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ORIGINAL ARTICLE

Enhancing Pecan Fruit Size and Nutrient Content through Foliar Application of Boron and Zinc

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K E Y W O R D S

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A B S T R A C T

Pecan fruit, also known as pecan nut, is a type of nut that is popular for its rich, buttery flavor and crunchy texture. This research aimed to investigate the effects of spraying boric acid and zinc sulfate on the physical traits of pecan fruit in Erbil, Iraq. The experiment was conducted in the spring of 2022 using a completely randomized block design with three levels of boric acid (0, 1500, and 3000 mg l^{-1}) and three levels of zinc sulfate (0, 2500, and 5000 mg l^{-1}). The spraying was carried out before the flower buds opened, and at the time of harvesting, various physical characteristics of the fruit were measured, including length, width, weight, kernel weight, percentage of hull, percentage of shell, percentage of kernel, and absorption of elements in leaves and nuts. The results showed that spraying with boric acid (3000 mg l^{-1}) and zinc sulfate (5000 mg l^{-1}) had the greatest effect on increasing fruit length, while the fruit width was highest in the zinc treatment (5000 mg l^{-1}), and it was significant compared to the control treatment. None of the treatments had a significant effect on fruit weight, kernel weight, percentage of shell, and percentage of hull skin. Moreover, the spraying significantly increased the amount of boron and zinc elements in leaves and nuts. Therefore, it can be concluded that spraying with boric acid and zinc sulfate can be an effective method to improve the physical characteristics of pecan nuts and increase the absorption of essential elements in leaves and nuts.

Introduction

The pecan nut, scientifically known as *Carya illinoinensis*, is a species of hickory tree native to North America. The tree grows up to 40 meters tall and can live up to 300 years (Bentley *et al*., 2019; Y. Huang *et al*., 2019). According to the FAO statistics of the World Food Organization, the United States is the world's largest producer of pecan nuts, accounting for around 80% of the global supply. Other major producers of

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pecan nuts include Mexico, Australia, and South Africa (Ávila Arce *et al*., 2020). The pecan nut is a popular food item, known for its rich, buttery flavor and versatility in both sweet and savory dishes. In terms of nutrition, pecans are a good source of healthy fats, protein, and fiber. They are also rich in vitamins and minerals, including vitamin E, thiamin, magnesium, and zinc (R. Huang *et al*., 2019). Some studies have also suggested that pecans may have health benefits, such as reducing inflammation and improving heart health (Atanasov *et al*., 2018; Bitok and Sabaté, 2018; McKay *et al*., 2018). Despite their popularity, pecan trees and their nuts face a number of challenges, including pests, diseases, and climate change. Farmers and researchers continue to work to develop new varieties of pecan trees that are more resilient to these challenges and can produce higher yields of high-quality nuts. The low yield and poor quality of pecan nuts in Iraq are caused by a number of factors, including the absence of low-nutrient components (Chehri and Sattar Abod, 2017).

Boron is an essential plant micronutrient which is involved in the creation of cell wall pectin, the production of malic acid, cellular division, the transportation of carbohydrates and enzymes (Keshavarz *et al*., 2011; Zhu *et al*., 2019; Mohit Rabary *et al*., 2022; Shiberu *et al*., 2023). Boron plays a significant part in both the germination and development of the pollen tube (Maliha *et al*., 2022; Shiberu *et al*., 2023). As one of the vital micronutrients, boron is essential for plant growth, meiotic division, and seed production (Sharafi and Raina, 2021). In kiwifruit, it is particularly important for producing fruits with sufficiently-sized seeds (Lago *et al*., 2015; Ajamgard *et al*., 2017). Additionally, boron facilitates the transfer of sugars in plants due to its sugar composition, which allows for faster passage through the cell's permeable membrane compared to simple sugars (Hegazi *et al*., 2018; Maliha *et al*., 2022). Insufficient boron levels can result in flowers falling off or underdeveloped fruits due to a lack of fertilization (Peng *et al*., 2015; Luo *et al*., 2020). Deficient boron levels can also result in gum formation in immature pecan fruits. A study by Yilmaz *et al*. (2021) revealed that applying a solution of boron and zinc during the flowering stage of pecan nuts did not have any impact on the weight, length, or width of the fruit. According to Wang *et al*. (2021) findings, applying boron with boric acid solution to Mahan pecans resulted in an 8% reduction in green skin percentage compared to the control group. This reduction led to an increase in the percentage of the kernel. However, the application of boron did not have an impact on the percentage of hard skin of the fruit (Griffin and Dean, 2017). In grapes, the application of boron solution through spraying has been found to improve both the yield and quality of the fruit. According to the report of Swathi *et al*. (2019), spraying boron on grape flowers and leaves has resulted in bigger pods and heavier bunches. Liu *et al*. (2014) stated that the size and sugar content of oranges were enhanced by the application of boron solution, while Liu *et al*. (2022) found that the use of boron solution increased fruit yield, weight, and diameter, as well as the amount of soluble solids and total sugar in oranges. In apples, insufficient boron causes the production of small and misshapen fruits, along with bitter spots (Oikonomou *et al*., 2019). Shiberu *et al*. (2023) reported that application of boron fertilizer in Black Cumin is the most influential in the flower and seed formation in the capsule.

One of the essential micronutrients required for the development and production of appropriately sized fruit is zinc (Rahman *et al*., 2020). This element is a component of the carbonic anhydrase enzyme present in all photosynthetic tissues, which is necessary for the biosynthesis of chlorophyll. Zinc also aids in the production of tryptophan, a precursor to auxin synthesis (Adhikari *et al*., 2016; Maliha *et al*., 2022). When peach trees lack zinc, it results in the production of small, deformed, and low-quality fruits (Yadav *et al*., 2013).

On the other hand, the use of zinc in mango trees has led to an increase in the weight of the fruit and its kernels (Elsheery *et al*., 2020). In zinc-deficient orange trees, spraying them with zinc during April and May has resulted in larger fruit size, higher soluble solids, and increased fruit juice (Amro, 2015; Chatrabnous *et al*., 2018; Norozi *et al*., 2019). However, it has been shown that applying zinc solution through spraying has no significant impact on the amount of the product, fruit weight, and acidity and soluble sugars in the fruit of apple trees (Zhang *et al*., 2016).

This study aimed to investigate the effects of foliar-applied boron and zinc on various physical and nutritional characteristics of pecan fruits.

Material and Methods

The study involved choosing trees from the Mahan cultivars that were 6 and 12 years old and planted 6×4 meters apart. The experiment was conducted using a completely randomized block design with 9 treatments and 3 repetitions, totaling 27 trees. The details of the treatments are presented in Fig. 1.

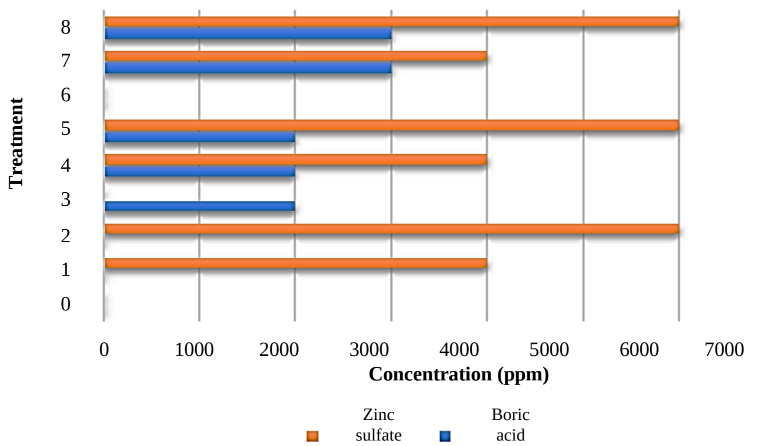

Fig. 1. Concentration of boron and zinc in each treatment.

In April 2022, before the flower buds opened, a solution of 8 liters was sprayed on each tree. To ensure proper absorption, the spraying was conducted during the cool afternoon hours. After harvest, fruits were picked from each tree and their desired characteristics were measured separately, including weight of fruit, kernel, percentage of hull, shell, kernel, length and width. To determine the nutritional value of fruits during June, a sample of 10 fruits was collected from each tree and analyzed for their zinc content. Additionally, leaf samples were gathered from the middle of non-bearing branches in July to assess levels of boron and zinc (Hounnou *et al*., 2019).

Results

The analysis of variance outcomes indicate that the fruit and kernel weight were not impacted by any of the treatments. Nevertheless, the treatment of zinc and the combination of boron and zinc had a notable influence on the fruit's length, while zinc treatment had a considerable effect on the fruit's width. None of the treatments had any effect on the percentage of hull, shell, or kernel (Table 1).

Table 1. A variance analysis on the effects of boron and zinc foliar application on fruit traits and nutrient concentrations in leaves and fruits of pecan.

Source of variations	df	Fruit weight	Kernel weight	Fruit length	Fruit width	Hull, %	Shell, %	Kernel, %	Fruit zinc	Fruit boron	Leaf zinc	Leaf boron
Boron	2	0.045	0.002	0.040	0.000	1.243	0.618	0.189	2.901	78.664*	0.746	10.631*
Zinc	2	0.050	0.001	0.124**	0.039**	0.053	0.032	0.589	8.881*	1.772	20.694*	11.081
Boron × Zinc	4	0.026	0.006	0.054*	0.001	2.779	0.655	1.701	3.622	12.837	6.588	1.135
Error	6	0.107	0.012	0.017	0.006	2.315	1.672	0.565	1.786	19.773	3.934	4.174
CV, %		8.455	9.225	3.591	3.344	3.819	2.945	3.525	4.959	9.785	6.631	8.189

*, **: Significant (p-value < 0.05) and very significant (p-value < 0.01)

According to the comparison of the mean values, the fruit weight and fruit kernel were not affected by any of the boron and zinc treatments. The application of boron did not alter fruit length, but both levels of zinc treatment (2500 and 5000 mg l^{-1}) caused an increase in fruit length (5%) compared to the control treatment. The study of mutual effects of boron and zinc elements revealed a significant increase in fruit length in all treatments except the third treatment at a level of 1% compared to the control. The fruit width was not affected by different boron levels or mutual effects of boron and zinc elements, but both levels of zinc treatment (2500 and 5000 mg l^{-1}) led to a significant increase in fruit width, with the increase being particularly significant in the 5000 mg l^{-1} treatment (Tables 2 and 3).

Table 2. The effect of different levels of boron and zinc on fruit characteristics and the amount of boron and zinc in fruit of pecan.

Traits \ Treatment	Zinc Sulfate (ppm)									Boric Acid (ppm)								
	0			2500			5000			0			1500			3000		
	1%	5%	Avg.	1%	5%	Avg.	1%	5%	Avg.	1%	5%	Avg.	1%	5%	Avg.	1%	5%	Avg.
Fruit weight (g)	a	a	3.5	a	a	3.6	a	a	3.6	a	a	3.7	a	a	3.5	a	a	3.5
Kernel weight (g)	a	a	1.1	a	a	1.1	a	a	1.1	a	a	1.1	a	a	1.1	a	a	1.1
Fruit length (cm)	b	b	3.3	a	a	3.4	a	a	3.5	a	a	3.3	a	a	3.4	a	a	3.5
Fruit width (cm)	b	b	2.0	ab	a	2.1	a	a	2.2	a	a	2.1	a	a	2.1	a	a	2.1
Hull (%)	a	a	34.3	a	a	34.7	a	a	34.8	a	a	34.8	a	a	34.2	a	a	34.8
Shell (%)	a	a	40.7	a	a	40.6	a	a	40.7	a	a	40.5	a	a	41.0	a	a	40.6
Kernel (%)	a	a	20.0	a	a	19.7	a	a	19.5	a	a	19.8	a	a	19.8	a	a	19.6
Fruit zinc (mg kg^{-1})	a	b	16.8	a	ab	18.4	a	a	19.5	a	a	18.6	a	a	17.3	a	a	18.8
Fruit boron (mg kg^{-1})	a	a	45.3	a	a	46.7	a	a	46.2	a	b	41.3	a	a	45.7	a	ab	51.2
Leaf zinc (mg kg^{-1})	a	b	26.8	a	b	26.9	a	a	29.4	a	a	28.0	a	a	27.7	a	a	27.5
Leaf boron (mg kg^{-1})	a	a	48.7	a	a	47.4	a	a	48.2	a	b	44.3	a	a	49.8	a	a	50.2

Note: The mean values displayed with identical letters in every column do not hold statistical significance.

Table 3. Reciprocal impact of varied boron and zinc levels on fruit characteristics and the concentration of boron and zinc in leaves and fruit

Treatment		Kernel (%)			Shell (%)			Hull (%)			Fruit width (cm)			Fruit length (cm)		
Boron (ppm)	**Zinc (ppm)**	**1%**	**5%**	**Avg.**	**1%**	**5%**	**Avg.**	**1%**	**5%**	**Avg.**	**1%**	**5%**	**Avg.**	**1%**	**5%**	**Avg.**
0	**0**	a	a	20.8	a	a	40.9	a	a	33.3	a	a	2.0	b	b	3.1
0	**2500**	a	ab	19.8	a	a	39.9	a	a	35.4	a	a	2.1	a	a	3.5
0	**5000**	a	b	18.7	a	a	40.7	a	a	35.7	a	a	2.1	a	a	3.4
1500	**0**	a	ab	19.5	a	a	40.9	a	a	34.5	a	a	2.0	ab	ab	3.2
1500	**2500**	a	ab	19.8	a	a	41.0	a	a	34.1	a	a	2.1	a	a	3.5
1500	**5000**	a	a	20.2	a	a	41.0	a	a	33.8	a	a	2.2	a	a	3.5
3000	**0**	a	ab	19.4	a	a	40.2	a	a	35.1	a	a	2.0	a	a	3.5
3000	**2500**	a	ab	19.4	a	a	41.0	a	a	34.5	a	a	2.1	a	a	3.4
3000	**5000**	a	ab	19.7	a	a	40.6	a	a	34.8	a	a	2.2	a	a	3.5

Treatment		Kernel weight (g)			Fruit weight (g)			Fruit zinc (mg kg^{-1})			Fruit boron (mg kg^{-1})			Leaf zinc (mg kg^{-1})			Leaf boron (mg kg^{-1})		
Boron (ppm)	**Zinc (ppm)**	**1%**	**5%**	**Avg.**	**1%**	**5%**	**Avg.**	**1%**	**5%**	**Avg.**	**1%**	**5%**	**Avg.**	**1%**	**5%**	**Avg.**	**1%**	**5%**	**Avg.**
0	**0**	a	a	1.2	a	a	3.6	a	c	15.9	a	a	37.0	a	bc	25.7	a	b	40.0
0	**2500**	a	a	1.1	a	a	3.7	a	abc	18.5	a	a	45.8	a	abc	28.7	a	ab	47.0
0	**5000**	a	a	1.2	a	a	3.7	a	a	21.3	a	a	41.2	a	a	29.6	a	ab	45.9
1500	**0**	a	a	1.1	a	a	3.4	a	bc	17.0	a	a	47.8	a	abc	26.9	a	a	52.4
1500	**2500**	a	a	1.2	a	a	3.7	a	abc	18.2	a	a	42.9	a	abc	26.7	a	ab	47.0
1500	**5000**	a	a	1.1	a	a	3.6	a	c	16.8	a	a	46.2	a	a	29.5	a	ab	50.0
3000	**0**	a	a	1.2	a	a	3.5	a	bc	17.4	a	a	51.0	a	abc	28.0	a	a	53.7
3000	**2500**	a	a	1.1	a	a	3.5	a	abc	18.6	a	a	51.5	a	c	25.2	a	a	48.3
3000	**5000**	a	a	1.1	a	a	3.6	a	ab	20.4	a	a	51.3	a	ab	29.1	a	a	48.7

Note: The mean values displayed with identical letters in every column do not hold statistical significance.

The research investigated the impact of spraying boron and zinc solutions on the amount of hull and shell in fruits, and found that none of the treatments had any effect on these characteristics. Additionally, the study found that varying levels of boron and zinc did not affect kernel percentage (Table 2). When boron and zinc were combined, it was observed that the kernel percentage decreased in the treatment with 5000 mg l^{-1} of zinc (Table 3). The analysis of variance showed that spraying with boron and zinc resulted in a significant increase in the concentration of these elements in both leaves and fruits (Table 2).

The results of the mean comparison indicate that the quantity of boron found in the fruit increased significantly when treated with 3000 mg l^{-1} of boric acid compared to the control treatment. Similarly, the amount of zinc present in the fruit showed a significant increase after being sprayed with 5000 mg l^{-1} of zinc sulfate in the spring (Table 2). The investigation of the interplay between boron and zinc elements revealed that the joint treatment of 3000 mg l^{-1} of boric acid and 5000 mg l^{-1} of zinc sulfate, as well as the treatment of 5000 mg l^{-1} of zinc sulfate on its own, resulted in a significant increase in both boron and zinc quantities in the fruit compared to the control treatment. Furthermore, the amounts of boron and zinc in the leaves also increased with the application of boron and zinc treatments (Tables 2 and 3).

Discussion

During the experiment, it was observed that the weight of both the fruit and the kernel did not increase significantly, which aligns with the results reported by (Yilmaz *et al*., 2021)) and (Y. Huang *et al*., 2019) in their research on pecan nuts. The findings of this study demonstrate that the application of zinc through spraying had an impact on the size of the fruit, in a manner consistent with the observations made by (Amro, 2015; Hounnou *et al*., 2019) on oranges. According to (Amro, 2015)'s findings, the application of a spray on orange trees during the months of April and May can lead to an increase in both fruit size and the concentration of soluble solids in the juice.

Additionally, research has indicated that the size of the fruit in oranges can be impacted by zinc. (Vahdati *et al*., 2021)'s research indicates that achieving desirable fruit size requires the presence of zinc, as it plays a crucial role in the production of auxin which is a key factor in promoting fruit growth. The study also demonstrated that zinc facilitates cell division in several fruits such as apricots, peaches, avocados, and oranges. Conversely, when these fruits experience zinc deficiency, the cells tend to be compressed with a lack of intercellular space, causing a delay in tissue differentiation specifically in peaches, apricots, and walnuts (Ahmed *et al*., 2012).

The findings indicate that the combination of boron (at a concentration of 1500 mg l^{-1}) and zinc (at a concentration of 5000 mg l^{-1}) resulted in the greatest enhancement in fruit length. This suggests that both of these elements have a notable impact on augmenting fruit size. According to the research conducted by (Swathi *et al*., 2019), the application of a boron solution on grapes resulted in an increase in both grape volume and bunch weight. Additionally, (Ahmed *et al*., 2012) found that spraying oranges with a boron solution increased the fruit's diameter which aligns with this research. Also highest yield (17.7 tone ha^{-1}) of Okra was obtained in foliar application of 0.2% Zn and 0.3% B combination (Maliha *et al*., 2022).

Our study found a positive and significant correlation between the zinc content and the length of the fruit. As the amount of zinc in the fruit increased, so did the length of the fruit. Additionally, we observed a positive and significant correlation between the length and weight of the fruit. The percentages of hull, hard skin, and kernel were not affected by solution spraying, which is consistent with previous research on researches on pecan nuts (Hounnou *et al*., 2019; Y. Huang *et al*., 2019; Yilmaz *et al*., 2021).

Although, no decrease in the percentage of hull was observed, which contradicts the findings of (Ferrara *et al*., 2023). This discrepancy may be attributed to differences in cultivation conditions and weather factors. Analysis of the zinc and boron content in the fruit revealed that spring spraying of pecans increased the concentration of these elements in both the fruits and leaves. These results are in agreement with the findings of (Ferrara *et al*., 2023) who reported that boric acid spraying increased the concentration of elements in both fruits and leaves. Furthermore, these results demonstrate that the spraying solution can be effectively transported to different parts of the plant. This finding is consistent with those of (Ibrahim and Tayib, 2019), who reported similar observations in pistachios.

Conclusions

The findings of this study indicate that foliar application of boron and zinc can be an effective strategy to improve certain physical characteristics of pecan fruit, including fruit length and width. Specifically, applying zinc sulfate at 5000 mg l^{-1} significantly increased fruit width, while the combination of 1500 mg l^{-1} boric acid and 5000 mg l^{-1} zinc sulfate gave the largest increase in fruit length. However, the treatments did not have a significant impact on fruit or kernel weight. Additionally, the foliar sprays increased the absorption and accumulation of boron and zinc in pecan leaves and nuts. Overall, this research demonstrates that targeted foliar sprays containing boron and zinc applied before flower bud opening can enhance the size of pecan fruit by increasing length and/or width. The increased boron and zinc concentrations in leaves and nuts show that the elements are successfully absorbed. Further studies could investigate the effects of different application timing, concentration, and frequency of the foliar sprays. Optimizing the foliar application protocols for boron and zinc may lead to additional improvements in pecan fruit size and quality.

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Conflict of interest

The authors declare no conflict of interest.

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