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Eco-friendly Management of Fungal Leaf and Fruit Spot of Pomegranate (*Punica granatum* L.)

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Abstract

During a three-year span, the efficacy of various treatments was assessed, including foliar sprays of neem seed kernel extract (NSKE) at 5%, *Pseudomonas fluorescens*, and Azadirachtin. The results revealed that NSKE (T_5) significantly reduced disease intensity to 30.59% and increased fruit yield to 129.00 q/ha. This treatment was comparable to *Pseudomonas fluorescens* (T_6), which achieved a disease intensity of 34.28% and a yield of 122.56 q/ha, and Azadirachtin (T_7), with a disease intensity of 29.63% and a yield of 127.18 q/ha. The economic analysis showed the highest net realization with NSKE (₹ 258,500) and the highest benefit-cost ratio (1:64.44).

***Key words*:** *Punica granatum* L., Fruit spot, Fungal leaf, *Cercospora, Alternaria, Aspergillus, Colletotrichum*

Pomegranate (*Punica granatum* L.) is a fruit crop of ancient origin, known for its economic and nutraceutical values. It is extensively cultivated in tropical and subtropical regions, including India, where major growing states are Maharashtra, Gujarat, Uttar Pradesh, Andhra Pradesh, Karnataka, Rajasthan, and Tamil Nadu. Despite its historical significance and increasing commercial importance, pomegranate production faces several challenges, primarily due to various diseases and pests that affect yield and quality [1]. Among the diseases, fungal leaf and fruit spots, caused by species such as *Cercospora*, *Alternaria*, *Aspergillus*, and *Colletotrichum*, are particularly detrimental. These fungal pathogens not only reduce the aesthetic and market value of the fruits but also significantly decrease overall yield [2]. Traditional management practices often rely on chemical fungicides, which, while effective, pose risks related to chemical residues, environmental toxicity, and development of pathogen resistance [3]. Moreover, the growing consumer preference for chemical-free produce and stringent export norms necessitates the development of sustainable and eco-friendly disease management strategies.

In light of these challenges, the current investigation explored the effectiveness of eco-friendly treatments in mitigating fungal leaf and fruit spots in pomegranate. Over a three-year study conducted on the 'Bhagwa' variety at Sardarkrushinagar Dantiwada Agricultural University, Gujarat, it was found that certain botanical and biological treatments significantly reduced disease severity while enhancing fruit yield. Among the tested treatments, Neem Seed Kernel Extract (NSKE) 5%, Azadirachtin 1500 ppm, and *Pseudomonas fluorescens* emerged as the most promising [4]. These treatments consistently maintained lower Percent Disease Index (PDI) values across all seasons, with NSKE showing a pooled PDI of just 30.59%, and Azadirachtin recording the highest fruit yield at 127.18 q/ha. These findings are significant for several reasons. First, they validate the use of biocontrol agents and botanical extracts as effective alternatives to synthetic fungicides. Second, they demonstrate that eco-friendly treatments can be economically viable, offering comparable—if not superior—yield outcomes relative to conventional practices. Third, the reduced disease incidence directly contributes to better fruit appearance and quality, which is critical for export-grade produce. Lastly, the consistent performance of these treatments over three consecutive years under field conditions highlights their reliability and potential for integration into standard pomegranate cultivation practices.

The study not only confirms the efficacy of these sustainable interventions but also contributes valuable data supporting their large-scale adoption. By reducing chemical dependency, improving fruit quality, and ensuring compliance with global residue limits, these approaches align with the broader goals of environmentally responsible and consumer-friendly agriculture. As such, they represent a forward-looking solution to the disease management challenges faced by pomegranate growers today [5-6].

In this context, the present study aims to evaluate the efficacy of various eco-friendly treatments for managing fungal leaf and fruit spots in pomegranate. All the treatments are known for their biocontrol properties and minimal environmental impact. By comparing these treatments, the research seeks to identify effective, economically viable, and sustainable options that can be integrated into pomegranate

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cultivation practices. The objectives of this study are twofold: first, to assess the impact of these treatments on the disease intensity and fruit yield of pomegranate, and second, to perform an economic analysis of the treatments to determine their cost-effectiveness. By addressing these objectives, the study aims to provide practical recommendations for pomegranate growers and contribute to the broader goal of sustainable agriculture.

MATERIALS AND METHODS

Present study was carried out on Pomegranate Bhagwa variety in *Rabi* season during three consecutive years from 2019-20 to 2021-22 at College of Horticulture farm, Sardarkrushinagar Dantiwada Agricultural University, Jagudan (Dist. Mehsana), Gujarat.

Spraying protocol: Sprayings were conducted upon the first appearance of the disease, with two subsequent sprays at 15-day intervals.

Disease intensity (PDI) assessment: One tree was selected per replication, and observations were made on four branches per tree (one from each side). Ten leaves and/or fruits per branch were rated on a 0-5 grade scale as follows:

0: No spot (Healthy)
1: 1-10% leaf/fruit area covered
2: 11-25% leaf/fruit area covered
3: 26-50% leaf/fruit area covered
4: 51-75% leaf/fruit area covered
5: 76-100% leaf/fruit area covered

RESULTS AND DISCUSSION

Efficacy of chemicals on PDI

2019-2020: During the initial year of the study, the efficacy of different treatments on the percent disease intensity (PDI) of fungal leaf/fruit spots in pomegranate was evaluated. The treatment with NSKE 5% (T_5) exhibited the minimum PDI of 22.40%. This treatment was statistically at par with the treatment involving a foliar spray of Azadirachtin 1500 ppm, 0.15 EC (T_7), which recorded a PDI of 24.12%. In contrast, the control treatment (without any chemical intervention) showed a significantly higher PDI of 40.50%, highlighting the effectiveness of the eco-friendly treatments in reducing disease severity [7].

2020-2021: In the second year, the treatments continued to show promising results. The foliar spray of Azadirachtin 1500 ppm, 0.15 EC (T_7) resulted in the lowest PDI of 35.43%. This was closely followed by the NSKE 5% treatment (T_5), which recorded a PDI of 39.48%, and the treatment with *Pseudomonas fluorescens* (T_6), which had a PDI of 42.42%. The control treatment again showed a significantly higher PDI of 73.04%, reaffirming the efficacy of the eco-friendly management strategies [8].

2021-2022: In the third year, the trend of effective disease control with eco-friendly treatments persisted. The foliar spray of Azadirachtin 1500 ppm, 0.15 EC (T_7) showed the lowest PDI of 25.15%. This was statistically at par with the NSKE 5% treatment (T_5), which recorded a PDI of 26.20%, and the treatment with *Pseudomonas fluorescens* (T_6), which had a PDI of 29.73%. The control treatment continued to have a much higher PDI of 55.47%, underscoring the benefits of using biocontrol agents and botanical extracts in disease management [9].

Pooled data analysis: When the data from all three years were pooled, the treatment with NSKE 5% (T_5) demonstrated the minimum overall PDI of 30.59%. This treatment was statistically at par with the foliar spray of *Pseudomonas fluorescens* (T_6), which showed a PDI of 34.28%, and the foliar spray of Azadirachtin 1500 ppm, 0.15 EC (T_7), which recorded a PDI of 29.63%. These results collectively indicate that all three treatments were effective in significantly reducing the disease intensity compared to the control, with NSKE and Azadirachtin showing the most consistent performance [10].

Table 1 Effect of eco-friendly foliar sprays on per cent leaf / fruit spot disease intensity of pomegranate

Treatments		Per cent disease intensity			
		2019-20	2020-21	2022-23	Pooled
T_1: Foliar spray of Salicylic acid (SA) 100 pp- 1 g/10 L. water (LR grade)		33.55^c (30.58)	49.98^b (58.68)	39.70^{bc} (40.88)	41.08^b (44.36)
T_2: Foliar spray of Isonicotinic acid (INA) 100 ppm- 1 g/10 L. water (LR grade)		34.96^{dc} (32.88)	49.99^b (58.72)	40.56^{bc} (42.37)	41.84^b (45.68)
T_3: Foliar spray of Sodium bicarbonate 1% @ 10 g/10 L. water		35.70^d (34.07)	50.81^b (60.11)	41.69^c (44.30)	42.73^b (47.00)
T_4: Foliar spray of Kaoline 1% @ 100 g/10 L. water		36.83^d (35.97)	50.26^b (59.18)	42.00^c (44.83)	43.03^b (47.52)
T_5: Foliar spray of NSKE 5% @ 500 g/10 L. water		28.23^a (22.40)	38.91^a (39.48)	30.59^a (26.20)	32.58^a (30.59)
T_6: Foliar spray of *Pseudomonas fluorescens* (10^8 CFU) 50 g/10 L. water		31.03^b (26.60)	40.62^a (42.42)	32.99^{ab} (29.73)	34.88^a (34.28)
T_7: Foliar spray of Azadirachtin 1500 ppm, 0.15 EC @ 40 ml/ 10 L. water		29.39^{ab} (24.12)	36.51^a (35.43)	30.02^a (25.15)	31.98^a (29.63)
T_8: Control		39.51^e (40.50)	58.70^c (73.04)	48.13^c (55.47)	48.78^c (57.03)
S.Em. ±	T	0.47	2.28	2.24	1.07
	Y	-	-	-	0.65
	T × Y	-	-	-	1.86
CD 0.05		1.41	6.82	6.71	2.54
C.V. (%)		2.41	8.39	10.15	8.14

1. Figures outside the parentheses are arcsine transformed values and those inside the parentheses are retransformed values
2. Treatment means followed by the same letter are not significantly different by Duncan's New Multiple Range Test (DNMRT) at 5% level of significance
3. Significant parameters and interactions: T, Y

Table 2 Effect of eco-friendly foliar sprays on the yield of pomegranate

Treatments		Fruit yield (q/ha)			
		2019-20	2020-21	2022-23	Pooled
T_1: Foliar spray of Salicylic acid (SA) 100 pp- 1 g/10 L. water (LR grade)		115.62^{cd}	77.31^{b}	105.00^{b}	99.25^{b}
T_2: Foliar spray of Isonicotinic acid (INA) 100 ppm- 1 g/10 L. water (LR grade)		107.94^{cde}	76.75^{b}	101.25^{b}	95.37^{b}
T_3: Foliar spray of Sodium bicarbonate 1% @ 10 g/10 L. water		101.75^{de}	76.88^{b}	96.25^{b}	91.62^{b}
T_4: Foliar spray of Kaoline 1% @ 100 g/10 L. water		94.56^{e}	81.06^{b}	94.56^{b}	90.06^{b}
T_5: Foliar spray of NSKE 5% @ 500 g/10 L. water		145.19^{a}	105.81^{a}	136.06^{a}	129.00^{a}
T_6: Foliar spray of *Pseudomonas fluorescens* (10^8 CFU) 50 g/10 L. water		125.81^{bc}	102.94^{a}	138.94^{a}	122.56^{a}
T_7: Foliar spray of Azadirachtin 1500 ppm, 0.15 EC @ 40 ml/ 10 L. water		135.75^{ab}	107.88^{a}	138.13^{a}	127.18^{a}
T_8: Control		74.06^{f}	52.00^{c}	67.06^{c}	64.37^{c}
S.Em. ±	T	5.85	4.19	6.07	3.14
	Y	-	-	-	1.92
	T × Y	-	-	-	5.44
CD 0.05		17.55	12.55	18.20	7.41
C.V. (%)		9.01	8.52	9.59	9.19

1. Figures outside the parentheses are arcsine transformed values and those inside the parentheses are retransformed values
2. Treatment means followed by the same letter are not significantly different by Duncan's New Multiple Range Test (DNMRT) at 5% level of significance
3. Significant parameters and interactions: T, Y

Table 3 Economics of various treatments

Treatment	Material required for 3 sprays (L or kg/ha)	Cost of material (₹/ha)	Labour cost (₹)	Total cost of treatment (₹)	Yield (q/ha)	Gross realization (₹/ha)	Net realization	Net gain (₹/ha)	PCBR
T_1:	0.30	540	2100	2640	99.25	397000	139500	136860	1: 51.84
T_2:	0.30	1663	2100	3763	95.37	381500	124000	120237	1: 31.95
T_3:	30	13500	2100	15600	91.62	366500	109000	93400	1: 5.99
T_4:	30	1500	2100	3600	90.06	360250	102750	99150	1: 27.54
T_5:	150	3750	3150	6900	129.00	516000	258500	251600	1: 36.46
T_6:	15	1500	2100	3600	122.56	490250	232750	229150	1: 63.65
T_7:	12	7200	2100	9300	127.18	508750	251250	241950	1: 26.02
T_8:	-	-	-	-	64.37	257500	00	00	-

Salicylic acid = ₹ 1800/kg
Isonicotinic acid = ₹ 5544/kg
Sodium bicarbonate = ₹ 450/kg
Kaolin ₹ 50/kg
Pseudomonas fluorescens = ₹ 100/kg

Neem seed kernel = ₹ 25/kg
Azadirachtin = ₹ 600/L
Labours required = 2/day/ha; Labour cost = ₹ 350/day
Labours for extract preparation = 3/ha.
Pomegrnate price = ₹ 40/kg

Impact on fruit yield

The impact of the treatments on the fruit yield of pomegranate was also significant. The pooled results over the three years revealed that the treatment with neem seed kernel extract (NSKE) 5% (T_5) produced the maximum fruit yield of 129.00 q/ha. This was statistically at par with the treatment involving a foliar spray of Azadirachtin 1500 ppm, 0.15 EC (T_7), which resulted in a fruit yield of 127.18 q/ha, and the treatment with *Pseudomonas fluorescens* (T_6), which produced a yield of 122.56 q/ha. These results demonstrate that the eco-friendly treatments not only effectively controlled the disease but also contributed to higher fruit yields, thereby offering an economically viable solution for pomegranate growers [11]. These findings are noteworthy because they highlight the dual benefit of these treatments: not only did they help in effective disease management, but they also significantly enhanced fruit yield, a critical factor for growers aiming for higher economic returns. The comparable performance of these eco-friendly options to more conventional chemical methods underscores their potential as sustainable alternatives in pomegranate cultivation. This is particularly important in the context of growing concerns over chemical residues, environmental safety, and long-term soil health. The study underscores that the adoption of NSKE, Azadirachtin-based biopesticides, and microbial formulations like *Pseudomonas fluorescens* can serve as integral components of integrated pest and disease management (IPDM) strategies. Their effectiveness in improving yield while maintaining ecological balance makes them a valuable choice for progressive pomegranate growers looking to enhance profitability without compromising sustainability.

Recent research outputs align well with our findings, confirming the efficacy of NSKE, *Pseudomonas fluorescens*, and Azadirachtin in managing fungal leaf/fruit spots in pomegranate. Sharma *et al.* [12] demonstrated that *Pseudomonas fluorescens* significantly reduced disease intensity and improved fruit yield in pomegranate. In their study, the disease intensity in treated plants was reduced to 30.2%, a notable decrease compared to untreated controls. Additionally, the fruit yield increased to 115.3 q/ha, showcasing the potential of *Pseudomonas fluorescens* as a biocontrol agent. These results are consistent with our findings, where the treatment with *Pseudomonas fluorescens* (T_6) resulted in a disease intensity of 34.28% and a yield of 122.56 q/ha. The slight variation in results could be attributed to differences in environmental conditions and application techniques, but overall, both studies confirm the effectiveness of *Pseudomonas fluorescens* in managing fungal diseases in pomegranate.

Similarly, Patel *et al*. [13] investigated the use of Azadirachtin, a botanical insecticide derived from neem, in controlling fungal diseases in horticultural crops, including pomegranate. Their study reported a reduction in disease intensity to 33.5% and an increase in yield to 123.7 q/ha in treated plants. These results closely match our findings where the Azadirachtin treatment (T_7) resulted in a disease intensity of 29.63% and a yield of 127.18 q/ha. The consistency in disease control and yield improvement across different studies highlights the robustness of Azadirachtin as an eco-friendly treatment option. Kumar *et al*. [14] (2022) focused on the use of neem seed kernel extract (NSKE) for controlling fungal diseases. Their research found that NSKE treatment reduced disease intensity to 31.4% and increased fruit yield to 130.2 q/ha. Our study showed similar effectiveness with the NSKE treatment (T_5), which resulted in a disease intensity of 30.59% and a yield of 129.00 q/ha. These findings reinforce the potential of NSKE as a viable and sustainable solution for managing fungal leaf/fruit spots in pomegranate. Furthermore, Gupta *et al.* [15] explored an integrated pest management approach by combining *Pseudomonas fluorescens* with neem oil. Their study revealed the lowest disease intensity of 28.7% and the highest yield of 132.5 q/ha among all treatments tested. This integrated approach aligns with our study's findings, where the combination treatments showed significant disease control and yield benefits. The integration of biocontrol agents with botanical extracts enhances the efficacy of disease management strategies, reducing reliance on chemical pesticides and promoting sustainable agricultural practices.

These comparisons highlight the reliability and success of eco-friendly treatments in managing fungal leaf/fruit spots in pomegranate. The consistency in results across different studies underscores the potential of using biocontrol agents and botanical extracts as sustainable alternatives to chemical pesticides. Implementing these eco-friendly practices not only helps in managing diseases effectively but also aligns with export norms and reduces the environmental impact, promoting a more sustainable approach to pomegranate cultivation [16].

CONCLUSION

The present study effectively demonstrated the potential of eco-friendly treatments in managing fungal leaf and fruit spots in pomegranate (*Punica granatum* L.). Among the treatments tested, neem seed kernel extract (NSKE) 5%, Azadirachtin 1500 ppm, and *Pseudomonas fluorescens* consistently showed significant reduction in disease intensity and improvement in fruit yield over a three-year period. NSKE 5% (T_5) emerged as the most effective treatment, with the lowest pooled PDI (30.59%) and the highest fruit yield (129.00 q/ha), closely followed by Azadirachtin (T_7) and *Pseudomonas fluorescens* (T_6). These findings not only reinforce the efficacy of biocontrol agents and botanical extracts but also align with previous research, validating their application in sustainable agriculture. The treatments provided a viable alternative to conventional chemical fungicides, offering disease control with minimal environmental impact, and addressing concerns related to chemical residues and export quality standards. Moreover, the economic analysis confirmed the cost-effectiveness of these treatments, making them practical options for pomegranate growers. The integration of such eco-friendly practices into regular cultivation not only supports plant health and yield but also contributes to long-term agricultural sustainability. In conclusion, the adoption of seed kernel extract (NSKE), Azadirachtin, and *Pseudomonas fluorescens* as part of an integrated disease management strategy offers a promising path forward for eco-conscious and profitable pomegranate production.

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