Research Article

Effect of Different Root Stocks on Kaghzi Lime During First Year of Growth and Insecticidal Suppression of Citrus Leafminer

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Abstract | This study highlights the performance of Kaghzi lime when grafted by using T-grafting on ten different root stocks during the first year of growth. About 90-100% bud-take success was observed in all cases. 70-80% grafted plants sprouted after two months of grafting. Maximum stem height and shoot length was found in Mithi, maximum stem girth in Kharna Khata and maximum number of leaves in Jatti Khati while Gadda Dehi was at the tail in all these characters. There was very slow or no growth during the months of November to January and June to July, and slow growth in October and February. Very rapid growth was observed during March to May and August to September. According to overall performance during the first year of growth Mithi and Kharna Khata found to be the most vigorous root stocks for Kaghzi lime closely followed by Jatti Khati and Jullunduri Khati. The growth of new foliage (flush) in citrus plants regulates the dynamics of pests like the citrus leafminer (*Phyllocnistis citrella*), which rely on soft tissues for oviposition and development, with flush production being influenced by weather, scion and root stock variety, and plant age. The application of insecticides during this season has proven highly effective in managing the citrus leafminer. All tested insecticides caused a significant reduction in citrus leafminer but on the basis of toxicity effect, thiamethoxam ranked 1st against citrus leafminer pests suppression 30.52, 44.16, and 69.48% during 5, 9 and 13 days after application, respectively.

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Introduction

Kaghzi lime (*Citrus aurantifolia* Swing.), commonly known as sour lime, is an economically significant member of the *Rutaceae* family, widely cultivated in the Indo-Pakistan subcontinent, particularly in Punjab (Usman *et al*., 2019). Its popularity among citrus growers has grown due to its high market returns, especially in summer when it is one of the few citrus fruits available alongside sweet lime. Renowned for its high Vitamin C content, Kaghzi lime is both nutritious and refreshing, making it a favorite for preparing traditional drinks like *Sakanjbeen*, which are highly preferred over other beverages during the summer (Jaiswal, 2016). Its dual appeal as a profitable cash crop and a culturally significant fruit highlights its importance in the region.

Root stock selection plays a vital role in fruit cultivation, particularly in the citrus industry, as it facilitates the rapid multiplication of true to type fruit trees a critical requirement for the development of the fruit industry (Hayat *et al*., 2022). The common method of propagating fruit plants, including citrus fruits, involves grafting or budding selected scion varieties onto compatible root stocks (Nimbolkar *et al*., 2016). The root stock provides mineral nutrients to the scion, which in turn translocate manufactured food back to the root stock. The growth habit, vigor, and fruit quality of a scion variety can vary significantly depending on the root stock used (Forner-Giner *et al*., 2020). Additionally, root stocks may perform differently under varying soil and climatic conditions for the same scion variety in different locations. While sour lime is traditionally propagated through seedlings due to its high degree of polyembryony, this method requires more time for the plants to bear fruit and does not always guarantee consistent quality (Liu *et al*., 2015). As noted by Hodgson (1967), T-budding and side-grafting are effective propagation methods for lime when suitable root stocks are selected (Bordoloi *et al*., 2022).

It has become crucial to identify a suitable root stock for Kaghzi lime that can produce uniformly growing plants with superior fruit quality in desirable quantities at an earlier age (Ravi, 2021). The current study aims to evaluate the effect of various root stocks on Kaghzi lime during the pre-bearing stage, focusing on compatibility, grafting success, and the scion's development in the first-year post-grafting. Numerous researchers have sought suitable root stocks for various fruit plants, including lime, to aid horticulturists in this field.

Root stocks influence various traits in fruit trees. These studies have emphasized that the selection of root stocks can have a profound impact on several important characteristics of fruit trees, including:

Tree hardiness: Root stocks affect the tree's ability to withstand environmental stresses, such as cold or drought. Certain root stocks provide better resistance to extreme weather conditions, improving the overall hardiness of the tree.

Vigor: Root stocks play a crucial role in controlling the growth rate and size of the tree. Some root stocks induce greater vigor, leading to faster tree growth, while others can slow down the growth, promoting a more compact tree that is easier to manage and harvest.

Precocity and prolificness: The selection of root stocks influences the age at which a tree begins to bear fruit (precocity). root stocks that enhance early fruit production contribute to faster returns on investment for commercial growers. Additionally, prolificness, or the ability of the tree to bear fruit abundantly, is also affected by root stock choice.

Fruit ripening time: Root stocks can affect the timing of fruit maturation. Some root stocks may lead to earlier or later fruit ripening, which can influence the harvest season and, consequently, marketability.

Fruit quality: Root stocks can influence fruit characteristics, such as size, color, taste, and overall quality. The nutrient availability and uptake regulated by the root stock contribute to the development of high-quality fruit.

These findings have been fundamental in modern horticulture, guiding the selection of root stocks to improve fruit production and quality. Root stock selection is a crucial decision for optimizing orchard management and achieving desired outcomes in terms of yield, fruit quality, and tree longevity. Additionally, they noted that the interaction between stock and scion is reciprocal in nature, further emphasizing the importance of root stock selection (Shivran *et al*., 2022). Sour orange was not considered a suitable root stock for limes, suggesting that sweet orange might be more appropriate (Bowman *et al*., 2021). Extensive research has been conducted on selecting desirable root stocks for various citrus fruits. Ollitrault *et al*., (2019), in his study on lemon root stock effects, observed that Eureka lemons grafted onto rough lemon root stock had lower juice content, total soluble solids, citric acid, and ascorbic acid, while fruits from Sampson tangelo exhibited higher juice content, total soluble solids, and acidity.

Similarly, Lemon (2019) confirmed that rough lemon produced vigorous and precocious trees with poor fruit quality, whereas sour orange root stock resulted in stunted trees that bore high-quality fruits. Singh *et al*. (2019) reported that rough lemon and *Cleopatra mandarin* root stocks induced higher juice content, total soluble solids, and relatively low acidity in various citrus fruits.

The reproduction of citrus leafminer is entirely reliant on the availability of young shoots with feather-stage to recently expanded tender leaves. Female psyllids require tender shoots for egg maturation and prefer opening buds and emerging shoots for oviposition. Over the subsequent 2–3 weeks, tender shoot and leaf tissues serve as resources for nymph and adult development as well as egg maturation. While adults can complete their development on tender tissues, they are also capable of feeding and surviving on fully developed leaves for several months.

Insecticides are currently a vital tool in managing citrus leafminer. Systemic neonicotinoid insecticides such as thiamethoxam, imidacloprid, clothianidin, dinotefuran and the newer insecticide cyantraniliprole, are approved for use in citrus. Additionally, studied Valencia orange grafted onto rough lemon, Rangpur lime, sweet orange, trifoliate orange, and Cleopatra mandarin root stocks, finding that Rangpur lime produced the highest yield and trees with the tallest and widest crowns among all root stocks tested.

Materials and Methods

The studies were carried out in the Fruit Plant Nursery at the Ayub Agricultural Research Institute, Faisalabad, during 2023-24. Kaghzi lime was grafted onto eleven-year-old plants of the following 10 root stocks:

All the plants used in this study were grown under uniform soil and climatic conditions and were of the same age at the time of grafting. To minimize heterozygosity, scion wood was sourced from a single Kaghzi lime plant. The experiment followed a Complete Randomized Design (CRD), and Duncan's Multiple Range Test was employed for comparing different characteristics across the root stocks. The scion was grafted onto each root stock using the T-grafting method, ensuring consistency in the propagation technique.

Table 1: *List of ten different root stocks.*

S. No.	Root stocks	Botanical name
1	AJ mberri Khati	*Citrus jambhiri* Lush.
2	Jatti Khati	*C. jambhiri* Lush.
3	Kharna Khata	*C. karna* Ruf.
4	Kaghzi lime	*C. aurantifolia* Swing.
5	Eureka lemon	*C. limon* (L.) Burn.f.
6	Mithi	*C. Jambhiri x C. limettioides*
7	Gadda Dehi	*Cinn, aurantiun* C.
8	Nasnaran	*C. Osbeck. Limonia*
9	Jullunduri Khati	*C. Lush. Jambhiri*
10	Mitha	*C. limettioides* Tan.

The following observations were made on each plant and averages were calculated for statistical analysis:
1. Percentage of bud-taken (T-grafting) success.
2. Effect of different root stocks on the scion

The following studies were made to see the stock scion interactions after 15 days intervals on various root stocks during the first year of growth:
(i) Time of bud-sprouting on various root stocks.
(ii) Stem height on various root stocks.
(iii) Stem girth on various root stocks.
(iv) Shoot length on stocks. various root
(v) Periodic increase in the number of leaves on various root stocks.

Stock scion compatibility

It was observed at the end of the studies. Average differences in the girth of stocks and scions were measured. Knapsack sprayer with hollow cone nozzle was used for spray after calibration. Calibration was done before the spray for measuring the quantity of water to be used for each treatment. Control trees were remained untreated. Five systemic neonicotinoid pesticides (thiamethoxam, imidacloprid, clothianidin, cyantraniprol and dinotefuran) and untreated control were against the population of citrus leafminer (Table 1). The data was recorded before spray and then after 3 days, 5 days and 7 days of spray application, respectively for each tree. For this purpose, six plants were randomly selected from each pesticide's application. Citrus leafminer population was counted with the help of a magnifying glass. The data was compiled and percent mortality was calculated by using Abbott' formula (Abbott, 1925).

$$\% \text{ Mortality} = \frac{\text{Population before spray} - \text{Population after spray}}{\textit{Population before spray}} \, x \, 100$$

Statistical analysis

The replication-wise average values recorded periodically were analyzed using analysis of variance (ANOVA) to assess the significance of each treatment, while the least significant difference (LSD) test at the 5% level was employed to determine the superiority of treatment means, with all statistical analyses performed using the Statistix (version 8.1) software for personal computers.

Results and Discussion

Kaghzi lime was grafted (T-grafted) on 10 root stocks to see its performance during first year of growth. The results are discussed as under:

Bud-take (Graftage) success

The success of bud take (T-grafting) for Kaghzi lime on various root stocks was observed, with 100% success on Jemberri Khati, Jatti Khati, Kaghzi lime, Eureka lemon, Mithi, Nasnaran, and Jullunduri Khati root stocks. The lowest success rate of 87.5% was observed in sweet lime. Kharna Khata and Gadda Dehi had grafting success rates of 95.45% and 88.9%, respectively. These results demonstrated a high percentage of successful grafting of Kaghzi lime on all the root stocks using the T-grafting method of plant propagation (Table 2).

Time of bud sprout

After two months of grafting, 70-80% of the grafts had sprouted on Kaghzi lime, Eureka lemon, Jullunduri Khati, Jatti Khati, Kharna Khata, and Nasnaran root stocks. In contrast, Gadda Dehi and sweet lime had 40% and 60% bud sprout success, respectively, at this stage. All grafted plants completed their bud sprouting by March of the following year (Table 2).

Stem height

The maximum stem height of Kaghzi lime was observed in Mithi (46.14 cm), followed by Kharna Khata and Jatti Khati, while Gadda Dehi had the minimum stem height (27.7 cm). The stem height in other root stocks fell between these extremes (Table 2). The differences were statistically significant. The mean fortnightly increase in stem height showed a slow growth rate in November and December, with no growth at all in January and February. Rapid growth was observed from March to May, followed by slower growth in June and July. A second period of rapid growth occurred from August to September. The relative growth increase in stem height was quite similar across all root stocks.

Khan (1948) found that Jamberri Khati was the top-performing root stock for Valencia Late sweet orange, while Galgal (lemon) and Sweet lime showed the least effect on stem height. Gadda Dehi was closely followed by Jamberri Khati, and other root stocks like Jullunduri Khati, Kharna Khata, and Mithi showed average performance. However, the findings of the present study differ from Khan's results, which could be attributed to differences in soil and climatic conditions between Sahiwal and Faisalabad, where the current study was carried out. Additionally, the different scion varieties used in both studies may have contributed to the contrasting results.

Stem girth

Maximum stem girth of Kaghzi lime was found on Kharna Khata (53 cms.) and minimum on Gadda Dehi (367 cms.) On other root stocks the stem girth was in between 409 and 521cms (Table 1). The results were highly significant statistically. Similarly, Khan (1948) mentioned that relative increase in stem girth was at its peak during the month of August which clearly showed that the growth rate was also influenced by the seasonal changes irrespective of the root stock which agrees with the present studies. However, it was mentioned that the stem girth was maximum on Gadda Dehi and Kharna Khata. In the present studies Kharna Khata showed the maximum stem girth and Gadda Dehi the minimum. The results were similar in case of Kharna Khata but did not agree with the findings in case of Gadda Dehi, which may be due to different scion varieties used in both these studies (Table 2).

Shoot length

Shoot length was measured fortnightly, with Mithi exhibiting the maximum shoot length of 34.56 cm, and Gadda Dehi showing the minimum at 17.96 cm. Other root stocks had intermediate shoot lengths, ranging from 22.46 cm to 33.60 cm (Table 2). The differences in shoot length were highly significant. Khan (1948) observed that, for Valencia orange, Jamberri Khati ranked highest in shoot extension growth, followed by Gadda Dehi, Mithi, Kharna Khata, Jatti Khati, Jullunduri Khati, with sweet lime

Table 2: *Bud-take success and morphological performance of Kaghzi lime grafted on 10 different root stocks during first year of growth.*

Root stocks	Bud-take success (Percentage)	Average stem height increase (cms.)	Average stem girth increase (cms.)	Average shoot length (cms.)	Total number of leaves (Final counts)	Average stem girths of scions and root stocks (cms.)	Mean difference between girth of scion root stocks (cms.)
Jamberri Khati	100	40.82	0.48	30.06	282	S. 1.324 R. 1.625	-0.301
Jatti Khati	100	43.69	0.50	33.60	443	S. 1.641 R. 1.266	+0.375
Kharna Khata	95.45	45.50	0.53	32.94	281	S. 1.797 R. 1.294	+0.503
Kaghzi lime	100	33.50	0 .43	24.73	138	S. 1.251 R. 0.924	+0.327
Eureka lemon	100	40.26	0.44	30.02	278	S. 1.576 R. 1.251	+0.319
Mithi	100	46.14	0.52	34.10	462	S. 1.930 R. 1.441	+0.489
Gadda Dehi	88	23.71	0.37	17.96	142	S. 1.340 R. 0.983	+0.357
Nasnaran	100	38.10	0.47	27.94	251	S. 1.733 R. 1.276	+0.457
Jullunduri Khati	100	41.70	0.46	32.03	196	S. 1.543 R. 1.132	+0.411
Sweet lime	87.5	31.68	0.41	22.64	167	S. 1.357 R. 1.211	+0.146

at the lowest position. Based on the present study, the root stocks can be ranked as follows in terms of shoot length: Mithi, Jatti Khati, Kharna Khata, Jullunduri Khati, Jamberri Khati, Eureka lemon, Nasnaran, Kaghzi lime, sweet lime, and Gadda Dehi. These findings align with Khan's results, except for Gadda Dehi, where the observed pattern did not match.

Number of leaves

The maximum number of leaves was observed in Mithi and Jatti Khati, while the minimum was found in Kaghzi lime and Gadda Dehi (Table 2). The differences, however, were not statistically significant. Khan (1948) had noted that Jamberri Khati exhibited more leaf area than Gadda Dehi, and the results of the present study were consistent with this observation. Fortnightly data on the relative increase in the number of leaves on Kaghzi lime grafted on various root stocks showed seasonal variation due to leaf shedding. There was no increase in leaf number from December to February, with the minimum number of leaves observed during this period. A slight increase in leaf number occurred from March to June, followed by a rapid increase from July to September. This pattern was consistent across most root stocks, except for Mithi, which showed a slightly higher number of leaves during these periods.

Stock scion compatibility

The study also evaluated the stock-scion compatibility of Kaghzi lime grafted on various root stocks. The final differences in the girth between the scions and root stocks at the grafting point are presented in Table 2. The smallest difference was observed in sweet lime (0.146 cm), while the largest was in Kharna Khata (0.503 cm). Jamberri Khati and Eureka lemon ranked second and third, respectively, with the other root stocks falling in between. A smaller difference between the girth of the scion and root stock indicates better compatibility. If the difference in stem size between the scion and root stock is larger, compatibility tends to decrease. The difference between the scion and root stock was positive in all cases, except for Jamberri Khati, where the root stock's girth exceeded that of the scion. Overall, the most vigorous growth of Kaghzi lime was observed on Mithi and Kharna Khata, followed by Jatti Khati, Jamberri Khati, and Jullunduri Khati. The results were least favorable for Gadda Dehi. Eureka lemon, Nasnaran, Kaghzi lime, and sweet lime showed better growth than Gadda Dehi but were still inferior to other root stocks in the study.

While sweet orange was historically recommended, modern citrus production has seen the introduction of more robust root stocks, such as trifoliate orange hybrids, which offer better resistance to diseases like citrus tristeza virus (CTV), Phytophthora root rot, and tolerance to abiotic stresses. For Kaghzi lime, choosing an appropriate root stock today would also depend on local conditions, pest/disease pressures, and soil characteristics (Bowman *et al*., 2021). Many researchers, including Freeman (1930), Webber (1932), Simson (1939), Fennah (1940), and Raj and Raja (1976), concluded that rough lemon was the most suitable and vigorous root stock for Kaghzi lime. Stafini (1934) recommended grapefruit as a better root stock, but Hodgson (1936, 1967) disagreed, finding that grapefruit did not improve the fruit quality of Bear's lime. The importance of rough lemon as a root stock for citrus fruits should not be overlooked, as highlighted by several researchers (Hodgson *et al*., 1937; Halma, 1943; Marleth, 1949; Bitter and Batchelor, 1951; Jawanda and Mehrotra, 1974; Bhullar and Naurival, 1975; Araujo and Batista, 1976), who found rough lemon to be ideal for citrus fruits, including Valencia Late sweet orange.

In the present study, Mithi, considered a sweet variety of rough lemon, was found to be the best root stock, with rough lemons such as Jatti Khati, Jullunduri Khati, and Jamberri Khati closely following. These findings align with previous research, confirming that Mithi (a type of rough lemon) is the most vigorous root stock for Kaghzi lime in the first year of growth. Other rough lemons, such as Jemberri Khati, Jatti Khati, and Jullunduri Khati, also proved effective, reinforcing the idea that rough lemon remains a preferred root stock for citrus fruits, including Kaghzi lime.

Application of neonicotinoid against citrus leafminer

The Table 3 presents data on the efficacy of various insecticidal treatments in reducing pest populations, as measured before and after treatment at 5-, 9-, and 13-days post-application. Each treatment is applied at a specific dose, with data showing the percentage reduction in pest populations over time. Here's a detailed breakdown: Treatments: Lists the insecticides tested (Clothianidin, Dinotefuran, Imidacloprid, Cyantraniliprole, Thiamethoxam, and Control). Dose: Specifies the application dose for each treatment (e.g., Clothianidin at 200 ml, Dinotefuran at 250 ml).

Pre-treatment data: The initial pest population before applying the treatment. Post-treatment data: Includes: Pest population reduction percentages at 5, 9, and 13 days after treatment for each insecticide. Control: A reference treatment without an insecticide. Clothianidin (200 ml): Shows moderate efficacy, with reductions of 27.84% (5 days), 49.43% (9 days), and 39.20% (13 days). Dinotefuran (250 ml): Displays limited reduction initially, with 4.97% (5 days) but improves to 23.60% (9 days) and 36.02% (13 days). Imidacloprid (500 ml): Has consistent efficacy, reducing pest populations by 19.28% (5 days), 36.75% (9 days), and 50.60% (13 days). Cyantraniliprole (200 gm): Similar trend to Dinotefuran, with reductions of 10.33% (5 days), 27.17% (9 days), and 36.41% (13 days). Thiamethoxam (100 gm): Demonstrates the highest efficacy, with reductions of 30.52% (5 days), 44.16% (9 days), and 69.48% (13 days). Control: Maintains the pest population at 75.80, indicating no reduction due to lack of treatment. The Table 3 effectively compares the relative performance of these treatments, highlighting Thiamethoxam as the most effective over time.

Table 3: *Efficacy of different pesticides against citrus leafminer at different intervals after first spray.*

Treatments	Dose	Pre-treatment data	Post-treatment data after		
			5 Days	9 Days	13 Days
			Reduction %age	Reduction %age	Reduction %age
Clothianidin	200ml	73.33	27.84	49.43	39.20
Dinotefuran	250ml	77.35	4.97	23.60	36.02
Imidacloprid	500ml	74.29	19.28	36.75	50.60
Cyantraniprole	200gm	74.20	10.33	27.17	36.41
Thiamethoxam	100gm	71.11	30.52	44.16	69.48
Control		75.80	-	-	-

Young citrus trees require effective pest management strategies to protect against pests like the citrus leafminer while minimizing the risk of pesticide resistance. Foliar application of systemic insecticides, such as neonicotinoids (imidacloprid, thiamethoxam, clothianidin, dinotefuran, Cyantraniliprole), provide extended protection (76–100% reduction of citrus leafminer for 10–29 days), but their shared mode of action necessitates rotation to delay resistance. Cyantraniliprole, a novel alternative, offers comparable efficacy against citrus leafminer and serves as a vital rotation partner for neonicotinoids in soil and foliar applications. Foliar sprays with up to five insecticides from different mode of action groups further enhance rotation options, reducing reliance on soil-applied neonicotinoids and cyantraniliprole. Effective pest management must also consider leafminer prevalence, pest pressure, pre-harvest intervals, budgets, equipment availability, and the conservation of beneficial arthropods. Integrating these considerations into a robust control and monitoring plan ensures sustainable and effective protection for young citrus trees.

Low levels of resistance to certain insecticides, including imidacloprid, chlorpyrifos, thiamethoxam, malathion, and fenpropathrin, have been reported. However, the high levels of pest suppression achieved (90–100%) over 24–68 days with foliar sprays, and for an even longer duration with soil-applied insecticides, suggest that resistance, if present, was likely minimal and did not significantly affect the efficacy of the treatments in the study areas. The systemic neonicotinoid insecticides, thiamethoxam, imidacloprid and clothianidin and a new insecticide cyantraniliprole are allowed in Florida citrus but their use as soil applications is limited by rate restrictions to young trees. Young trees flush often and are best protected with soil drenches or possibly.

Thiamethoxam (20%) demonstrated comparable effectiveness in managing citrus leafminer. However, the availability of new, promising insecticides, along with several already registered products showing high efficacy against leafminer, expands the range of tools for pest control. Additionally, other insecticides effective against sucking pests and citrus leafminer may also offer potential benefits in integrated management strategies (Stansly and Qureshi, 2007). Systemic insecticide injections have been used to manage pests in Florida citrus. Previously, neonicotinoids such as imidacloprid, thiamethoxam, and clothianidin were the primary systemic insecticides approved for drench application, offering prolonged protection against citrus leafminer and, to a lesser extent, citrus leafminer.

However, as all three share the same Mode of Action (MoA), their rotation was limited to sprays with different MoAs to reduce the risk of resistance development. Cyantraniliprole (MoA) has demonstrated comparable effectiveness as a drench application, significantly reducing ACP and citrus leafminer populations. This makes it a valuable rotation partner for managing resistance in ACP and other citrus pests.

Conclusions

The study on Kaghzi lime grafted on different rootstocks revealed that Mithi was the best-performing rootstock, demonstrating superior growth metrics. T-grafting was found to be viable for propagating Kaghzi lime, with seasonal variations in growth and leaf production highlighting the importance of environmental conditions. The evaluation of neonicotinoid insecticides against citrus leafminer showed Thiamethoxam as the most effective treatment, significantly reducing pest populations. However, insecticide use needs careful management to avoid resistance development, emphasizing the importance of rotation among different insecticide modes of action.

Recommendations

The study suggests using Mithi rootstock for Kaghzi lime grafting to maximize growth potential, while considering other rootstocks like Kharna Khata and Jatti Khati. The T-grafting method is recommended for efficient propagation. Environmental factors significantly influence growth rates, so optimizing soil conditions, watering, and nutrient availability is crucial. Thiamethoxam and Imidacloprid are recommended for citrus leafminer control, along with other insecticides. Further research is needed to explore the long-term impacts of rootstocks on fruit quality and yield, as well as insecticide efficacy in pest management. Investigations into Kaghzi lime compatibility with other rootstocks and climate variability's impacts are also recommended. These recommendations can improve Kaghzi lime cultivation productivity and sustainability, contributing to better economic outcomes and environmental stewardship in citrus farming.

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Novelty Statement

The study evaluates Kaghzi lime grafted on various root stocks using the T-grafting method, revealing significant performance metrics like bud-take success and growth rates. Mithi rootstock is identified as the optimal choice for improved Kaghzi lime cultivation. The research also highlights the effectiveness of neonicotinoid insecticides against citrus leafminers, with Thiamethoxam being the most effective treatment. This study integrates grafting performance evaluations with innovative pest management strategies, contributing to sustainable citrus farming practices and enhancing economic and environmental outcomes in Kaghzi lime production.

Author's Contribution

Akbar Hayat and Muhammad Hasnain: Performed the experiment and collected data.
Atif Iqbal and Muhammad Akram: Write first manuscript and Managed overall crop.
Ghulam Mustafa and Naeem Arshad Mann: Helped in paper write up.
Imran Ali, Shamim Akhtar and Abdul Ghaffar: Performed the statistical analysis.
Abdul Noor and Javeed Shabbir Dar: Collected the literature and supervised the study.

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

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