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Field evaluation of combination fungicides against late blight disease in potato (*Solanum tuberosum*)

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Potato (*Solanum tuberosum* L.) is an important vegetable crop commercially cultivated in most parts of country. It occupies 2.2 million ha area with the total production of 53.58 million metric tonnes and average productivity is 24.35 metric tonnes/ha (Anonymous 2022). In Uttarakhand, potato is cultivated in 26867.46 ha area while total production is 367309.04 metric tonnes and average productivity is 13.67 metric tonnes/ha. The average productivity in Uttarakhand is very low as compared to national average productivity. There are several factors responsible for low productivity of potato in Uttarakhand such as poor availability of quality seeds of high yielding varieties, rainfed condition and poor management of late blight disease. Being an off season crop, its demand in the markets is very high due to which farmers get premium price of their produce. Thus, hills of Uttarakhand provide enormous opportunity for large scale cultivation of potato as an off season. It has been realized that if farmers grow high yielding varieties along with effective management of late blight disease, the present productivity in the state can be doubled as we have observed in the present investigations. Among several diseases of potato, late blight disease caused by *Phytopthora infestans* is the major and most common destructive and widely spread pathogen affecting every part of the plant including stem, leaves and tubers. Late blight can potentially cause a 100% crop loss by total destruction of all plants in a field within a week or two when weather is cool and wet and average yield losses due to late blight vary from year to year ranges from 11–74% in Northern hills (Khalid and Grover 2021).

The experiment on field efficacy of different fungicides against the late blight disease of off season potato was conducted at Chani village of Almora district in Uttarakhand during February–July of 2020, 2021 and 2022. The field trials were laid out by G B Pant University of Agriculture and Technology, Krishi Vigyan Kendra, Matela, Almora, Uttarakhand. There were six treatments including farmer's practice. The various commercial formulations of the treatments were T_1, Cabrio Top; T_2, Curzate; T_3, Spectrum; T_4, Ridomil Gold; and T_5, Bavestin while Dithan-M 45 was applied in T_6 [farmer's practice (control)]. The investigation was carried out in a randomized block design (RBD) with four replications. In order to find out the right time of first spray, crop monitoring at regular interval with farmers participatory mode was followed. First spray was initiated after the 20–30% occurrence of late blight disease and spray was repeated 10 days after the first spray. The first application of different fungicides was done when moderate severity of late blight disease was observed during monitoring the crop. Incidence of late blight disease was recorded a day before fungicides application and also, after two sprays done at 10 days interval. Observations on incidence of late blight disease were recorded after 7 and 15 days of second spray.

Data on percentage disease incidence, production and economics were recorded at the time of harvest by calculating the disease severity (formula given) and data on disease severity were recorded using 0–9 disease rating scales in Table 1 on the day before spray and at weekly intervals after spraying (Admasiae *et al.* 2021). Details of treatments are given in Table 2. The per cent disease incidence was calculated as:

$$\text{Disease incidence} = \frac{\text{No. of infected plants}}{\text{Total no. of plants}} \times 100$$

The incidence of late blight disease recorded one day before intervention of fungicides in different treatments varied from 33.95–35.75% in 2020, 26.43–34.65% during 2021 and 20.45–23.89% in 2022. The effect of two spraying of fungicides showed that on the incidence of late blight disease which was significantly superior over all other treatments in all the three years of investigation. The observations taken on incidence of late blight disease in T_3

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Table 1 Rating scale for the assessment of late blight severity on potato leaves

Rating scale	Disease incidence (%)	Level of resistance/susceptibility
0	No disease	Small lesion on the inoculated point with the lesion area
1	10%	Less than 10% of the whole leaflet
3	10% and 20%	Lesion area between 10% and 20% of the whole leaflet
5	20% and 30%	Lesion area between 20% and 30% of the whole leaflet, Waterish area less than 50% of the whole leaflet
7	30% and 60%	Lesion area between 30% and 60%
9	Over 60%	Lesion area over 60% of the whole leaflet

revealed that it was 4.72% after 7 days of spray and 1.89% after 15 days of spray during 2020. Similarly in 2021, the incidence was 3.86% and 1.06% after 7 and 15 days of spray, respectively. Consequently, same trend was observed in 2022. The T_1 and T_2 were the next best treatments in which incidence of late blight was 16.92% and 14.43% after 7 days of spray, while after 15 days of spray, it was 10.32% and 12.39% during 2020. Almost same trend was realized in T_1 and T_2 treated plots during 2021 and 2022. The data presented in Table 3 showed that mancozeb (T6) sprayed plots showed high incidence of disease which was closely followed to carbendazim (T_5) in all the three years of investigation. The studies conducted on comparative efficacy of different fungicides and their combinations in different parts of the country by Goutam *et al.* (2018), Lal *et al.* (2018) and Mhatre *et al.* (2021) indicated that 2–3 sprayings of combination of fungicides namely Metiram + Pyraclostrobin, Cymoxanil + Mancozeb and Metalaxyl + Mancozeb have been found effective against late blight disease in potato. In the present investigation also Metiram + Pyraclostrobin, Cymoxanil + Mancozeb and Metalaxyl + Mancozeb showed their effectiveness but combination of Azoxystrobin + Tebuconazole gave tremendous impact in management of late blight of potato. Neupane *et al.* 2018 laid out an investigation on relative efficacy of different fungicides alone and in combination against late blight disease in which they reported that combination of fungicides was found effective against incidence of late blight disease. In fact, the combination of Azoxystrobin + Tebuconazole is a new molecule hence it has not been studied and evaluated against late blight disease of potato. That is why there is no report available about its efficacy for the management of late blight. However, it has been recommended by Directorate of Plant Protection Quarantine and Storage (Anonymous 2022).

The performance of various fungicides had given their impact on yield according to incidence of late blight. The fungicide which reduced disease incidence of late blight fetched maximum yield. Accordingly, spraying of azoxystrobin + tebuconazole gave highest yield, i.e. 302.39 q/ha in 2020, 308.52 q/ha during 2021 and 318.72 q/ha in 2022. This treatment was significantly superior over remaining treatments in respect of yield during all the three years of studies. The observations recorded on yield from various treatments showed that besides T_3, the performance of T_1 and T_2 manifested almost same results and were non-significant among each other in all the three years. The yield received from T_1 was 238.21 q/ha, 246.84 q/ha and 258.67 q/ha respectively during 2020, 2021 and 2022. Similarly, T_2 recorded 232.81 q/ha in 2020, 251.67 q/ha during 2021, while 257.25 q/ha in 2022. The lowest yield was obtained from the mancozeb treated plots (T6) which was 156.94 q/ha in 2020, 158.55 q/ha during 2021 and 164.34 q/ha in 2022. The field trials carried out by Khadka *et al.* (2020) against late blight by using different fungicides revealed that combination of fungicides such as Metiram + Pyraclostrobin, Cymoxanil + Mancozeb and Metalaxyl + Mancozeb were found more effective as compared to fungicide used alone. Pandit *et al.* (2020) and Khadka *et al.* (2020) also evaluated fungicides alone and in combinations in which they found that combinations of fungicides exhibited magnificently against late blight and provided profitable yield.

The result of the field trials revealed that application of azoxystrobin + tebuconazole (T_3) also gave visible impact on gross income, net income and B:C ratio in all the three consecutive years. The T_3 sprayed plots received maximum net income among all the treatments which was ₹448050/ha in 2020, ₹459290/ha during 2021 and ₹479220/ha in 2022. However, T_1 and T_2 were the next best treatments in respect of net income. The net income recorded from T_1 was ₹322180/ha, ₹337430/ha and ₹358010/ha, respectively during 2020, 2021 and 2022. Similarly, T_2 obtained net income of ₹311750/ha in 2020, ₹347460/ha during 2021

Table 2 Treatment details used during the study

Treatment detail	Commercial formulation	Dose
Metiram 55% + Pyraclostrobin 5% WG (T_1)	Cabrio Top	2 g/litre of water
Cymoxanil 8% + Mancozeb 64% WP (T_2)	Curzate	2 g/litre of water
Azoxystrobin 11% + Tebuconazole 18.3 w/w SC (T_3)	Spectrum	1 ml/litre of water
Metalaxyl 8% + Mancozeb 64% WP (T_4)	Ridomil Gold	2 g/litre of water
Carbendazim 50% WP (T_5)	Bavestin	1 g/litre of water
Farmer's practice (Mancozeb 75% WP) (T_6)	Dithane-M 45	2 g/litre of water

Table 3 Impact of fungicide combination on incidence of late blight disease and economics in off season potato cultivation during 2020, 2021 and 2022

Name of treatments/ Fungicides	Incidence of late blight disease (%) before intervention			Incidence of late blight disease (%) 7 days after spray			Incidence of late blight disease (%) 15 days after spray			Yield (q/ha)			Cost of cultivation (₹/ha)			Gross income (₹/ha)			Net income (₹/ha)			B:C ratio		
Year	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022
T_1	34.33	31.20	21.56	16.92	10.28	8.37	10.32	8.68	7.06	238.21	246.84	258.67	1,54,240	1,56,250	1,59,330	476420	493680	517340	322180	337430	358010	3.08	3.15	3.24
T_2	35.75	34.65	22.37	14.43	9.64	8.96	12.39	7.79	7.88	232.81	251.67	257.25	1,53,870	1,55,880	1,58,650	465620	503340	514500	311750	347460	355850	3.02	3.22	3.24
T_3	34.69	26.43	23.89	4.72	3.86	2.55	1.89	1.06	0.95	302.39	308.52	318.72	1,56,730	1,57,750	1,58,220	604780	617040	637440	448050	459290	479220	3.85	3.91	4.02
T_4	34.21	30.74	20.45	18.35	12.10	10.30	14.72	9.40	8.78	221.46	233.24	244.61	1,50,380	1,52,390	1,55,780	442920	466480	489220	292540	314090	333440	2.94	3.06	3.14
T_5	35.53	29.40	23.76	26.83	24.08	22.24	22.81	22.52	19.75	171.38	174.80	186.21	1,41,250	1,44,550	1,48,720	342760	349600	372420	201510	205050	223700	2.42	2.41	2.50
T_6	33.95	32.86	22.43	28.41	27.32	25.80	23.68	24.86	22.52	156.94	158.55	164.34	1,38,350	1,41,850	1,45,280	313880	317100	328680	175530	175250	183400	2.26	2.23	2.26
SEm±	0.941	0.732	0.723	0.439	0.769	0.668	0.311	0.451	0.362	2.253	7.485	4.329	-	-	-	-	-	-	-	-	-	-	-	-
CD (P=0.05)	NS	2.337	NS	1.400	2.456	2.131	0.992	1.438	1.154	7.191	23.891	13.816	-	-	-	-	-	-	-	-	-	-	-	-

Sale price: ₹2000.00/qt during 2020, 2021 and 2022. Treatment details are given in Table 2.

and ₹355850/ha in 2022. The data taken on economics indicated that mancozeb (T_6) recorded lowest net income of ₹175530/ha, ₹175250/ha and ₹183400/ha, respectively during 2020, 2021 and 2022. Consequently, almost same trend was observed in T_5 which received ₹201510/ha in 2020, ₹205050/ha during 2021 and ₹223700/ha in 2022. The result of the field experiments highlighted by Lal *et al.* (2017a), Majeed *et al.* (2017) and Lal *et al.* (2017b) in their research papers indicated the effectiveness of combination of fungicides showing enhancement in net income and B:C ratio. They have evaluated fungicides individually along with three combinations of fungicides such as Metiram + Pyraclostrobin, Cymoxanil + Mancozeb and Metalaxyl + Mancozeb in which they found that these combinations of fungicides provided remunerative net income and B:C ratio as against of fungicides assessed individually. These researchers also emphasized that all three combinations of fungicides were at par in respect of their performance in management of late blight disease. Almost same result is obtained in the present experimentation as combination of Metiram + Pyraclostrobin, Cymoxanil + Mancozeb and Metalaxyl + Mancozeb manifested considerable impact in increasing the profitability but combination of fungicides, i.e. azoxystrobin + tebuconazole proved to be most promising in terms of all parameters pertaining to economics like gross income, net income and B:C ratio.

SUMMARY

Potato is commercially important vegetable crop in hills of Uttarakhand and grown as an off season. Farmer's get remunerative return of their potato because of the off season. It was observed that incidence of late blight disease hampered the production and majority of the farmers used mancozeb fungicide which did not provide expected relief from the menace of late blight disease. Accordingly, interventions were made on combination of fungicides to find out their field efficacy against late blight disease of potato on farmer's field. The result of the experimentation revealed that two spraying of azoxystrobin + tebuconazole @1 ml/litre of water at moderate severity stage of late blight disease proved to be most effective treatment on reduction of incidence, increase in yield and net income over all other treatments in all the three consecutive years. The T_3 has been investigated as best treatment in all the respects among various treatments. The summary of the investigation advocates that two spraying of modern combination of fungicides namely, azoxystrobin + tebuconazole even at moderate severity stage of late blight disease gave tremendous impact on its management throughout the crop season. Considering its impact of three years investigation against late blight disease in off season potato, this novel combination of fungicide may be recommended to the farmer's of the country.

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