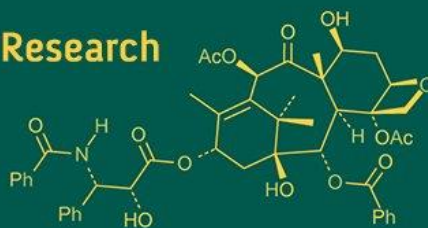


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Synergism of Famoxadone and Cymoxanil in the management of *Alternaria solani* on potato (*Solanum tuberosum* L)

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Abstract

Potato (*Solanum tuberosum* L.) is the third most important food crop globally, yet its productivity is severely constrained by early blight caused by *Alternaria solani*, which can result in 5-50% yield loss under favorable conditions. The present study evaluated the efficacy, phytotoxicity and economic feasibility of the fungicide mixture Famoxadone 16.6% + Cymoxanil 22.1% SC against early blight in potato under Nilgiris agro-climatic conditions during Kharif 2023 and Rabi 2023-2024. Field experiments were conducted in a Randomized Block Design with seven treatments, including different dosages of the test fungicide, standard checks (Azoxystrobin and Mancozeb) and an untreated control. Results revealed that Famoxadone 16.6% + Cymoxanil 22.1% SC at 600 ml/ha (T4) recorded the lowest Percent Disease Index (8.51% in Kharif and 9.00% in Rabi) and the highest tuber yield (256.30 q/ha and 260.30 q/ha, respectively), significantly outperforming standard checks. Growth parameters such as shoot length, root length, tubers per plant and tuber weight were also maximized in T4, followed by T3 (500 ml/ha). No phytotoxic effects were observed at any dosage. Economic analysis confirmed the superiority of T4, which achieved the highest benefit-cost ratio (2.09 in Kharif and 2.03 in Rabi). These findings establish Famoxadone 16.6% + Cymoxanil 22.1% SC as a safe, effective and economically viable fungicide mixture for managing potato early blight.

Keywords: *Alternaria solani*, Cymoxanil, famoxadone, fungicide efficacy, potato

Introduction

Potato (*Solanum tuberosum* L.) is the third most significant food crop globally after rice and wheat, serving as a staple and an income source in many developing nations [1]. Globally grown in nearly 140 countries with a annual production of 376 million metric tons. Beyond its economic role, potato is nutritionally important, supplying carbohydrates, proteins and vital micronutrients, thereby contributing to worldwide food security [2]. In India, it is considered an important cash crop however, productivity is often limited by various biotic and abiotic stresses. Among the biotic challenges, fungal diseases were particularly damaging, with early blight caused by *Alternaria solani* being one of the most prevalent and yield-reducing diseases across potato-growing regions [3]. Early blight is widespread in nearly all potato-producing areas, thriving under warm and humid conditions can cause serious yield losses. The disease first appears as small, irregular, dark brown to black lesions on older leaves, which enlarge into characteristic concentric “target spots” [4, 5]. Severe infestations often result in premature defoliation, reduced tuber development, poor storage quality and yield losses ranging from 5% to 50% under favorable conditions [6]. Traditionally, disease management strategies have relied on cultural practices such as planting healthy seed tubers, adopting crop rotation, maintaining sanitation and careful handling at harvest and storage [7]. However, under high disease pressure, fungicides remain the most widely adopted and dependable approach. Since the 1970s, fungicides with targeted biochemical modes of action have transformed disease management. Nevertheless, extensive and repetitive use has driven the development of fungicide-resistant *A. solani* population's worldwide. Resistance to major fungicide classes such as Quinone outside Inhibitors (QoI) and Succinate Dehydrogenase Inhibitors (SDHI) has been reported, making fungicide resistance one of the foremost challenges in sustainable potato disease control [8, 9, 10, 11].

This has emphasized the urgent need for fungicides with novel or combined modes of action. Modern fungicides are designed to work effectively at lower doses, offer improved crop safety and minimize environmental risks, while supporting higher yields and better plant health [12]. A notable example is the combination of famoxadone, a QoI fungicide, with cymoxanil, a cyanoacetamide-oxime fungicide with systemic and curative properties. Their complementary action reduces the likelihood of resistance and ensures broad-spectrum disease suppression. Famoxadone disrupts mitochondrial respiration in pathogens, whereas cymoxanil inhibits sporulation and prevents secondary disease spread. Such mixtures have shown promising efficacy in several field crops [13]. However, comprehensive field evaluations of this combination against potato early blight, particularly under Indian agro-climatic conditions, are still limited. The present study was conducted in the Nilgiris district of Tamil Nadu during the 2023 *Kharif* and 2023-2024 *Rabi* seasons to evaluate the effectiveness, phytotoxicity, benefit cost ratio and its influence in yield.

Materials and Methods

Field experiments were carried out using a Randomized Block Design (RBD) with three replications and seven treatments (T1-T7) at Kathadimattam village, Nilgiris district, Tamil Nadu (11.4078682° N, 76.6946872° E) during the *Kharif* 2023 and *Rabi* 2023-2024 seasons to assess the efficacy of the fungicide Famoxadone 16.6% + Cymoxanil 22.1% SC against potato early blight, a disease favoured by the temperate and humid climate of the region. The widely cultivated potato variety Kufri Jyothi was used as a planting material. The experimental field was prepared by deep ploughing and fertilized with NPK at the recommended dose of 120:100:120 kg/ha. Plots were laid out with ridges 30 cm high and inter-row spacing of 60 cm. Standard agronomic practices were followed, and no plant protection measures were applied in the trial plots. The test fungicide, Famoxadone 16.6% + Cymoxanil 22.1% SC, was applied at four different concentrations, while Mancozeb 75% WP and Azoxystrobin 23% SC served as standard checks, alongside an untreated control. Fungicide solutions were prepared in 600 L of water per hectare to ensure uniform coverage and applied thrice at 15-day intervals, beginning at the onset of disease symptoms. The Percent Disease Index (PDI) was recorded 15 days after each spray to evaluate treatment effectiveness. The percent disease index was calculated [14].

$$\text{Percent disease index} = \frac{\text{Sum of numerical rating}}{\text{Total number of plants observed}} \times \frac{100}{\text{Maximum grade}}$$

Growth and yield parameters

The growth and yield parameters viz., shoot length, root length, no. of tubers per plant and weight of tubers was recorded at the time of harvest.

Phytotoxicity

Phytotoxicity study was made on 1,3,5,7 and 10 days after spraying. Observations were made for specific parameters viz., chlorosis, necrosis, scorching, epinasty and hyponasty [15].

Treatment details

T₁: Foliar application of Famoxadone 16.6% + Cymoxanil 22.1% SC @ 300 ml/ha, T₂: Foliar application of

Famoxadone 16.6% + Cymoxanil 22.1% SC @ 400 ml/ha, T₃: Foliar application of Famoxadone 16.6% + Cymoxanil 22.1% SC @ 500 ml/ha, T₄: Foliar application of Famoxadone 16.6% + Cymoxanil 22.1% SC @ 600 ml/ha, T₅: Foliar application of Azoxystrobin 23% SC @ 500 ml/ha, T₆: Foliar application of Mancozeb 75% WP @ 1000 g/ha, T₇: Control (Untreated).

Benefit Cost Ratio (BCR) and Cost-benefit analysis

The benefit-cost ratio (BCR) was worked out using the formula, BCR = Total returns/Total cost. The cost of potato tubers @ Rs. 1300/q during *Kharif* 2023, Rs. 1250/q during *Rabi* 2023-2024 and the cost of chemicals viz., Famoxadone 16.6% + Cymoxanil 22.1% SC @ Rs. 5706/L, Azoxystrobin 23% SC @ Rs. 3640/L and Mancozeb 75% WP @ Rs. 600/kg were considered to calculate the cost-benefit analysis.

Statistical analysis

All collected data were subjected to an Analysis of Variance (ANOVA) for a Randomized Block Design (RBD) using OPSTAT software at a 5% significance level. Duncan's Multiple Range Test (DMRT) was performed using WASP 2.0 to compare treatment means.

Results and Discussion

Eco-friendly management of early blight in potato remains a major challenge under high disease pressure. Although cultural and biological approaches show promise, chemical management continues to be the most practical and reliable strategy under field conditions, with new-generation fungicides playing a vital role in overcoming fungicide resistance in *A. solani* [16]. The present study demonstrated that Famoxadone 16.6% + Cymoxanil 22.1% SC was highly effective in suppressing early blight incidence and improving yield attributes across both *Kharif* 2023 and *Rabi* 2023-2024 (Table 1). Among the treatments, T₄ (600 ml/ha) consistently recorded the lowest Percent Disease Index (PDI), with values of 8.51% in *Kharif* and 9.00% in *Rabi*, followed by T₃ (500 ml/ha) with 8.79% and 9.09%, respectively. T₂ (400 ml/ha) also showed considerable efficacy (9.13% and 10.66%), outperforming T₆ (Mancozeb 75% WP, 9.45% and 10.79%) and T₅ (Azoxystrobin 23% SC, 10.07% and 10.92%), while T₁ (300 ml/ha) was least effective. The untreated control (T₇) exhibited the highest disease severity, with PDIs of 31.56% and 32.54% in the respective seasons. Yield trends mirrored the disease control data, with T₄ producing the highest tuber yield (256.30 q/ha in *Kharif*; 260.30 q/ha in *Rabi*), significantly exceeding other treatments. (Figure 1). These findings indicate that the fungicide remains effective even at slightly reduced doses, offering flexibility in field use.

The fungicidal treatments also enhanced plant growth and yield attributes compared to the untreated control. During *Kharif* 2023, T₄ resulted in the greatest improvements, recording maximum shoot length (58.26 cm), root length (34.62 cm), number of tubers per plant (18.19), and average tuber weight (512.60 g), followed by T₃ with 56.03 cm, 33.25 cm, 17.22 and 502.14 g, respectively (Table 2). In contrast, the untreated control exhibited the lowest values across all parameters. Comparable trends were observed during *Rabi* 2023-2024, reaffirming the consistency of T₄ across seasons (Figure 2). Famoxadone + Cymoxanil achieved 60-70% control under field conditions [17, 18] and

broad-spectrum efficacy against both early and late blights in potato ^[19]. The role of QoI fungicides such as Famoxadone and Azoxystrobin, particularly in mixtures with Cymoxanil or Mancozeb, has been emphasized for both their curative activity and their role in resistance management ^[16]. The economic viability of the treatments was confirmed by benefit-cost ratio (BCR) analysis. The highest BCR was consistently obtained with T4, recording values of 2.09 in Kharif and 2.03 in Rabi, followed by T3 (2.07 and 2.02). Yield benefits and profitability gains through fungicidal suppression of early blight have been noted significant improvements in growth traits and tuber yield following fungicide application ^[20, 21]. Importantly, Famoxadone 16.6% + Cymoxanil 22.1% SC was found safe at all tested doses, with no phytotoxic effects such as chlorosis, necrosis, scorching, epinasty, or hyponasty

observed up to 10 days after spraying, even at the highest concentration of 600 ml/ha.

The consistent efficacy of this fungicide across seasons, coupled with its effectiveness at slightly reduced doses, enhances its suitability for farmer adoption. The ability to lower application rates without compromising efficacy not only reduces production costs but also minimizes chemical loading, aligning with eco-friendly management. Nevertheless, reports of QoI-resistant *A. solani* strains from potato-growing regions (8, 9) highlight the need for careful resistance monitoring and fungicide stewardship. Although mixtures such as Famoxadone + Cymoxanil reduce the risk of resistance development, their sustainability depends on judicious rotation with other chemistries and integration into broader Integrated Disease Management (IDM) programs.

Table 1: Effect of foliar application of fungicide Famoxadone 16.6% + Cymoxanil 22.1% SC on the incidence of early blight of Potato during the Kharif and Rabi season

Tr. No.	Percent Disease Index						Percent reduction over control		Tuber yield (q/ha)	
	After 1 st spray*		After 2 nd spray*		After 3 rd spray*					
	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
T ₁	09.11 (17.56)	08.21 (16.65)	9.69 (18.13)	09.71 (18.15)	10.67 (19.06)	11.15 (19.50)	66.19	65.73	224.4	230.4
T ₂	07.01 (15.35)	06.12 (14.32)	08.25 (16.69)	09.01 (17.46)	09.13 (17.58)	10.66 (19.05)	71.07	67.24	247.9	250.9
T ₃	06.43 (14.68)	05.22 (13.20)	07.84 (16.26)	08.46 (16.90)	08.79 (17.24)	09.09 (17.54)	72.14	72.06	251.0	256.0
T ₄	06.22 (14.44)	05.00 (12.92)	07.63 (16.03)	08.33 (16.77)	08.51 (16.96)	09.00 (17.45)	73.03	72.34	256.3	260.3
T ₅	08.32 (16.76)	07.32 (15.69)	09.07 (17.52)	09.46 (17.91)	10.07 (18.50)	10.92 (19.29)	68.09	66.44	231.9	236.9
T ₆	07.82 (16.23)	06.61 (14.89)	08.85 (17.30)	09.25 (17.70)	09.45 (17.90)	10.79 (19.76)	70.05	66.84	239.5	242.7
T ₇	23.07 (28.70)	20.69 (27.05)	27.36 (31.53)	26.65 (31.08)	31.56 (34.17)	32.54 (34.78)	-	-	191.5	195.9
SEd	0.10	0.11	0.09	0.09	0.12	0.06	-	-	2.4	1.8
CD	0.32	0.35	0.29	0.27	0.37	0.18	-	-	7.2	5.4

* Mean of three replications

Table 2: Effect of foliar application of fungicide Famoxadone 16.6% + Cymoxanil 22% SC on biometrics of Potato during the Kharif and Rabi season

Tr. No.	Treatment details	Shoot length (cm)*		Root length (cm)*		No. of tubers per plant*		Weight of tuber per plant (g)*	
		Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
T ₁	Famoxadone 16.6% + Cymoxanil 22.1% SC @ 300 ml/ha	46.27	43.88	23.56	24.24	09.52	10.26	454.85	460.80
T ₂	Famoxadone 16.6% + Cymoxanil 22.1% SC @ 400 ml/ha	53.76	53.99	30.23	31.65	15.06	15.85	495.81	500.00
T ₃	Famoxadone 16.6% + Cymoxanil 22.1% SC @ 500 ml/ha	56.03	55.36	33.25	34.36	17.22	16.95	502.14	512.00
T ₄	Famoxadone 16.6% + Cymoxanil 22.1% SC @ 600 ml/ha	58.26	58.79	34.62	35.20	18.19	18.35	512.60	520.60
T ₅	Azoxystrobin 23% SC @ 500 ml/ha	48.56	47.32	26.65	25.59	11.36	12.02	467.80	472.80
T ₆	Mancozeb 75% WP @ 1000 g/ha	51.65	50.72	29.96	28.35	14.05	14.36	481.54	485.40
T ₇	Control	42.99	43.26	20.03	20.69	06.98	07.14	383.25	391.80
	SEd	1.23	1.40	0.52	0.35	0.41	0.63	3.52	3.53
	CD	3.70	4.20	1.58	1.06	1.25	1.90	10.57	10.60

* Mean of three replications

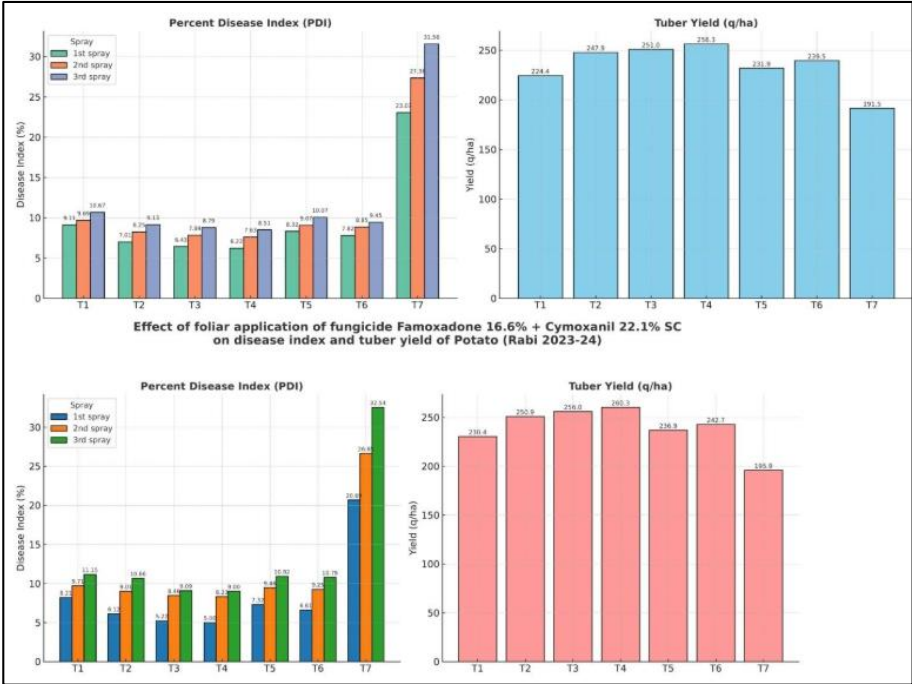


Fig 1: Graph showing effect of foliar application of fungicide on potato during the Kharif 2023 and Rabi season 2023-2024

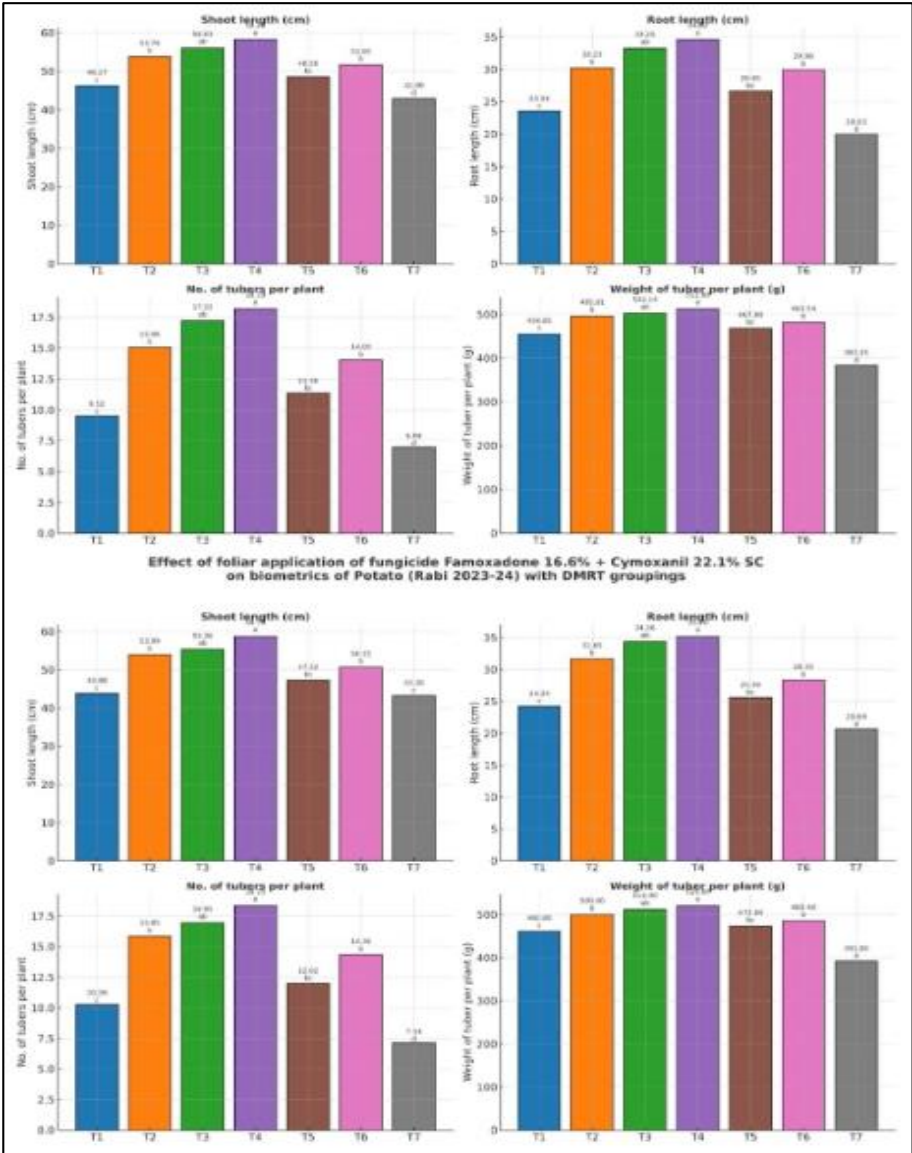


Fig 2: Graph showing effect of foliar application of fungicide on growth parameters of potato during the Kharif 2023 and Rabi season 2023-2024

Conclusion

Chemical control remains indispensable, long-term management of early blight should integrate fungicides with cultural practices such as crop rotation, balanced nutrition and canopy management, along with eco-friendly options including biological control agents and organic amendments. Collectively, these findings establish Famoxadone 16.6% + Cymoxanil 22.1% SC as a highly effective, safe and economically viable option for early blight management in potato. However, its long-term utility depends on its integration into sustainable IDM strategies to ensure durable disease control and prevent fungicide resistance.

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