @ 0.2% and Dimethomorph 50% WP @ 0.1% + Chlorothalonil 75% WP @ 0.2% was highly effective as tank mixed fungicides with high B:C ratio in managing late blight of potato.

AUTHORS' CONTRIBUTION

Conceptualization of research (Lal, M. Sharma S. and Chakrabarti SK); Designing of the experiments (Lal, M. Sharma S. and Kumar M); Execution of field/lab experiments and data collection (Lal, M. Yadav, S); Analysis of data and interpretation (Chaudhary S. Lal M. and Sharma S); Preparation of the manuscript (Lal, M. Chaudhary, S and Sharma S).

DECLARATION

The authors declare no conflict of interest.

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