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ASSESSING THE IMPACT OF DIVERSE ROOTSTOCKS ON THE QUALITY ATTRIBUTES OF FEUTRELL'S EARLY CITRUS FRUITS

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ABSTRACT

Feutrell's early, a renowned citrus variety, holds a pivotal role in Pakistan's agricultural economy, contributing significantly to export revenues and playing a vital part in sustaining the country's citrus industry. Despite their historical significance, local rootstocks in Pakistan encounter challenges such as susceptibility to diseases, limited adaptability to changing climates, and hindered overall productivity, necessitating a search for alternative solutions. This study assessed the performance of exotic citrus rootstocks at the Postgraduate Agricultural Research Station (PARS), University of Agriculture, Faisalabad. Six treatments, including four exotic rootstocks (Rough lemon, Cleoptera mandarin, Troyer citrange, Carrizo citrange, Cox mandarin, *Poncirus trifoliata*), were budded with Feutrell's early. Statistical analysis revealed good compatibility in scion/rootstock ratio. Rough lemon exhibited maximum plant height and canopy volume. Cox mandarin, especially in combination with Feutrell's early, demonstrated superior results in various parameters, suggesting its potential to replace traditional rootstocks and address challenges faced by the citrus industry in Pakistan.

Keywords: Exotic root stocks, Rough lemon, Troyer citrange, Cox Mandarin, Fruit size, Scion/stock ratio

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1. INTRODUCTION

Citrus is a globally renowned fruit crop known for its delightful flavor, taste, aroma, and numerous health benefits (Goldenberg et al. 2018). The consumption of citrus fruits and juices has been linked to improved immune function and a decreased risk of chronic diseases (Lv et al. 2015). According to the FAO's world crop production statistics (FAO 2022), approximately 15.73 million tons of citrus fruit were harvested from 1.07 million hectares in 2020. In Pakistan, citrus fruits hold a prominent position, with a total production of 2.30 million tons from 145.18 thousand hectares. While various citrus species are cultivated commercially, the Kinnow and Feutrell's Early mandarin varieties stand out as promising choices, sought after in both domestic and international markets due to their high fruit quality and recognized health benefits (Qureshi et al. 2022).

Citrus cultivation has a rich history spanning centuries, primarily relying on grafted plants, and rootstocks occupy a pivotal position in shaping the growth and progression of citrus plants (Hayat et al. 2022). These rootstocks exert considerable influence over the physiological and biochemical characteristics of scion cultivars. They contribute significantly to factors such as plant vigor, overall quality, fruit yield, and the capacity to withstand diverse environmental pressures (Hayat et al. 2021). The intricate interaction between scions and rootstocks is paramount within the context of fruit production, orchestrating the flow of essential mineral nutrients, hormones, and carbohydrates (Albacete et al. 2015). In the complex landscape of fruit production, both scions and rootstocks are regarded as fundamental constituents, cohesively determining outcomes. The careful selection of an appropriate rootstock stands as a pivotal decision during orchard establishment, ultimately defining the potential for sustained and optimal returns (Hayat et al. 2022).

The selection of rootstock is a critical decision that greatly impacts the growth, quality, and productivity of citrus trees. Different rootstocks are employed worldwide due to their significant influence on scion vigor, fruit size, juice quality, and yield. In Pakistan, rough lemon is widely planted on dry and light soils in Punjab, while sour orange is more commonly used on wet and heavy soils in the Khyber Pakhtunkhwa province. However, both rootstocks can face challenges such as diseases, short lifespan, and excessive growth. The benefits of choosing

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suitable rootstocks for citrus species have been extensively demonstrated in other citrus-producing countries like China, Brazil, USA, Mexico, Spain, and Australia (Kaplankiran et al. 2001). To enhance the citrus industry in Pakistan, there is immense potential to diversify the use of rootstocks, aiming for improved productivity, quality, and extended fruit production periods.

Different citrus rootstocks exhibit variations in their adaptation to soil types, root dispersion patterns, and dependence on mycorrhiza, leading to differences in leaf mineral element concentration in both rootstocks and grafted cultivars, and ultimately affecting vegetative growth, quantity, and quality of the fruit (Bassal 2009). Rootstock selection also influences various leaf traits, including chlorophyll content (García-Sánchez et al. 2002) and the concentration of mineral elements in citrus leaves (Mattos Jr et al. 2003; Toplu et al. 2008). Rootstock utilization is considered essential in citrus production as it helps address challenges related to soil conditions, climate, pests, and diseases. Studies have reported significant differences in the concentration of specific mineral elements, such as Mg, Cu, and B, in the scion leaf of citrus cultivars grafted onto different rootstocks (Georgiou, 2002). Furthermore, citrus rootstocks have been found to exhibit significant variations in iron absorption (Pestana et al. 2005).

This study investigates how various rootstocks impact the fruit quality and yield of Feutrell's Early mandarin in the agroecological conditions of Punjab, Pakistan. These rootstocks, introduced with Australian Aid through the Australia Pakistan Agriculture Sector Linkages Program, administered by the Australian Centre for International Agricultural Research, are crucial for addressing challenges related to soil conditions, climate, pests, and diseases. The research, guided by a conceptual framework, emphasizes the interplay between grafted plants, rootstocks, and scions, influencing the flow of nutrients and hormones. The study's significance lies in contributing to knowledge, especially in regions like Pakistan, where diversifying rootstock usage can enhance productivity, quality, and extend fruit production periods (Hayat et al. 2022). Despite limitations such as potential disease challenges and excessive growth (Qureshi et al. 2022), this research holds promise for optimizing citrus cultivation in Pakistan and addressing global rootstock selection challenges, leading to improved fruit quality, yield, and sustainable production practices.

The paper is organized into sections focusing on a literature review of global citrus cultivation, challenges in current rootstock practices in Pakistan, and a conceptual framework guiding the study. It further outlines the research design and methodology, presents results and discussions on Feutrell's Early mandarin under varied rootstocks, and concludes with implications and recommendations for optimizing citrus cultivation in Pakistan and future research avenues. The organized structure ensures a comprehensive exploration of the study's objectives, methods, and findings.

2. MATERIALS AND METHODS

2.1. Plant Material and Experimental Site

The present research was conducted at the Postgraduate Agricultural Research Station (PARS), University of Agriculture, Faisalabad. It involved a block of Feutrell's early mandarin scion cultivar grafted onto five different rootstocks: Troyer citrange, Carrizo citrange, Poncirus trifoliate, Cox-mandarin, and Cleopatra mandarin. Rough lemon rootstock, the commercial choice in Punjab province, was used as the control treatment and compared with the five new rootstocks. Eighteen trees, with three trees for each graft combination, were planted in a square orchard layout with 18x18 feet spacing. Standard agronomic practices were followed, including irrigation, fertilizer application, organic matter management, pest control, and other recommended practices. Data was collected for various parameters, and laboratory analysis was performed to evaluate the physical and biochemical fruit quality of Feutrell's early from different rootstocks. The objective of the experiment was to compare the influence of different rootstocks on the fruit quality of Feutrell's early mandarin.

2.2. Physical Parameters

The fruits were weighed using a digital weighing balance (g). The average peel thickness (mm) was measured using a Vernier caliper. Fruit size (mm) was determined by using following formula:

$$\text{Fruit size (mm)} = \text{Fruit diameter (mm)} \times \text{Fruit height (mm)}$$

The juice from each sample was extracted, strained to remove seeds and pulp, and then measured in a graduated cylinder (mL).

2.3. Sensory Parameters

A group of five experts assessed sensory attributes including taste, flavor, and aroma. Feutrell’s early fruit was sliced into small pieces and placed randomly in front of the panel. The outcomes were expressed using a scoring

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system ranging from 1 to 9, where 1 indicated poor and unusable, 3 denoted reasonable quality with limitations, 5 represented decent quality suitable for sale, 7 signified very good quality, and 9 indicated superb quality, following the guidelines established by Peryam and Piligram (1957).

2.4. Biochemical Parameters

The measurement of total soluble solids (TSS) in fresh feutrell's early fruit juice was conducted at room temperature using a digital refractometer (ATAGO, RX 5000, Japan), and the results were reported in °Brix. The titratable acidity (TA) of the juice was estimated by titrating a mixture of 10mL juice and 20mL distilled water with a 0.1 N NaOH solution, employing phenolphthalein as an indicator, as described by Razzaq et al. 2015. pH of the fruit juice was measured by using Digital pH Meter.

To determine the sugar content, a 10mL sample of fresh juice was placed in a 250mL volumetric flask. Distilled water (100mL), 25% lead acetate solution (25mL), and 20% potassium oxalate solution (10mL) were added. The final volume was achieved by adding distilled water. The mixture was thoroughly mixed and filtered using Whatman No. 2 filter paper. The total sugar content was then determined using the titration-based Fehling's solution method, following the procedure outlined in previous research (Khalid et al. 2012). The results of the total sugar analysis were expressed as a percentage.

The ascorbic acid content in freshly squeezed Feutrell's early fruit juice was analyzed by filtering it through a 100mL flask using a 0.4% oxalic acid solution. The resulting filtrate was then titrated against the blue dye of 5,6-dichlorophenolindophenol, following the method outlined by Razzaq et al. (2014). The ascorbic acid content was quantified and expressed as mg 100mL^{-1} FW.

2.5. Statistical Analysis

The experiment was conducted using a Randomized Complete Block Design (RCBD) layout, consisting of six treatments and three replications. All the collected data was analyzed using Statistix 8.1 software for performing analysis of variance (ANOVA) and pairwise mean comparisons.

3. RESULTS

3.1. Physical Parameters

***3.1.1. Fruit size (mm)*:** The obtained results highlight a noteworthy level of statistical significance, particularly in terms of the substantial variability observed in fruit size among the Feutrell's early cultivars grafted onto various citrus rootstocks. It's essential to note that the control group, T0 (Rough lemon X Feutrell's early), had the biggest fruit, measuring 3094.22cm. T1 (Cleopatra mandarin X Feutrell's early) was close at 2975.67cm, followed by T3 (Carrizo citrange X Feutrell's early) at 2927.97cm. In contrast, the smallest fruit was in T5 (*Poncirus trifoliata* X Feutrell's early) at 1572.83cm, as seen in Fig. 1A. This indicates the profound influence of rootstock selection on fruit size. These findings underscore the paramount importance of rootstock choices in determining fruit size outcomes.

***3.1.2. Fruit weight (g)*:** The study emphasized the significant impact of graft combinations on fruit weight, revealing noteworthy variations among Feutrell's early cultivars grafted onto diverse citrus rootstocks. In these graft combinations, the fruit weight exhibited considerable variation. The maximum fruit weight of 99g was observed in T0 (Rough lemon X Feutrell's early) plants, followed closely by T4 (Cox mandrain X Feutrell's early) with 96.67g and T1 (Cleopatra mandarin X Feutrell's early) with 91.67g. In contrast, the lowest fruit weight of 10.33g was recorded in T5 (*Poncirus trifoliata* X Feutrell's early). The average fruit weight of the other plants was 87g for T4 (Cox mandarin X Feutrell's early) and 84.67g for T2 (Troyer citrange X Feutrell's early). These findings underscore the pivotal role of rootstock selection in shaping fruit weight and overall fruit quality.

3.1.3. Peel thickness (mm): The study found some interesting differences in the thickness of Feutrell's early fruit peels, although these differences weren't quite large enough to be considered highly significant. Treatments T2 (Troyer citrange X Feutrell's early), T3 (Carrizo citrange X Feutrell's early), T1 (Cleopatra mandarin X Feutrell's early), and T4 (Cox mandarin X Feutrell's early) exhibited higher peel thickness, measuring 4.33, 3.77, 3.67 and 3.67mm, respectively. In contrast, Feutrell's early fruit in T0 (Rough lemon X Feutrell's early) showed the minimum peel thickness among the selected Feutrell's early fruits, as depicted in Fig. 2A. However, increased peel content can be disadvantageous as it reduces the ratio of edible pulp to peel, resulting in a smaller portion of the fruit that can be consumed.

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3.1.4. Percentage of the Juice (mL): The performance of Feutrell's early grafted onto Cox mandarin (54.67mL), Rough lemon (50mL), and Cleopatra mandarin (48.33mL) displayed statistically similar juice volumes, with all of these scion-rootstock combinations yielding the highest juice volumes. Similarly, fruits from Carrizo citrange and Troyer citrange exhibited juice volumes of 46.33 and 42.33mL, respectively. In contrast, *Poncirus trifoliata* yielded the lowest juice volume at 18mL. Fruits with higher juice content are not only preferred in the juice market but also in the fresh fruit market. It's worth noting that all the rootstocks in our trial had a juice percentage exceeding the minimum requirement for most citrus varieties intended for fresh fruit consumption, which is typically set at 35%.

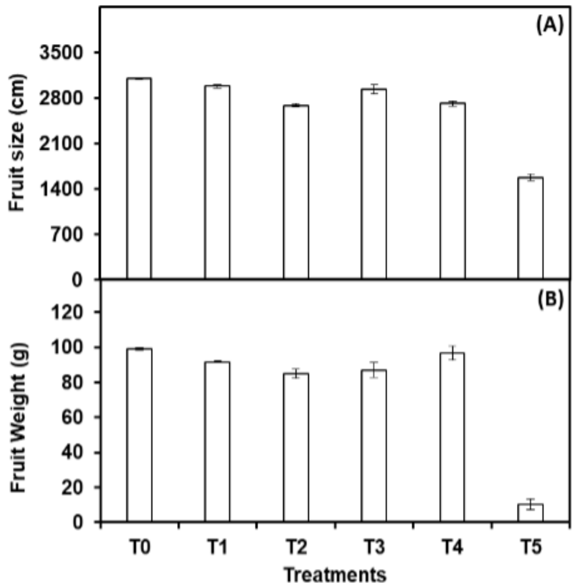

Fig. 1: Fruit size (A) and Fruit weight (B) of Feutrell's early graft on various citrus rootstocks. Vertical bars indicate mean±SE (n≥3 plants per grafted plants, 3 replicates).

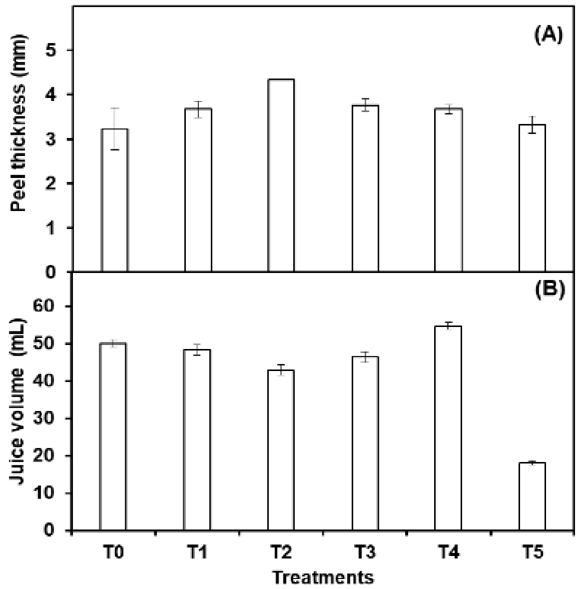

Fig. 2: Peel thickness (A) and Juice volume (B) of Feutrell's early graft on various citrus rootstocks. Vertical bars indicate mean±SE (n≥3 plants per grafted plants, 3 replicates).

3.2. Sensory Parameters

Sensory attributes, including taste, aroma, and flavor, exhibited a significant impact on maintaining the sensory qualities of Feutrell's early when grafted onto various rootstocks. Notably, the sensory evaluation unveiled the substantial influence of the Cox mandarin rootstock on the taste, aroma, and flavor of Feutrell's early fruits. The results revealed that most treatments performed admirably, with the exception of T0 (Rough lemon X Feutrell's early) and T5 (*Poncirus trifoliata* X Feutrell's early), as illustrated in Table 1. Among the treatments, T4 (Cox mandarin X Feutrell's early) emerged as the top performer, consistently delivering exceptional sensory qualities that enhanced the overall fruit experience. This finding underscores the pivotal role of rootstock selection, particularly the Cox mandarin, in influencing the sensory attributes of Feutrell's early fruits, ultimately contributing to improved consumer satisfaction.

3.3. Biochemical Parameters

3.3.1. Total soluble solids (°Brix): Total soluble solids (TSS) is a crucial parameter in citrus fruit because they directly contribute to its taste, sweetness, and overall quality. The study yielded highly significant results, with the greatest variability observed in the total soluble solids of Feutrell's early fruits grafted on different citrus rootstocks. Fruits harvested from Feutrell's early, grafted onto Cox mandarin rootstock, and displayed the highest total soluble solids (TSS) content, measuring 11.37°Brix. Following closely, those grafted onto Troyer citrange rootstock exhibited a TSS content of 11.12°Brix. In stark contrast, the lowest TSS contents were recorded in Feutrell's early fruits grafted onto Rough lemon rootstock, with a TSS measurement of 8.87°Brix (Fig. 3A).

3.3.2. Titratable Acidity (%): Titratable acidity revealed significant differences among Feutrell's early plants when grafted onto various citrus rootstocks. Feutrell's early fruits grafted onto *Poncirus trifoliata* rootstock (44.9%) were discovered to be more acidic, while those on other rootstocks were found to be less acidic, as depicted in Fig. 3B. T3, with Carrizo citrange rootstock, followed closely with an acidity of 26.87%, while T4, using Cox mandarin

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rootstock, had a good acidity of 24.36%. Conversely, the control group, T0, which had Rough lemon rootstock for Feutrell's early, showed the lowest acidity at 10.9%. The other combinations, T2 (Troyer citrange X Feutrell's early) with 22.77% acidity and T1 (Cleopatra mandarin X Feutrell's early) with 19.43% acidity, fell in between. These results highlight how different citrus rootstocks can significantly affect the acidity of Feutrell's early fruit.

3.3.3. Juice pH: The results were highly significant when examining juice pH levels in Feutrell's early fruits grafted onto various citrus rootstocks. Among the treatments, the control treatment, T0 (Rough lemon X Feutrell's early), showed the highest juice pH value, measuring 5.75. Following closely, T4 (Cox mandarin X Feutrell's early) displayed a juice pH of 5.53, while T2 (Troyer citrange X Feutrell's early) had a pH of 5.29. In contrast, T1 (Cleopatra mandarin X Feutrell's early) exhibited the lowest juice pH value among all treatments, measuring 5.07. These findings underline the notable influence of rootstock selection on the acidity of Feutrell's early fruits, with implications for fruit quality and taste.

Table 1: Sensory evaluation of Feutrell's early graft on various citrus rootstocks

Treatments	Organoleptic Parameters					
	Fruit color	Pulp color	Taste	Aroma	Flavor	Overall acceptability
T0	5.333^{B}	7.000^{B}	6.667^{B}	7.000^{B}	7.333^{B}	7.333^{B}
T1	8.333^{A}	9.000^{A}	9.000^{A}	8.667^{A}	8.667^{A}	8.667^{A}
T2	8.667^{A}	8.000^{A}	9.000^{A}	8.333^{A}	9.000^{A}	9.000^{A}
T3	9.000^{A}	8.667^{A}	8.333^{A}	8.333^{A}	8.667^{A}	9.000^{A}
T4	9.000^{A}	9.000^{A}	8.333^{A}	9.000^{A}	9.000^{A}	9.000^{A}
T5	6.333^{B}	7.333^{B}	7.333^{B}	7.333^{B}	7.333^{B}	6.667^{B}

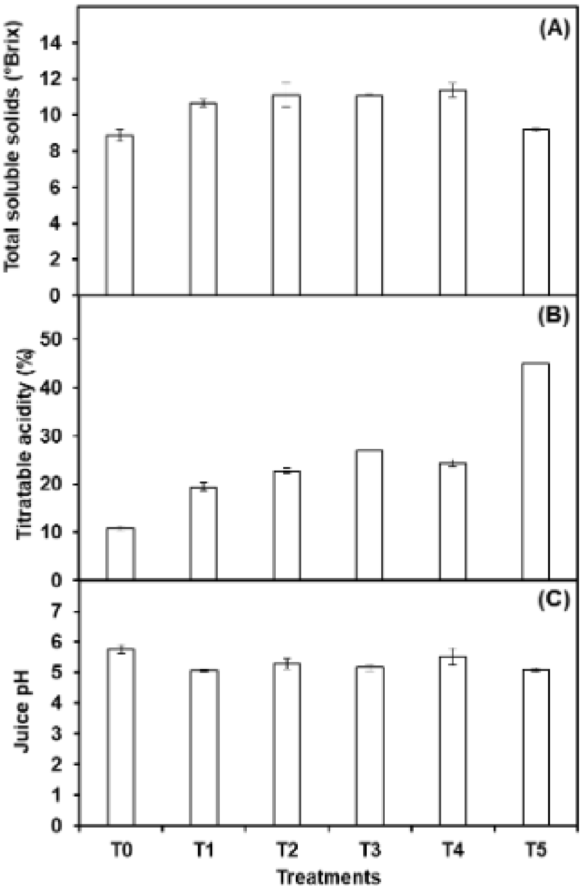

Fig. 3: TSS (A), TA (B) and Juice pH (C) of Feutrell's early graft on various citrus rootstocks. Vertical bars indicate mean±SE (n≥3 plants per grafted plants, 3 replicates).

3.3.4. Total Sugars (%): Sweetness is a crucial quality parameter for fruits, often regarded as the combined content of sucrose, glucose, and fructose, which signify ripeness. In our study, the results displayed highly significant variations in the total sugar content of Feutrell's early fruits grafted onto different citrus rootstocks. The highest levels of total sugars were observed in Feutrell's early grafted onto Cox mandarin at 49.23%, closely followed by Troyer citrange at 48.87, and *Poncirus trifoliata* at 39.13%. In contrast, the lowest total sugar content

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was recorded in the control treatment, T0 (Rough lemon X Feutrell's early), with a value of 37.43%, as illustrated in Fig. 4A. These findings highlight the substantial impact of citrus rootstock selection on the overall sweetness of Feutrell's early fruits, a key factor in their ripeness and consumer appeal.

3.3.5. Vitamin C Content (mg100g^{-1}FW): The ascorbic acid content demonstrated significant differences among Feutrell's early fruit plants grafted onto different citrus rootstocks. Notably, the performance of T4 (Cox mandarin X Feutrell's early) at 4.23mg100g^{-1}FW, the control treatment T0 (Rough lemon X Feutrell's early) at 3.7mg100g^{-1}FW, and T1 (Cleopatra mandarin X Feutrell's early) at 3.7mg100g^{-1}FW were statistically indistinguishable, with all of these scion and rootstock combinations displaying the highest levels of ascorbic acid. Conversely, T5 (*Poncirus trifoliata* X Feutrell's early) and T2 (Troyer citrange X Feutrell's early) exhibited lower levels of ascorbic acid at 3.23mg100g^{-1}FW and 3.17mg100g^{-1}FW, respectively. Among the treatments, T3 (Carrizo citrange X Feutrell's early) displayed the lowest ascorbic acid content at 2.83mg100g^{-1}FW. These findings underscore the significant influence of citrus rootstock selection on the ascorbic acid content of Feutrell's early fruits, which plays a vital role in their nutritional value and quality.

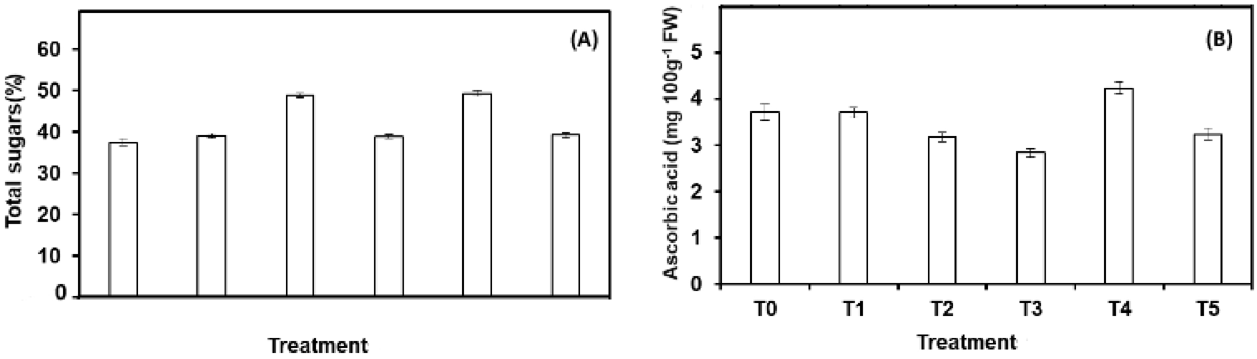

Fig. 4: Total sugars (A) and Ascorbic acid (B) of Feutrell's early graft on various citrus rootstocks. Vertical bars indicate mean±SE (n≥3 plants per grafted plants, 3 replicates).

4. DISCUSSION

Rootstocks play a pivotal role in determining the growth, development, and overall performance of citrus trees. In recent years, the citrus industry has witnessed a surge in the pursuit of novel rootstocks that can thrive across diverse geographical regions and adapt to varying environmental dynamics. This research endeavor stems from a collective commitment to optimize citrus production, both quantitatively and qualitatively. This study focuses on the influence of different rootstocks on Feutrell's early cultivars, shedding light on the significance of this rootstock selection.

One of the most tangible and economically relevant aspects of citrus fruit quality is its size and weight. Our study reveals substantial variations in these parameters among Feutrell's early cultivars grafted onto different rootstocks. Notably, the control treatment (T0 = Rough lemon X Feutrell's early) exhibited the largest fruit size (3094.22cm), while the minimum fruit size was observed in T5 (*Poncirus trifoliata* X Feutrell's early). These findings emphasize the critical role played by rootstocks in influencing fruit development. The observed variations are not merely cosmetic; they carry profound implications for the citrus industry. The differences between the control treatment and T5 highlight the varied impact of rootstocks on growth parameters. We posit that these distinctions arise from rootstocks' influence on nutrient availability, physiological processes, and hormonal regulation within the grafted plants. Our results align with a precedent study by Hayat et al. (2019), which underscores the significance of appropriate rootstock selection to counteract size reduction challenges during the initial growth stages of citrus trees. This interplay between rootstock and fruit size can have far-reaching consequences, affecting marketability, consumer preferences, and overall economic viability.

While fruit size and weight are readily visible parameters, the thickness of the fruit peel might not be as conspicuous but is equally significant. Variations in peel thickness among treatments, although not reaching statistical significance, indicate a potential influence of rootstocks on fruit skin development. Rootstock-induced alterations in peel thickness could be indicative of changes in the underlying physiology and biochemistry of the fruit skin. The results align with the findings of Yildiz et al. (2013), who reported that Rhode Red Valencia orange trees grafted onto Carrizo and Troyer rootstocks displayed the largest fruit diameter, while Valencia Late on Carrizo rootstock exhibited the smallest fruit diameter.

The variation in juice percentage among treatments further underscores the role of rootstocks in determining juice content. A higher juice percentage is often desirable in citrus fruits, as it directly impacts juice extraction efficiency and overall fruit utility. Our findings align with previous research conducted by Ahmed et al. (2007), highlighting the substantial influence of rootstocks on juice content. Rootstock-mediated changes in nutrient uptake, water relations, and fruit development processes are likely responsible for these variations.

Sensory attributes are paramount in determining consumer acceptance and market value. Sensory evaluation revealed the diverse performance of treatments, with T4 emerging as the top performer. These results are consistent with previous findings by Aguilar-Hernández et al. (2020) and Mourão Filho et al. (2007), affirming the pivotal role of rootstock selection in enhancing sensory attributes. The sensory appeal of citrus fruits is multifaceted, encompassing aspects like flavor, aroma, texture, and overall taste experience. Rootstock-induced variations in these attributes can substantially influence consumer preferences and market demand.

The chemical composition of citrus fruits is a complex interplay of various compounds, each contributing to the overall quality and nutritional value. Highly significant variations were observed in total soluble solids, with the highest levels in T4 and T2. In contrast, the control treatment exhibited the lowest total soluble solids, echoing the findings of Al-Jaleel et al. (2005). Total soluble solids encompass sugars, organic acids, and other soluble compounds, collectively influencing flavor, sweetness, and sensory perception.

Titratable acidity, another crucial component of citrus chemistry, exhibited variations consistent with rootstock selection, in line with Hifny et al. (2013). Rootstock influence on juice pH and sugar content was evident. While T0 and T4 exhibited higher pH values, T1 had the lowest pH. Sugar content also aligned with rootstock variation, corroborating earlier studies by Georgiou (2002) and Jaskani et al. (2006). The intricate interplay of rootstocks with the citrus tree's physiology and biochemistry contributes to these chemical variations.

Citrus fruits are celebrated for their high vitamin C content, primarily in the form of ascorbic acid. In this study, ascorbic acid content showed similarities among treatments, with T4, T0, and T1 displaying the highest levels. This parallels previous research emphasizing the role of rootstocks in determining ascorbic acid concentration. Our findings are consistent with previous studies that reported ascorbic acid (Vitamin C) levels in *Citrus paradisi* (Gorinstein et al. 2004; Kelebek 2010) and *Citrus sinensis* (L.) Osbeck (Kelebek and Selli 2011), supporting the significance of ascorbic acid concentration as an indicator of mandarin juice quality.

Moreover, this research underscores the critical importance of rootstock selection in citrus cultivation. The observed variations in fruit size, weight, peel thickness, juice content, sensory attributes, and chemical composition are not arbitrary; they are intrinsically linked to the choice of rootstock. Rootstocks exert their influence through a complex web of physiological, biochemical, and molecular processes within the grafted plants.

Our findings emphasize the need for a nuanced approach to rootstock selection, considering the specific goals of citrus cultivation. Different rootstocks can impart diverse characteristics to the same cultivar, allowing growers to tailor their citrus production to meet market demands and consumer preferences. As we delve deeper into understanding the intricacies of rootstock-citrus interactions, further research in this direction promises to enhance citrus cultivation practices, leading to improved fruit quality, increased yields, and sustained growth in the citrus industry.

The future of citrus cultivation lies beneath the soil, in the roots that anchor these iconic trees. Rootstocks hold the key to unlocking the full potential of citrus orchards, ensuring that each fruit that graces our tables is a testament to the meticulous science happening beneath the surface.

5. CONCLUSION

The present study offers compelling evidence supporting Feutrell's early grafted with Cox mandarin rootstock as a highly promising replacement for the problematic Rough lemon rootstock, displaying substantial improvements in sensory and biochemical characteristics while maintaining the integrity of other critical qualitative and quantitative traits. This grafting combination shows tremendous potential in enhancing fruit quality and overall productivity. Nevertheless, the study underscores the necessity for further investigations to determine the long-term viability and fruit-bearing capacity of plants grafted with Feutrell's early and Cox mandarin, ensuring their sustainable adoption in horticultural practices and commercial orchards. Future research endeavors should focus on elucidating the extended lifespan and resilience of this grafting combination in diverse environmental conditions to optimize its widespread application in modern fruit cultivation.

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