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Research Article

Comparative Efficacy of Exogenous Chemical Applications for Controlling Citrus Scab (*Elsinoë fawcettii*) in *Citrus reticulata* Blanco

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Abstract | Citrus scab caused by the pathogen *Elsinoë fawcettii* represents a prevalent and economically important phyto-pathological disorder of citrus species, especially under agroecological conditions characterized by elevated temperature and high relative humidity. An experiment was conducted on kinnow plants consecutively three years 2020-21, 2021-22 and 2022-23. The aim of the study was to find out the most suitable fungicide against the citrus scab disease in Kinnow Mandrin (*Citrus reticulata* Blanco). The study was conducted on 20 years old kinnow plants having planting distance of 6.1 m x 6.1 m. The treatments were applied before flowering in March, after fruit setting in April and in the months of August in consecutive three years. Various chemicals i.e., Azoxystrobin (1 ml/L of Water), Pyraclostrobin+Metiram (1.5 g/L of Water), Difenoconazole+Azoxystrobin (1 ml/L of Water), Copper Oxychloride+Cymoxanil(2 ml /L of Water), Copper hydro oxide (2.5 g/L of Water), Tebuconazole+Trifloxystrobin (0.5 g/L of Water), Fluoxstrobin (1 ml/L of Water), and Bordeaux mixture 1% (1:1:100) and results were compared with Control. Diseased data for citrus scab was collected /recorded after fifteen days of the last spray. This study demonstrates the superior efficacy of Difenoconazole+Azoxystrobin (1 ml/L of Water) and Bordeaux mixture (1%) in controlling citrus scab in Kinnow. These systemic fungicides offer significantly better disease suppression and yield improvement than Fluoxstrobin (1 ml/L of Water) and control (non-treated with chemicals). Integrating these fungicides with timely applications for Kinnow disease management programs can substantially improve fruit quality and farmer profitability.

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Introduction

Kinnow mandarin (*Citrus reticulata* Blanco) is a commercially significant citrus cultivar extensively cultivated in Pakistan (Hayat *et al*., 2022). However, its productivity is severely constrained by several major biotic stressors, including Asian citrus psyllid (*Diaphorina citri* Kuwayama), citrus whitefly (*Dialoeurodes citri* Ashmead), sooty mold (*Capnodium citri*), and dieback caused by *Colletotrichum* *gloeosporioides*, collectively leading to yield reductions of up to 70%. The findings validate the IPM approach as an ecologically and economically sustainable strategy for managing key pest complexes in Kinnow mandarin cultivation (Meena *et al*., 2025). Citrus scab is one the most dangerous disease of citrus (Malik *et al*., 2021). In Pakistan citrus holds a prominent position as a major cash crop, contributing significantly to the livelihoods of farmers and the national horticultural economy. In Pakistan total citrus was grown on area of 152,716 hectares with production of 2.32 MMT in the yar 2020-2021, including major share of Punjab province 2.24 MMT on 141,178 hectares (GOP,2023).

Citrus represents one of the most widely cultivated and economically significant fruit crops worldwide. Renowned for their high content of vitamins, minerals, and dietary fiber, citrus fruits contribute substantially to human nutrition and health. Among citrus species, oranges dominate global trade, accounting for over 50% of total citrus production. Various Phyto pathological disorders, not only impact foliage but also affect fruit quality directly, leading to visible blemishes and deformities that compromise marketability (Van Zyl, 2019). To determine effective management strategies for citrus die-back and scab diseases, the individual and combined effects of mustard oil cake, urea, triple super phosphate (TSP), muriate of potash (MOP), cow dung, the fungicide Bavistin, irrigation, and pruning have also been evaluated by various researchers (Alam *et al*., 2020).

The incidence of citrus scab is spreading throughout the globe devastating orchards badly (Alam *et al*., 2020). It is caused by the fungus *Elsinoë fawcettii*, (Dewdney, 2019). In one of previous study the citrus scab pathogen was effectively suppressed by bio-sulfur at 500-, 1000-, and 2000-fold dilutions. In field trials, the incidence of citrus scab on spring-flush leaves was 40.3% in untreated plots, compared to 5.3%, 10.3%, 12.3%, 15.3%, and 24.0% in plots treated with imibenconazole, 2-4 and 6-6 lime-Bordeaux mixtures (commonly adopted in eco-friendly cultivation), 500-fold diluted bio-sulfur, lime sulfur, and 1000-fold diluted bio-sulfur, respectively. For citrus fruit, disease incidence was 79.3% in the untreated control, and 4.0%, 33.8%, 42.0%, 43.3%, 44.8%, and 78.0% in treatments with imibenconazole, 2-4 lime-Bordeaux mixture, 6-6 lime-Bordeaux mixture, 500-fold diluted bio-sulfur, lime sulfur, and 1000-fold diluted bio-sulfur, respectively. Given that citrus scab infections can initiate as early as May with the emergence of the spring flush, prophylactic treatments should be applied by mid to late April to optimize disease management, enhance control efficacy, and reduce labor and production costs (Oh *et al*., 2020).

Pruning, sanitation and irrigation management are some non-chemical factors to control citrus scab management (Gohel *et al*., 2022). These are phytopathogenic fungi of significant concern in citrus cultivation due to their association with citrus scab disease. Both species synthesize a distinctive group of red to orange pigments known as elsinochromes, a class of non-host-selective, photosensitizing phytotoxins essential for full virulence and necrotic lesion development on host tissues. *E. fawcettii* is the causal agent of citrus scab (previously categorized into sour orange scab and common scab) and infects a broad range of *Rutaceae* species and hybrids globally. The biosynthesis of elsinochrome in *E. fawcettii* is tightly coordinated with conidiation, and emerging evidence suggests that shared environmental and physiological cues regulate both secondary metabolism and asexual reproduction. Further elucidation of these regulatory networks may provide novel targets for disease management. This review underscores the significance of *Elsinoë* spp. as critical pathogens in citrus pathosystems, highlighting their taxonomy, pathogenicity, and the pivotal role of elsinochrome in disease development. Understanding the molecular and environmental regulation of elsinochrome biosynthesis offers valuable insight into fungal virulence mechanisms and may inform future strategies for disease control (Chung, 2011). "Essential oils (EOs) are natural plant-derived products characterized by a complex composition of bioactive volatile compounds, many of which exhibit well-documented antibacterial properties. The combined application of citrus-derived essential oils demonstrated efficacy in suppressing the phytopathogenic bacterium "*Streptomyces scabiei*" (Prieto *et al*., 2024).

According to Bushong and Timmer (2000) that evaluated benomyl, fenbuconazole, and azoxystrobin against citrus scab and Melanose. The results showed that all three fungicides effectively controlled scab when applied before infection. Benomyl remained effective up to 72 hours after inoculation, while fenbuconazole and azoxystrobin worked best within 16–48 hours post-inoculation. For Melanose, only azoxystrobin showed strong preventive action; the others were ineffective before or after infection. Overall, the study suggests that post-infection sprays can help manage scab but not Melanose under field conditions. Another safe fungicide Fluoxastrobin has been applied for control of fungicidal diseases of kinnow (Adaskaveg *et al*., 2022). Pyraclostrobin and metiram are fungicidal agents employed for the management of fungal pathogens in crops. Pyraclostrobin is a systemic strobilurin-class fungicide that inhibits mitochondrial respiration by blocking electron transfer at the cytochrome bc_1 complex (Complex III), thereby disrupting ATP synthesis and arresting fungal development. In contrast, metiram is a non-systemic dithiocarbamate fungicide that functions as a multi-site contact protectant. It acts by inhibiting essential enzymatic processes during spore germination and early fungal growth stages, thereby preventing infection establishment on plant surfaces (Abd El-Rahman *et al*., 2018). Tebuconazole and Trifloxystrobin have also been found to successfully cure scab in stone fruits by reducing production of conidia (Lalancette *et al*., 2015).

Table 1: *Various chemicals used to control citrus scab (E. Fawcettii) in Kinnow*

Treat-ments	Chemicals applied as foliar spray	Concentration of active ingredient
$_{T}1$	Azoxystrobin	1 ml/L of Water
T_2	Pyraclostrobin+Metiram	1.5 g/L of Water
T_3	Difenoconazole+Azoxystrobin	1 ml/L of Water
T_4	Copper Oxychloride + Cymoxanil	2 ml /L of Water
T_5	Copper hydro oxide	2.5 g/L of Water
T_6	Tebuconazole+Trifloxystrobin	0.5 g/L of Water
T_7	Fluoxstrobin	1 ml/L of Water
T_8	Bordeaux Mixture 1%	(1:1:100)
T_9	Control	-

Among the fungal diseases, citrus scab has emerged as a prevalent and economically significant issue. The disease is characterized by the formation of superficial, corky lesions on the fruit surface, which greatly diminish the marketability of affected fruits, especially in the fresh produce sector. Citrus scab is prevalent in many humid, citrus-growing regions globally. The etiology of citrus scab is complex, involving multiple fungal species whose identification is complicated by the limitations of traditional morphological and cultural diagnostic methods. Therefore, accurate species-level identification requires the use of molecular diagnostics and host specificity assays. Among the molecular tools available, enzyme-linked immunosorbent assay (ELISA) and polymerase chain reaction (PCR) are commonly employed, with PCR offering superior specificity and sensitivity for pathogen detection (Munir *et al*., 2020). Disease management with chemical and biochemical fungicides applications, screening, natural controlling agents, disease free citrus nursery development is necessary for food security and safety (Jyothi and Shilpa, 2020). Keeping in view of the above-mentioned facts it is necessary to find out the most suitable fungicide against the citrus scab disease in Kinnow under subtropical and semi-arid regions of Punjab.

Materials and Methods

A series of experiments were conducted on kinnow plants consecutively three years 2020-2021, 2021-2022 and 2022-2023 for control of citrus scab. Kinnow plants used in the research study were grafted on rough lemon (*Citrus jambhiri*) seedlings. Square system layout was followed as planting geometry for kinnow plants with 6.1 m x 6.1 m at Citrus Research Institute, Sargodha- 40100. The study was conducted in three consecutive years (during 2020-21, 2021-22 and 2022-23) on 20 years old kinnow plants. Various treatments (chemical ingredients along with its concentrations) i.e., Azoxystrobin @ 1 ml/L of Water, Pyraclostrobin+Metiram @1.5 g/L of Water, Difenoconazole+Azoxystrobin @1 ml/L of Water, Copper Oxychloride +Cymoxanil@2 ml/L of Water, Copper Hydro Oxide 2.5 g/L of Water, Tebuconazole+Trifloxystrobin @0.5 g/L of Water, Fluoxstrobin @1 ml/L of Water, Bordeaux mixture @1% (1:1:100) were applied on kinnow Mandrin (*Citrus reticulata* Blanco) plants and results were compared with control (non-treated plants) (Table 1). The foliar sprays were applied before flowering in February/March, after fruit setting in April and in the month of August. Disease data for citrus scab were collected /recorded after fifteen days of the last spray.

Bordeaux mixture preparation

Bordeaux mixture, a conventional fungicidal formulation, was synthesized by the admixture of aqueous solutions of copper (II) sulfate ($CuSO_4$) and calcium hydroxide [$Ca(OH)_2$], commonly referred to as hydrated lime. The standard preparation ratio is denoted as 10-10-100, indicating a composition of

Table 2: *Efficiency of various chemicals on disease incidence (%) on leaf and fruit of kinnow plants to control citrus scab (E. Fawcettii) during 2020-21, 2021-22 and 2022-23*

Fungicides (Treatments)	Disease Incidence (%) (Fruit) 2020-21	Disease Incidence (%) during 2021-22	Disease Incidence (%) during 2022-23
T1(Azoxystrobin)	8±0.41 D	5.25±0.27 D	4.25±0.26 DE
T2 (Pyraclostrobin+Metiram)	10±0.47 B	9.25±0.45 B	8.25±0.44 B
T3 (Difenoconazole+Azoxystrobin)	4±0.20 G	3.0±0.25 E	2.25±0.12 F
T4 (Copper Oxychloride+Cymoxanil)	9±0.42 C	9.75±0.46 B	8.50±0.43 B
T5 (Copper hydro oxide)	6±0.29 E	5.25±0.27 D	4.50±0.23 D
T6 (Tebuconazole+Trifloxystrobin)	7±0.34 E	7.25±0.35 C	6.50±0.31 C
T7 Fluoxstrobin	8±0.36 D	9.25±0.48 B	8.25±0.39 B
T8 (Bordeaux mixture 1%)	5±0.24 F	3.5±0.25 E	3.50±0.16 E
T9 (Control)	30±1.61 A	33.25±1.73 A	29.25±1.52 A
L.S.D value	0.74	2.064	2.064

Means sharing different letters in a row or in a column are statistically significant (P≤0.05). The values after ± indicate standard deviations

10 pounds of copper sulfate, 10 pounds of hydrated lime, and 100 gallons of water. The copper sulfate solution was added gradually to the lime solution with continuous stirring to ensure proper mixing and to prevent precipitation. Alternatively, both solutions were poured simultaneously into a third container under constant agitation to achieve a homogeneous final Bordeaux mixture. The copper sulfate and lime components were solubilized independently in water prior to their combination, resulting in the final suspension known as Bordeaux mixture.

From each selected tree, 4–5 branches were chosen randomly from different sides (north, south, east, west, center) to ensure even representation. On each branch, all the fruits present were counted. The total number of fruits per tree were also counted.

Physicochemical analysis of fruits

The polar and equatorial diameters of the fruit were measured using a vernier caliper, and the results were recorded in centimeters (cm). Fruit weight was determined using an analytical balance, with measurements expressed in grams (g). The thickness of the fruit peel was also measured using a vernier caliper. Juice was extracted using a mechanical juice extractor, and the extracted juice was subsequently weighed.

For the assessment of organoleptic quality, a subjective rating technique based on a hedonic scale ranging from 0 to 10 was employed, as described by Krum (1955). A sensory evaluation panel comprising three trained judges was formed to determine the average sensory score. Each panelist independently consumed the fruit samples and evaluated attributes such as taste and flavor, assigning scores accordingly.

The total soluble solids (TSS) content of the juice was determined using an Abbe's stage refractometer (Model RL 1372), and the results were expressed as a percentage (%). Total titratable acidity (TA) was estimated according to the method described by Horwitz (1960). For each sample, 10 mL of juice was transferred to a conical flask, slightly diluted with distilled water, and titrated against 0.1 N sodium hydroxide (NaOH) solution using 2–3 drops of phenolphthalein as an indicator. The titratable acidity was calculated and expressed as a percentage using the following equation:

$$Acidity\ (\%) = \frac{Volume\ of\ juice\ (mL) \times NNaOH \times 0.0064 \times 100}{Volume\ of\ juice\ taken\ for\ titration\ (mL)}$$

The total soluble solids to titratable acidity (TSS/TA) ratio was computed by dividing the TSS (%) by the TA (%), as outlined by Horwitz (1960).

Disease assessment

Each fruit was visually inspected for symptoms of citrus scab, which include raised, corky, scabby lesions. The assessment during peak disease expression (mid to late fruit development stage) was conducted.

The number of fruits showing typical scab symptoms per tree was recorded and calculation of citrus scab disease Incidence was done by following equation:

$$\text{Citrus Scab Incidence (\%)} = \left(\frac{\text{Number of infected fruits}}{\text{Total Number of Fruits Observed}}\right) \times 100$$

Experimental design and statistical analysis

The experiment was laid out under Randomized Complete Block Design (RCBD) with 9 treatments having 4 replications with 3 number of plants / replication and a total of 108 plants. Significance among treatment of means were compared by using Tuckey Highest Significant Difference Test (HSD) at $P \leq 0.05$ with STATISTIX 8.1.

Results

It was found that during 2020-2021, the minimum citrus scab incidence (4%) on kinnow fruits was found in treatment T_3 (Difenoconazole+Azoxystrobin@1 ml/L of Water), followed by T_8 (Bordeaux mixture) (5%), T_5 (Copper hydro oxide) (6%), and T_6 (7%). Maximum disease incidence in chemical foliar application was observed in T_2 (Pyraclostrobin+Metiram) (10%) and in control plants (30%) (Table 2).

Results revealed that during 2021-22, the maximum citrus scab disease control/minimum incidence of citrus scab on kinnow fruits was found in treatment T_3 (Difenoconazole+Azoxystrobin@1 ml/L of Water) (3.0%), T_8 (Bordeaux mixture 1%) (3.5%) followed by T_5 (Copper hydro oxide) (5.25%) and T6 (7.25%), while among chemical treatments minimum control/maximum incidence of disease was observed in T_4 (Copper Oxychloride+Cymoxanil) (9.75%). However, maximum incidence (33.25%) of disease was observed in control (Table 2).

However, during 2022-23, the maximum citrus scab disease control/minimum citrus scab incidence on kinnow fruits was found in treatment T_3 (Difenoconazole+Azoxystrobin@1 ml/L of Water) (2.25%), T_8 (Bordeaux mixture 1%) (3.5%) followed by T_5 (Copper Hydro Oxide) (4.50%) and T6 Tebuconazole+Trifloxystrobin (6.5%), while among chemical applications maximum incidence of citrus scab (8.50%) was found in T_4 (Copper Oxychloride+Cymoxanil). However, non-treated plants (control) revealed maximum incidence of citrus scab (29.25%) (Table 2).

On overall basis, Difenoconazole+Azoxystrobin and (Bordeaux mixture 1%) best controlled the incidence of scab on kinnow fruits among selected chemical used.

There was significant difference ($P \leq 0.5$) among treatments applied regarding TA (%). During 2020-21, Difenoconazole+Azoxystrobin (17.5%) and Bordeaux mixture 1% (17.4%) showed significantly ($P \leq 0.5$) higher titratable acidity (%). Similarly, during 2021-22, the maximum titratable acidity (%) was calculated on plants treated with Difenoconazole+Azoxystrobin (18.2%) and Bordeaux mixture 1% (17.5%). However, during 2022-23, the maximum titratable acidity (%) was calculated on plants treated with Difenoconazole+Azoxystrobin (17.5%) and at par with Bordeaux mixture 1% (17.6%). While minimum value of TA was found in control in three consecutive years (Figure 1).

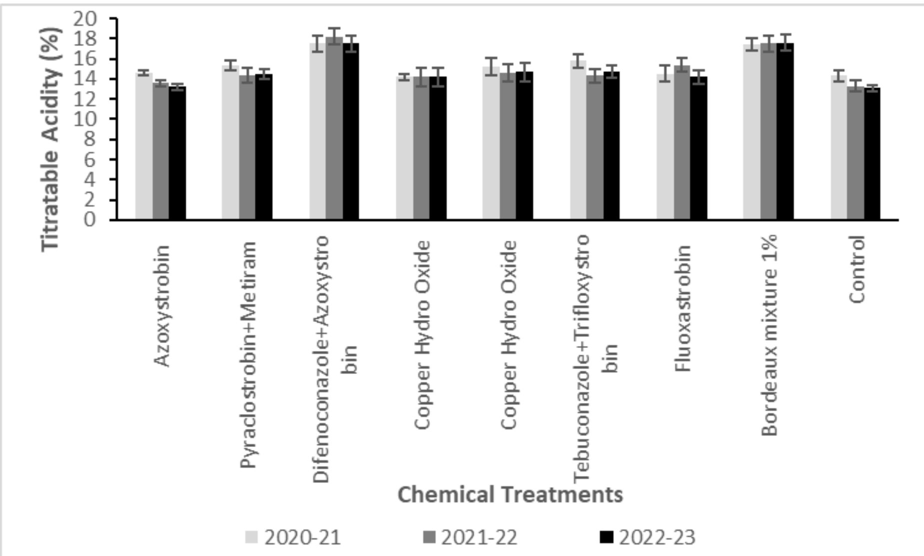

Figure 1: *Impact of various chemicals on TA (%) of Kinnow during 2020-21, 2021-22 and 2022-23*

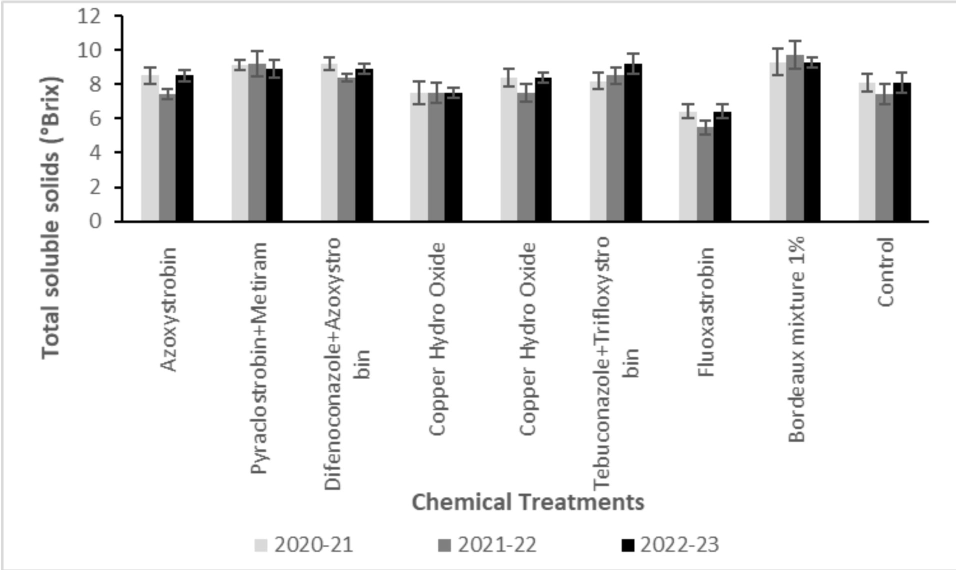

Figure 2: *Impact of various chemicals on total soluble solids (°Brix) of Kinnow during 2020-21, 2021-22 and 2022-23.*

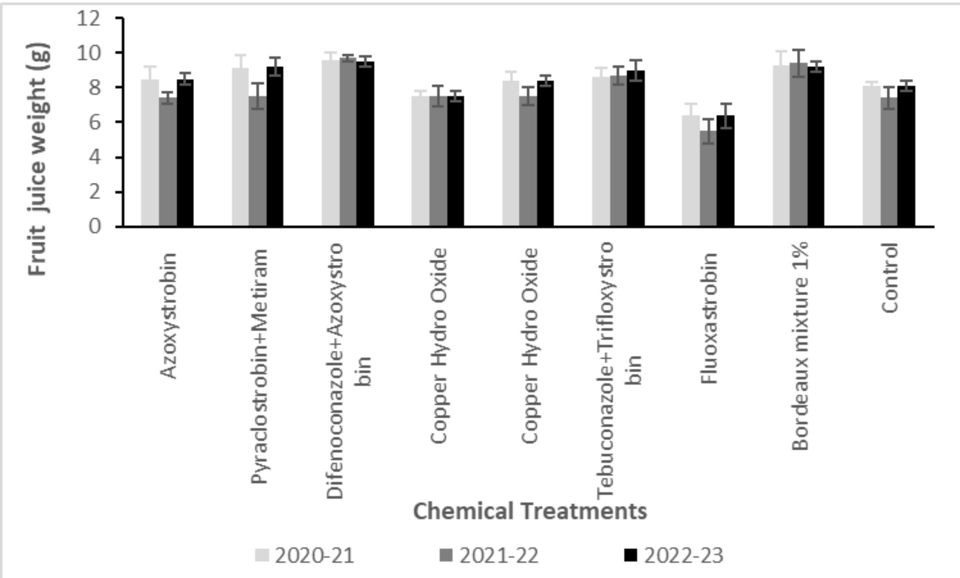

Figure 3: *Impact of various chemicals on fruit juice weight (g) of Kinnow during 2020-21, 2021-22 and 2022-23.*

There were significantly higher total soluble solids were calculated on plants treated with Difenoconazole+Azoxystrobin (9.5°Bx) and Bordeaux mixture 1% (9.3°Bx) during 2020-21. However, during 2021-22, the maximum total soluble solids were calculated on plants treated with Difenoconazole+Azoxystrobin (9.2°Bx) and Bordeaux mixture 1% (9.7°Bx). However, during 2022-23, the maximum total soluble solids (Brix) were calculated on plants treated with Difenoconazole+Azoxystrobin (9.6°Bx) and Bordeaux mixture 1% (9.3%). While on overall basis minimum TSS was recorded in control during consecutive years (Figure 2).

A significantly ($P\leq0.5$) higher average fruit juice weight (g) was calculated on plants treated with Difenoconazole+Azoxystrobin (9.6 g) and Bordeaux mixture 1% (9.3 g) during 2017-18. However, during 2020-21. It was observed that maximum average fruit juice weight (g) was calculated on plants treated with Difenoconazole+Azoxystrobin (9.7 g) and Bordeaux mixture 1% (9.4 g) during 2021-22. However, during 2022-23, the maximum average fruit juice weight (g) was calculated on plants treated with Azoxystrobin at par with Difenoconazole+Azoxystrobin (9.6 g) and Bordeaux mixture 1% (9.3 g). While during three consecutive years on overall basis, the minimum fruit juice weight was found where no chemical was sprayed (control) (Figure 3).

A significantly ($P\leq0.5$) maximum average peel of fruit weight (g) was recorded on plants treated with Difenoconazole+Azoxystrobin (35.6 g) and Bordeaux mixture 1% (34.8 g) during 2020-21. However, during 2021-22, the maximum average fruit juice weight (g) was calculated on plants treated with Difenoconazole+Azoxystrobin (35.4 g) and Bordeaux mixture 1% (35.1 g). However, during 2022-23, the maximum average fruit juice weight (g) was calculated on plants treated with Azoxystrobin at par with Difenoconazole+Azoxystrobin (35.5 g) and Bordeaux mixture 1% was at par with Tebuconazole+Trifloxystrobin (35.1 g). While during three consecutive years on overall basis, the minimum average peel of fruit weight (g) was found where no chemical was sprayed (control) (Figure 4).

There was significant difference ($P \leq 0.5$) in mean values of rage weight when foliar spray of selected fungicides was applied. However, during 2020-21, the maximum average rag weight (g) was calculated on plants treated with Difenoconazole+Azoxystrobin (44.4 g) and Bordeaux mixture 1% (43.8 g). The maximum average rag of fruit weight (g) was calculated on plants treated with Difenoconazole+Azoxystrobin (45.5 g) and Bordeaux mixture 1% (44.2 g) during 2021-22. However, during 2022-23, the maximum average rag weight (g) of fruit was calculated on plants treated with Azoxystrobin at par with Difenoconazole+Azoxystrobin (45.3 g) and Bordeaux mixture 1% (43.9). While during three consecutive years on overall basis, the minimum average rag of fruit weight (g) was found where no chemical was sprayed (control) (Figure 5).

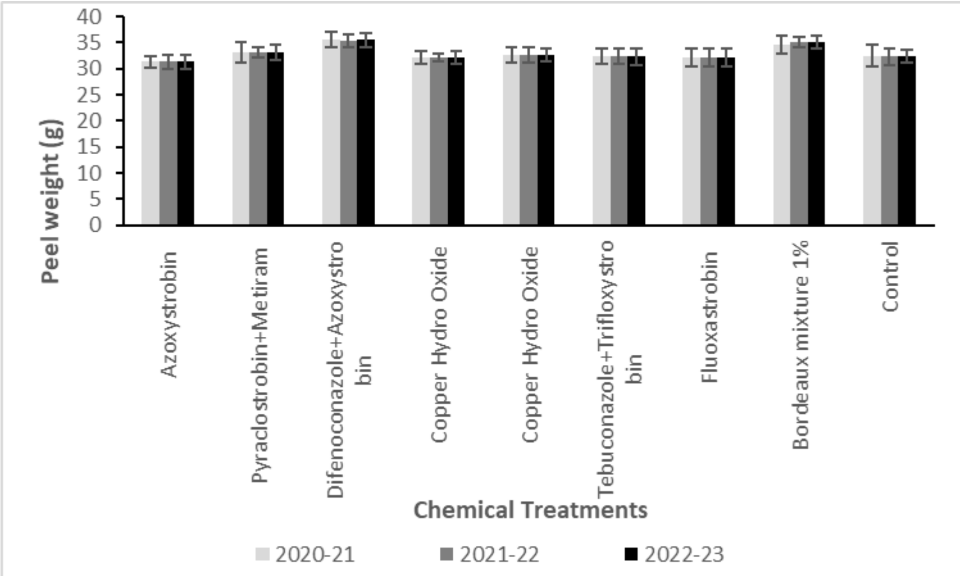

Figure 4: *Impact of various chemicals on peel weight (g) of Kinnow during 2020-21, 2021-22 and 2022-23.*

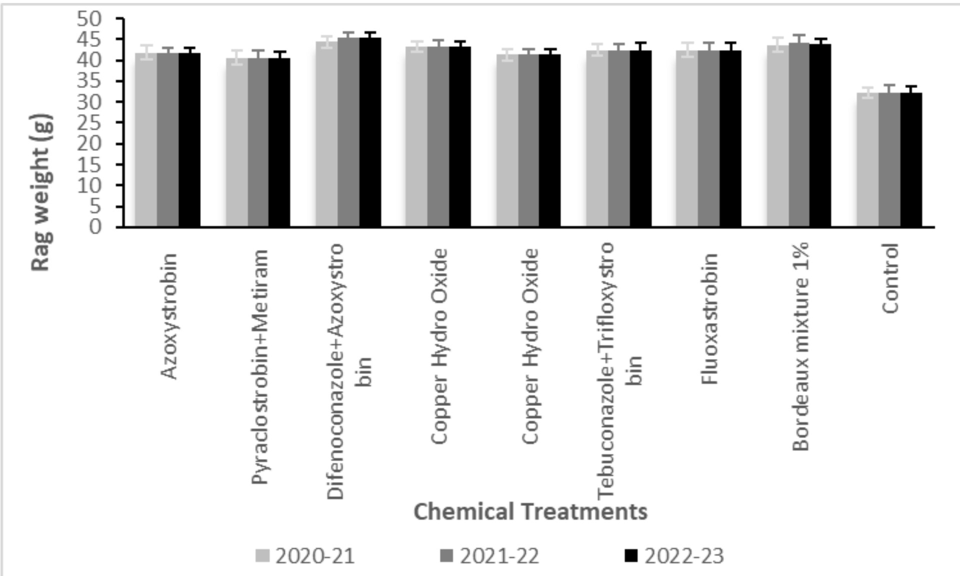

Figure 5: *Impact of various chemicals on rag weight (g) of Kinnow during 2020-21, 2021-22 and 2022-23.*

Discussion

In present study a solution of Difenoconazole+Azoxystrobin was applied as foliar spray which was found most effective in controlling citrus scab. Meena *et al.* (2025) demonstrated that the IPM treatment (T_1) consistently exhibited the lowest mean densities of psyllid and whitefly populations, as well as minimal severity of sooty mold and dieback, in comparison to conventional farmer practices (T_2) and untreated controls (T_3). Disease progression, quantified via the Area Under Disease Progress Curve, and pest population fluctuations, monitored from the 11th to 52nd Standard Meteorological Week (SMW), revealed a treatment-dependent trend, with maximum infestation in T_3, followed by T_2 and T_1. Interestingly, the highest populations of natural enemies (coccinellids, *Chrysoperla* spp., and spiders) were observed in the untreated plants (control), followed by the IPM and then the conventional practice. Economically, T1-IPM treatment yielded the highest average fruit production and the most favorable benefit-to-cost (B:C) ratio compared to T_2 and T_3.

Similar to our results of Difenoconazole+Azoxystrobin a previous experiment on citrus conducted by Mondal *et al.* (2005), the influence of salicylhydroxamic acid, an alternative oxidase inhibitor, on the sensitivity of five fungal species to azoxystrobin and pyraclostrobin was evaluated. Given that *Alternaria alternata* exhibited mycelial insensitivity to azoxystrobin, the effect of azoxystrobin alone and in combination with SHAM was assessed specifically at the spore germination stage for this species. Arutselvan *et al.* (2023) revealed that in citrus disease management Bordeaux mixture has special attention due to its unique properties of developing immunity in citrus plants.

The field trials of Wang *et al.*, 2016, revealed that azoxystrobin alone, as well as in combination with difenoconazole, provided high levels of disease suppression against tobacco brown spot. Three applications of azoxystrobin at 0.094, 0.19, and 0.28 kg a.i./ha, and the Azoxystrobin+Difenoconazole mixture at 0.15, 0.22, and 0.29 kg a.i./ha achieved control efficacies ranging from 86.00% to 89.67% and 86.14% to 89.23%, respectively. In contrast, difenoconazole alone (0.12 kg a.i./ha) resulted in moderate disease control, with efficacy ranging from 55.14% to 58.41%. No phytotoxic effects were observed in treated plants across all fungicide treatments. These results indicate that azoxystrobin, either individually or in combination with difenoconazole, represents a promising chemical control strategy for managing tobacco brown spot under field conditions.

The scab is a fungal disease which infected the fruits in current research however, in one of previous research it has been described that antifungal efficacy of ten fungicides—thiophanate-methyl, difenoconazole, hexaconazole, Metalaxyl + Mancozeb, metiram, mancozeb, azoxystrobin, dodine, chlorothalonil, and fosetyl-aluminum—was evaluated using the poisoned food technique at concentrations of 25, 50, 100, 200, and 400 ppm. The results indicated that the majority of fungicides demonstrated maximum mycelial growth inhibition at the highest concentration tested (400 ppm). Specifically, Metalaxyl + Mancozeb, mancozeb, thiophanate-methyl, metiram, and fosetyl-aluminum exhibited inhibitory effects of 100%, 84.86%, 65.57%, 52.96%, and 49.55%, respectively, at 400 ppm. A premix formulation of azoxystrobin and difenoconazole exhibited substantial antifungal activity, achieving 94.95% inhibition at 300 ppm. Notably, difenoconazole, hexaconazole, dodine, and chlorothalonil completely suppressed *A. citri* mycelial growth across all tested concentrations, indicating their superior efficacy.

In present research the incidence of disease was due to the fact that infected citrus tissues typically develop erumpent, wart-like scab lesions, which are indicative of fungal colonization and associated cellular damage. Elsinochrome belongs to the perylene quinone class of fungal phytotoxins. These compounds act as photosensitizers, capable of absorbing visible light and facilitating the generation of reactive oxygen species (ROS), such as superoxide radicals and singlet oxygen, through interaction with molecular oxygen. These ROS are responsible for oxidative membrane damage, lipid peroxidation, and electrolyte leakage, culminating in localized host cell death and symptom expression (Prieto *et al.*, 2024).

During current research, applications time was carefully selected i.e., applied before flowering in March, after fruit setting in April and in the months of August. Diseased data for citrus scab disease was collected /recorded after fifteen days of the last spray. In one of previous research, the efficacy of disease control declined progressively with increasing intervals between fungicide application and pathogen inoculation, with the correlation between disease suppression and leaf expansion most accurately represented by a quadratic model. In post-inoculation assays targeting citrus scab and melanose, pyraclostrobin demonstrated substantial curative activity, achieving disease control levels exceeding 75% when applied within 48 hours post-inoculation. Conversely, copper hydroxide and famoxadone exhibited negligible post-infection efficacy. These findings indicate that applications of pyraclostrobin during the spring flush of citrus trees are significantly more effective in managing melanose, scab, and Alternaria brown spot compared to treatments with famoxadone or copper hydroxide (Mondal *et al*., 2007).

Khan *et al*. (2008) conducted research and proved that juice content exhibited dynamic variation influenced by multiple factors, generally increasing with fruit maturation and subsequently declining post-physiological maturity. Throughout the observation period, juice content remained inconsistent. 'Feutrell's Early' recorded the highest juice content (52.50%) on December 3rd, which declined to the lowest value on December 30th. Statistical analysis indicated that fruits harvested on December 18th and January 30th had significantly lower juice content, while the remaining treatments did not differ significantly. In *C. reticulata* Blanco cv. Kinnow mandarin, the highest juice content (55.50%) was recorded in fruit harvested on April 23rd, whereas the lowest value (49.70%) was observed on January 7th. Early-season fruits exhibited reduced juice content, which increased progressively during fruit development and ripening. However, a subsequent decline in juice content was noted with delayed harvesting, indicating post-maturity deterioration. This reduction in juice percentage is indicative of quality degradation, consistent with findings reported by Gill *et al*. (1986).

Conclusions and Recommendations

This study highlights the superior efficacy of the difenoconazole and azoxystrobin combination in managing citrus scab (*E. fawcettii*) in *C. reticulata* (Kinnow). The systemic fungicidal mixture provided significantly greater disease suppression and yield enhancement compared to fluoxastrobin and the untreated control. Moreover, the application of a 1% Bordeaux mixture effectively reduced scab incidence. The use of fungicides at their recommended doses, integrated with timely foliar applications, can be regarded as an optimal component of sustainable disease management programs aimed at maintaining fruit quality and enhancing grower profitability.

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Novelty Statement

This study presents findings from a three-year field investigation evaluating both systemic and contact fungicides for controlling citrus scab in Kinnow mandarin under hot and humid subtropical conditions. Unlike earlier studies that were limited to a single season or fewer treatments, this work highlights the consistently better performance of Difenoconazole + Azoxystrobin along with Bordeaux mixture when applied at key growth stages such as before flowering, after fruit set, and before the monsoon. In addition to effective disease control, the study also demonstrates improvements in yield and potential economic returns, offering a practical and reliable spray schedule for managing citrus scab in established orchards.

Authors' Contribution

Malik Abdul Rehman: Designed the experiment and treatment plan
Shafqat Ali: Applied treatments according to research plan
Muhammad Ghayoor Husnain: Assisted in data analysis and preparation of manuscript.
Mujahid Ali: Assisted in the interpretation of results and made graphical/tabular presentation of data
Salman Ahmad: Discussed the results and formatted the references

Generative AI and AI-assisted technology statement
The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest
The authors have declared no conflict of interest.

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