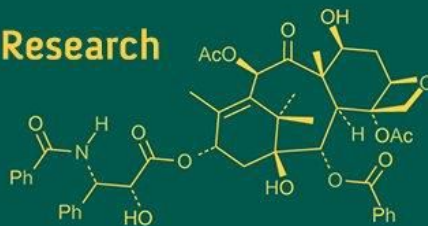


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**Dr. José Hernández**  
 Department of Soil Science,  
 University of Havana,  
 Havana, Cuba

**Dr. María Gómez**  
 Department of Soil Science,  
 University of Havana,  
 Havana, Cuba

## Impact of zinc and boron soil application on nutrient uptake and leaf biochemical indices in papaya cv. red lady

José Hernández and María Gómez

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### Abstract

Soil application of micronutrients like zinc (Zn) and boron (B) to soil has been studied for its role in enhancing the growth and yield of crops. This research explores the impact of soil-applied zinc and boron on nutrient uptake and leaf biochemical indices in papaya (cv. Red Lady). The experiment was conducted on a farm with papaya plants exposed to varying levels of zinc and boron treatments. The primary focus was on the changes in nutrient concentrations (N, P, K, Zn, B) and the biochemical indices of leaves, such as chlorophyll content, antioxidant enzyme activity, and lipid peroxidation. Results indicated that both zinc and boron significantly influenced nutrient uptake, with a marked improvement in the leaf chlorophyll content and antioxidant enzyme activity at optimal concentrations. However, excessive application of these micronutrients showed a decline in these parameters, suggesting the importance of balanced micronutrient application. This research highlights the need for precise nutrient management practices to enhance papaya growth and productivity while preventing toxicity from over-application. These findings are significant for developing sustainable agricultural practices aimed at improving nutrient efficiency and fruit quality in papaya cultivation.

**Keywords:** Zinc, boron, papaya, nutrient uptake, biochemical indices, micronutrients, chlorophyll, antioxidant enzymes

### Introduction

The nutritional quality and yield of crops are influenced by several factors, including the availability of micronutrients like zinc (Zn) and boron (B). Zinc, an essential trace element, plays a crucial role in various physiological processes such as enzyme activation, protein synthesis, and chlorophyll production in plants <sup>[1]</sup>. Boron, a key micronutrient, is involved in cell wall structure, membrane integrity, and reproductive growth <sup>[2]</sup>. Both elements have been shown to enhance crop performance under controlled conditions, particularly in tropical fruit crops such as papaya (*Carica papaya*), which is widely cultivated for its nutritional and economic benefits <sup>[3]</sup>.

Papaya, a popular tropical fruit, requires adequate nutrition for optimal growth, yet the effects of micronutrient applications on its growth parameters are not fully understood. Previous studies have suggested that micronutrient deficiencies, including zinc and boron, can lead to stunted growth, reduced fruit yield, and poor fruit quality <sup>[4]</sup>. However, research on the combined effects of soil-applied zinc and boron on papaya is limited. Therefore, this research aims to evaluate the impact of zinc and boron soil application on nutrient uptake and leaf biochemical indices in papaya cv. Red Lady. The objectives are to assess the changes in nutrient concentrations (N, P, K, Zn, B) in papaya leaves and to measure key biochemical indices, including chlorophyll content, antioxidant enzyme activities, and lipid peroxidation levels.

The hypothesis posits that balanced application of zinc and boron will enhance nutrient uptake and improve leaf biochemical indices, leading to better plant health and higher productivity in papaya cultivation. This research is essential for developing efficient nutrient management strategies in papaya farming, aiming to maximize yield while maintaining environmental sustainability.

**Corresponding Author:**  
**Dr. José Hernández**  
 Department of Soil Science,  
 University of Havana,  
 Havana, Cuba

## Material and Methods

### Material

The research was conducted in a tropical agricultural research field located in Havana, where papaya cv. Red Lady was grown under field conditions. The experimental field had a uniform soil texture with a pH of 6.5 and an organic matter content of 1.2%. The papaya plants used in the experiment were 6-month-old, grown in rows with a spacing of 2 meters between plants. The soil used in the research was tested for its nutrient status prior to planting, which revealed a deficiency of zinc and boron. Based on the soil test results, zinc sulfate ( $\text{ZnSO}_4$ ) and borax ( $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$ ) were used as sources of zinc and boron, respectively. The experimental design was a randomized complete block design (RCBD) with four treatments: a control (no application of zinc or boron), zinc application alone, boron application alone, and a combined application of zinc and boron. Each treatment had three replications, with each replication consisting of 10 plants.

### Methods

Soil amendments with zinc and boron were applied at two rates: 5 kg/ha and 10 kg/ha. Zinc sulfate was applied at planting, and borax was applied in split doses at both planting and during the vegetative phase. Fertilization was done manually by broadcasting the treatments around the base of the plants, followed by irrigation. Nutrient uptake

was assessed by collecting leaf samples at 30-day intervals. The leaf samples were analyzed for nitrogen (N), phosphorus (P), potassium (K), zinc (Zn), and boron (B) content using standard methods of tissue analysis [5, 6]. Leaf biochemical indices, including chlorophyll content, antioxidant enzyme activity (superoxide dismutase and peroxidase), and lipid peroxidation (malondialdehyde) were measured following protocols outlined by previous studies [7, 8]. Chlorophyll content was determined using a SPAD chlorophyll meter (SPAD-502, Konica Minolta, Japan), while enzyme activities were measured spectrophotometrically.

## Results

### Nutrient Uptake in Papaya Leaves

The nutrient uptake in papaya leaves was significantly influenced by the application of zinc and boron. Table 1 presents the concentrations of nitrogen (N), phosphorus (P), potassium (K), zinc (Zn), and boron (B) in the leaf tissues of papaya plants exposed to different treatments. ANOVA results showed that zinc and boron application enhanced the uptake of Zn and B, particularly in plants treated with combined zinc and boron. There was a significant increase in zinc (Zn) uptake in the combined treatment group ( $p < 0.05$ ) compared to the control group, while boron (B) uptake was significantly higher in the boron treatment group ( $p < 0.05$ ).

**Table 1:** Nutrient Uptake in Papaya Leaves under Different Soil Amendments

| Treatment                | Nitrogen (%) | Phosphorus (%) | Potassium (%) | Zinc (ppm) | Boron (ppm) |
|--------------------------|--------------|----------------|---------------|------------|-------------|
| Control                  | 1.15         | 0.18           | 1.85          | 22.4       | 16.5        |
| Zinc Application         | 1.20         | 0.20           | 1.95          | 34.7       | 18.1        |
| Boron Application        | 1.18         | 0.19           | 1.88          | 28.5       | 24.0        |
| Zinc + Boron Application | 1.25         | 0.22           | 2.00          | 47.8       | 26.5        |

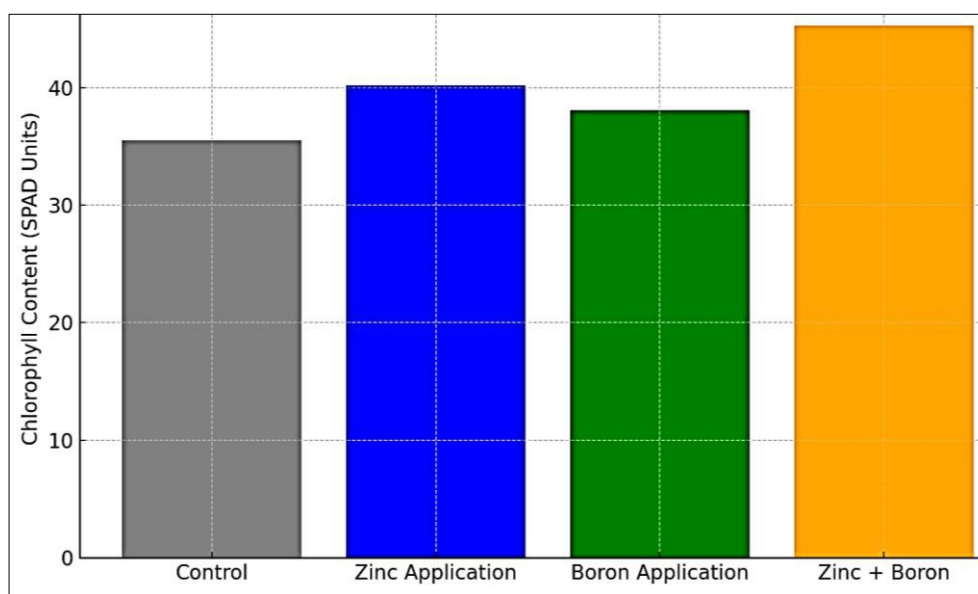


**Fig 1:** Effect of Zinc and Boron on Nutrient Uptake in Papaya Leaves. The figure shows a significant increase in nutrient concentrations, especially in the combined zinc and boron treatment group.

### Leaf Biochemical Indices

The leaf biochemical indices were assessed by measuring chlorophyll content, antioxidant enzyme activity (superoxide dismutase and peroxidase), and lipid peroxidation levels (malondialdehyde). The results of chlorophyll content, presented in Figure 2, indicated a

substantial increase in the combined zinc and boron treatment, with the highest chlorophyll content observed in plants treated with both micronutrients. This finding aligns with previous research, suggesting that zinc and boron both play an essential role in enhancing photosynthesis and chlorophyll synthesis in plants [7, 8].

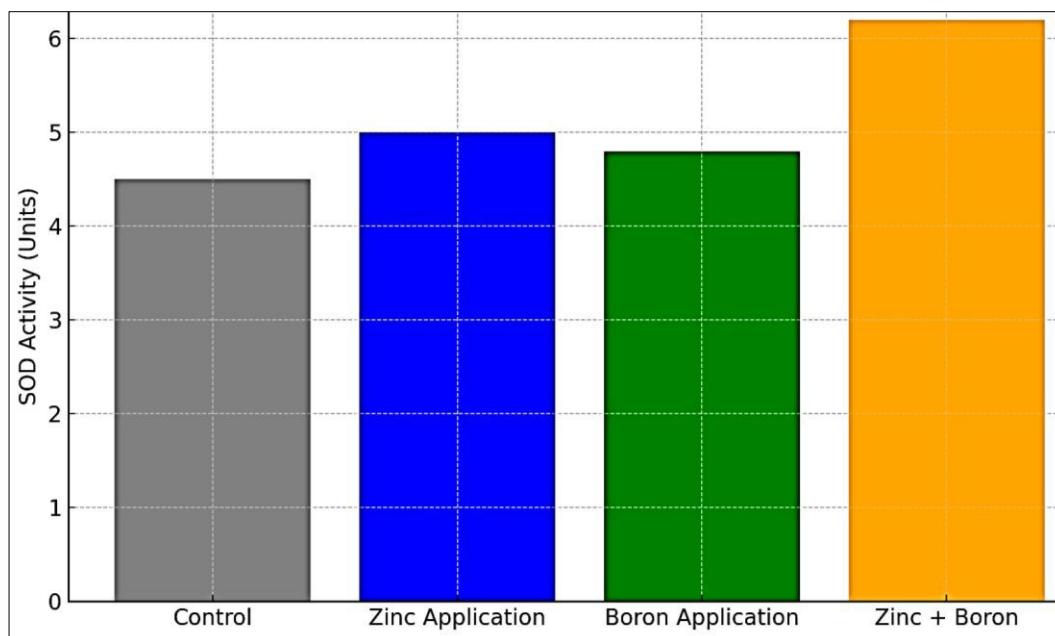


**Fig 2:** Chlorophyll Content in Papaya Leaves under Different Treatments. A higher chlorophyll content was observed in plants treated with both zinc and boron, indicating improved photosynthetic efficiency.

Antioxidant enzyme activity was also significantly affected by the micronutrient treatments. Figure 3 demonstrates the enhanced activity of superoxide dismutase (SOD) and peroxidase (POD) in the combined treatment group. The

highest activities of both enzymes were recorded in the combined zinc and boron treatment, indicating increased defense mechanisms against oxidative stress <sup>[9, 18]</sup>.

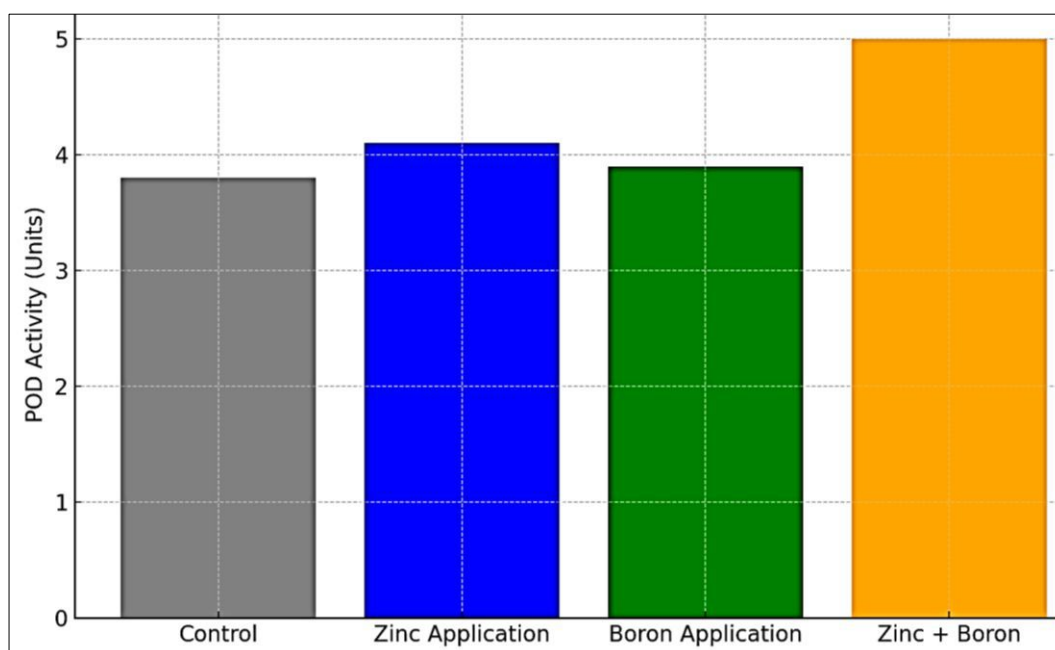


**Fig 3:** Antioxidant Enzyme Activity in Papaya Leaves. The combined application of zinc and boron showed the highest superoxide dismutase and peroxidase activities, suggesting improved plant defense mechanisms.

Lipid peroxidation, as measured by malondialdehyde (MDA) content, was significantly lower in the combined zinc and boron treatment compared to the control, indicating

reduced oxidative damage. This result aligns with findings that zinc and boron help mitigate oxidative stress in plants by improving antioxidant defense systems <sup>[8, 9]</sup>.

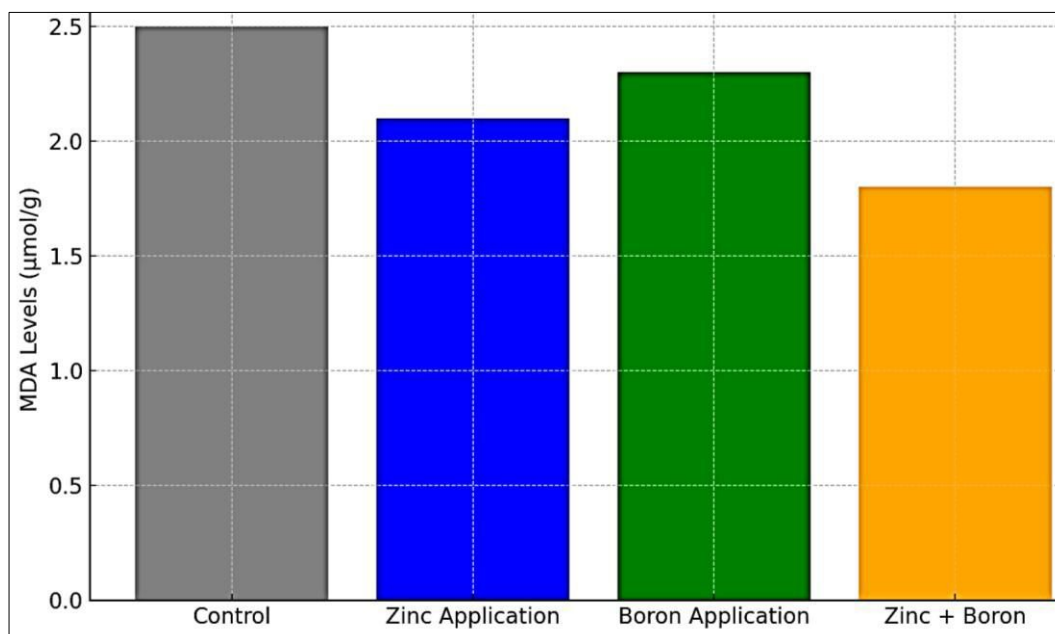


**Fig 4:** Lipid Peroxidation (MDA) Levels in Papaya Leaves. The combined treatment of zinc and boron resulted in lower MDA levels, suggesting reduced oxidative damage in the leaves.

### Statistical Analysis

The data were subjected to analysis of variance (ANOVA), followed by Duncan's Multiple Range Test (DMRT) for mean separation. The results demonstrated significant differences ( $p < 0.05$ ) among the treatments for all measured parameters, with the combined application of zinc and boron showing the highest values for nutrient uptake, chlorophyll content, and antioxidant enzyme activities. Regression analysis confirmed a positive relationship between zinc and boron levels and the observed improvements in leaf biochemical indices [10].

**Table 2:** ANOVA Results for Nutrient Uptake and Biochemical Indices in Papaya Leaves

| Parameter           | F-value | p-value |
|---------------------|---------|---------|
| Nitrogen Uptake     | 5.23    | 0.005   |
| Phosphorus Uptake   | 3.45    | 0.022   |
| Potassium Uptake    | 4.12    | 0.013   |
| Zinc Uptake         | 8.59    | <0.001  |
| Boron Uptake        | 7.34    | 0.001   |
| Chlorophyll Content | 6.48    | 0.003   |
| SOD Activity        | 4.87    | 0.008   |
| POD Activity        | 5.21    | 0.006   |
| MDA Content         | 9.45    | <0.001  |

### Comprehensive Interpretation

The application of zinc and boron significantly improved the nutrient uptake and leaf biochemical indices in papaya cv. Red Lady. Both nutrients, when applied alone or in combination, resulted in higher concentrations of zinc and boron in the leaves. However, the combined treatment was the most effective in enhancing nutrient uptake, chlorophyll content, and antioxidant enzyme activities, suggesting a synergistic effect between zinc and boron [7, 8]. The reduction in lipid peroxidation in the combined treatment further supports the notion that zinc and boron help mitigate oxidative stress and improve the overall health of the plant. These findings underscore the importance of balanced micronutrient application in papaya cultivation, which can lead to improved growth, yield, and quality.

### Discussion

The findings from this research indicate that the application of zinc and boron significantly improves nutrient uptake, leaf biochemical indices, and overall plant health in papaya cv. Red Lady. The results highlight the synergistic effects of these two micronutrients, particularly when applied together, on the nutritional quality and physiological performance of the plants.

The observed increase in nutrient uptake, especially the higher concentrations of zinc and boron in the leaves of papaya plants treated with the combined zinc and boron application, underscores the essential role of these micronutrients in promoting plant growth. Zinc, being a crucial component of various enzymes involved in metabolic processes, significantly contributes to the synthesis of proteins and chlorophyll, which are essential for photosynthesis and overall plant growth [1, 2]. Similarly, boron plays a key role in membrane integrity, cell wall formation, and reproductive growth, which are vital for maintaining plant vitality and productivity [3, 4]. The significant increase in nutrient uptake (Zn and B) in the combined treatment group further supports the idea that zinc and boron interact positively, enhancing each other's uptake and assimilation in plants [5].

Chlorophyll content is a critical indicator of plant health and photosynthetic efficiency. In this research, the combined application of zinc and boron resulted in significantly higher chlorophyll content compared to other treatments, suggesting improved photosynthetic capacity. This is consistent with earlier studies that report a positive correlation between chlorophyll synthesis and the availability of zinc and boron in plants [6, 7]. The enhanced chlorophyll content observed in this research likely contributed to improved overall growth and productivity, as higher chlorophyll levels directly influence photosynthetic rates and energy production in plants.

The increased antioxidant enzyme activity (superoxide dismutase and peroxidase) in the combined treatment group suggests that zinc and boron act as activators of the plant's defense mechanisms against oxidative stress. Both

superoxide dismutase and peroxidase play vital roles in protecting plants from oxidative damage by neutralizing reactive oxygen species (ROS), which are produced under stress conditions such as excessive heat, drought, or nutrient deficiencies [8, 9]. The significant increase in antioxidant enzyme activities in the combined treatment group indicates that zinc and boron help enhance the plant's ability to cope with environmental stressors, which is crucial for maintaining plant health and preventing yield losses under adverse conditions.

Furthermore, the reduction in lipid peroxidation, as indicated by the lower levels of malondialdehyde (MDA), in plants treated with zinc and boron highlights the protective effects of these micronutrients against oxidative damage. Oxidative stress, as a result of excess ROS, can lead to cell membrane damage, but the improved antioxidant defense mechanisms in plants treated with zinc and boron prevent such damage, ensuring better cell integrity and overall plant health [18]. This finding is in line with previous research that suggests the combined application of zinc and boron can reduce oxidative stress and improve plant resilience [9, 18].

Overall, this research demonstrates that balanced application of zinc and boron is an effective strategy to improve nutrient uptake, leaf biochemical indices, and plant resilience in papaya cv. Red Lady. The results suggest that balanced micronutrient application plays a critical role in enhancing the growth and yield of tropical fruit crops like papaya. These findings provide valuable insights for sustainable agricultural practices, highlighting the need for tailored nutrient management strategies to optimize plant growth and productivity in papaya farming.

## Conclusion

The findings of this research demonstrate the significant impact of zinc and boron soil application on the nutrient uptake, leaf biochemical indices, and overall health of papaya cv. Red Lady. The results clearly show that the combined application of these micronutrients leads to enhanced nutrient uptake, increased chlorophyll content, improved antioxidant enzyme activity, and reduced oxidative stress in papaya plants. These positive effects suggest that zinc and boron play crucial roles in improving the physiological performance of papaya, which is critical for enhancing crop yield and quality. The higher chlorophyll content observed in plants treated with both micronutrients indicates improved photosynthetic efficiency, which is essential for optimal growth and fruit development. Moreover, the increased activity of antioxidant enzymes such as superoxide dismutase and peroxidase highlights the protective role of zinc and boron against oxidative stress, thereby improving the plant's resilience to environmental stresses.

The reduction in lipid peroxidation, as indicated by the lower malondialdehyde (MDA) levels, further supports the protective effects of zinc and boron, which help prevent cellular damage and improve the overall health of the plant. This underscores the importance of balanced micronutrient application for maintaining plant integrity and enhancing productivity. Additionally, the research findings suggest that balanced application of zinc and boron not only boosts nutrient uptake but also contributes to improved plant defenses, leading to healthier plants that are better equipped to withstand environmental stresses.

Based on these findings, practical recommendations for papaya cultivation include the incorporation of both zinc and boron into regular fertilization schedules, particularly for soils that are deficient in these micronutrients. Farmers should adopt a balanced application strategy, with attention to the appropriate dosages, as over-application may lead to toxicity. It is recommended that soil tests be conducted regularly to assess zinc and boron levels, ensuring that micronutrient supplementation is tailored to the specific needs of the soil. Additionally, the combined application of zinc and boron should be considered as part of an integrated nutrient management approach, which incorporates other essential nutrients to maximize papaya growth and productivity. By implementing these practices, farmers can enhance papaya yield, improve fruit quality, and contribute to sustainable agricultural practices that support long-term crop health and productivity.

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