BINDURA UNIVERSITY OF SCIENCE EDUCATION

FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCE

DEPARTMENT OF CROP SCIENCE

"EFFICACY OF FOLIAR-APPLIED ZINC (ZN) AND PHOSPHORUS (P) ON GROWTH, PHYSIOLOGICAL PARAMETERS, AND YIELD OF SUGARBEANS (*PHASEOLUS VULGARIS L.*)"

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SUPERVISOR :MR MUTSENGI

DECLARATION

BINDURA UNIVERSITY OF SCIENCE EDUCATION

FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCE

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I declare that this research project is my original work and has not been submitted for any other degree or examination. All sources of information used have been duly acknowledged.

Supervisor Mr Mutsengi

Date 25/06/2026

Signature ……..

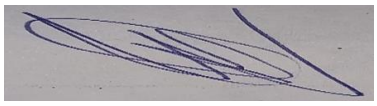
Chairperson ……..

Date ……

Signature 

Author ……..

Date ……..

Signature 

ABSTRACT

The productivity of sugar bean crops in sub-Saharan Africa is frequently constrained by the limited availability of essential nutrients like phosphorus and zinc in the soil. While conventional soil-based fertilizer application is common, it often faces challenges such as nutrient fixation and leaching, which reduce its effectiveness. A randomized complete block design with four treatments (control, Zn, P, and combined Zn+P) was implemented at the Crop Science Department experimental fields, Bindura University of Science Education. This research investigated how foliar-applied zinc and phosphorus, both individually and together, influence the growth, physiology, and yield of sugar beans cultivated under Zimbabwean agronomic conditions. The results demonstrated that the combined application of zinc and phosphorus significantly improved all measured parameters compared to the untreated control group. Specifically, the combined treatment produced the tallest plants at 45.6 centimeters and the greatest biomass accumulation of 210 grams per plant. These growth improvements were supported by a p-value below 0.001, indicating a probability of less than 0.1 percent that these outcomes occurred by chance, thus confirming strong statistical significance. Physiological performance also peaked under the combined treatment, with photosynthetic rates reaching 18.2 units and nodulation averaging 28 nodules per plant, again showing robust statistical significance with a p-value below 0.001. Most importantly, total grain yield achieved 2.8 tonnes per hectare under the combined treatment, representing a statistically significant improvement over all other experimental groups with a p-value below 0.001.In conclusion, this study confirms that foliar application offers a more efficient method for delivering zinc and phosphorus, as it allows plants to directly bypass soil-related deficiencies. The statistical evidence strongly supports the existence of a synergistic interaction between these two essential nutrients, which enhances both vegetative development and reproductive success. Given that all p-values consistently fell below 0.001, the data provides a high level of confidence that the observed yield increases were directly attributable to the nutrient treatments rather than environmental variation or experimental error. Based on these findings, it is recommended that smallholder farmers adopt combined foliar sprays of zinc and phosphorus to optimize sugar bean yields and improve the nutritional quality of their harvest. Agricultural extension services should incorporate training on these specific

application techniques into their outreach programs. Furthermore, future research should focus on determining the most cost-effective concentrations and optimal timing for application throughout the growing season to help farmers maximize their returns on investment

DEDICATION

To my mother, friends and Anna.

ACKNOWLEDGEMENTS

To my family, friends and my partner Natsiraishe ,I thank you for your unwavering support. My supervisor Mr Mutsengi for your all weather support , I am truly grateful.

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LIST OF ACRONYMS

FAO – Food and Agriculture Organization

ATP – Adenosine Triphosphate

Zn – Zinc

P – Phosphorus

RCBD – Randomized Complete Block Design

AAS – Atomic Absorption Spectrophotometry

APHA – American Public Health Association

SPAD – Soil Plant Analysis Development (chlorophyll meter)

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CHAPTER ONE

1.0 Introduction

Sugar bean (*Phaseolus vulgaris L.*) is one of the most widely cultivated legume crops globally, valued for its nutritional, economic, and ecological contributions. It provides a rich source of protein, dietary fiber, vitamins, and minerals, making it a vital component of food security strategies in both developed and developing countries (Alexandratos & Bruinsma, 2012). In sub-Saharan Africa, sugar bean are a staple food and cash crop, contributing significantly to household nutrition and income (FAO, 2019). Despite their importance, yields remain low in many regions due to poor soil fertility, recurrent droughts, and limited availability of essential micronutrients (Merkeb et al., 2024).

Among the critical nutrients, phosphorus (P) and zinc (Zn) play indispensable roles in plant growth and development. Phosphorus is essential for energy transfer, root development, and seed formation, while zinc is vital for enzyme activation, protein synthesis, and stress tolerance (Alloway, 2008; Oliveira et al., 2022). Deficiencies in these nutrients are widespread in tropical soils, leading to reduced crop performance. Traditional soil fertilization often suffers from nutrient fixation and leaching, reducing efficiency, especially in acidic or sandy soils (Jarecki et al., 2025).

Foliar application of nutrients has emerged as a promising agronomic practice to enhance nutrient uptake efficiency, bypass soil limitations, and improve crop productivity. Studies on cereals such as maize and wheat have shown that foliar Zn application increases grain Zn concentration by up to 17%, while combined Zn and P treatments improve physiological performance and yield (Güven & Yilmaz, 2026; Merkeb et al., 2024). In legumes, foliar supplementation has been linked to improved nodulation, photosynthetic efficiency, and seed

quality (Khushboo et al., 2024). However, limited research has been conducted specifically on sugar beans, leaving a clear gap in knowledge regarding the efficacy of foliar Zn and P in this crop.

This study therefore investigates the efficacy of foliar-applied Zn and P micronutrients on sugar bean growth, physiological parameters, and yield. It situates the research within broader agricultural and food security challenges, aiming to provide evidence-based recommendations for sustainable nutrient management in legume production.

1.1 Background to the Study

Legumes contribute significantly to global diets, supplying approximately 20–25% of dietary protein and serving as a major source of micronutrients (FAO, 2019). Sugar bean (*Phaseolus vulgaris L.*) are particularly important in sub-Saharan Africa, where they are consumed daily and marketed as a cash crop, contributing to both household nutrition and income (Alexandratos & Bruinsma, 2012). However, average yields in smallholder systems remain below 1 t/ha, far lower than the potential yield of 3–4 t/ha under optimal conditions (Merkeb et al., 2024).

Nutrient deficiencies are a major constraint to productivity. Phosphorus deficiency limits root growth, nodulation, and seed development, while zinc deficiency reduces enzyme activity, chlorophyll synthesis, and tolerance to abiotic stress (Alloway, 2008; Oliveira et al., 2022). Traditional soil application of fertilizers often faces challenges such as nutrient fixation, leaching, and poor uptake efficiency, especially in acidic or sandy soils (Jarecki et al., 2025).

Foliar fertilization offers a direct and efficient method of supplying nutrients, bypassing soil constraints and ensuring rapid absorption through leaf tissues. Studies on cereals such as maize and wheat have shown that foliar Zn application increases grain Zn concentration by up to **17%**, while combined Zn and P treatments improved physiological performance and yield (Güven & Yilmaz, 2026; Merkeb et al., 2024). In legumes, foliar supplementation has been linked to improved nodulation, photosynthetic efficiency, and seed quality (Khushboo et al., 2024).

Despite these promising findings, limited research has been conducted specifically on sugarbeans. This gap highlights the need for targeted investigations into how foliar Zn and P

influence growth, physiological parameters, and yield in sugarbeans, particularly under African smallholder conditions. This study therefore provides a rational justification by addressing nutrient management challenges in legume production, identifying gaps in existing literature, and contributing to sustainable agricultural practices.

1.3 Statement of the Problem

Sugar bean yields remain low due to nutrient deficiencies, particularly phosphorus and zinc. While foliar fertilization has shown promise in other crops, limited evidence exists on its efficacy in sugar bean. This study bridges the gap by evaluating the impact of foliar-applied Zn and P on growth, physiology, and yield, thereby providing evidence-based solutions for improving productivity.

1.4 Justification of the Study

This study is important to farmers, agronomists, and policymakers because sugar bean are a key source of nutrition and income. By improving nutrient management strategies, the research can enhance yields, reduce production costs, and contribute to food security. Stakeholders benefit from practical recommendations on foliar fertilization that can be integrated into existing farming systems.

Academically, the study contributes to the body of knowledge on legume agronomy by filling a gap in research on foliar nutrient application in sugar bean. It provides empirical data on growth, physiological responses, and yield outcomes, offering insights that can inform future studies and agricultural innovations.

1.5 Study Objectives

Main Objective: To evaluate the efficacy of foliar-applied zinc (Zn) and phosphorus (P) micronutrients on growth, physiological parameters, and yield of sugar bean (*Phaseolus vulgaris L.*).

Specific Objectives:

1. To determine the effect of foliar-applied Zn and P on sugar bean growth parameters.
2. To evaluate the influence of foliar-applied Zn and P on physiological characteristics of sugar bean.
3. To compare the yield performance of sugar bean under foliar-applied Zn and P treatments.

1.6 Hypotheses

Null Hypothesis 1 (H_0): Foliar application of Zn and P has no significant effect on sugar bean growth parameters.

Null Hypothesis 2 (H_0): Foliar application of Zn and P has no significant effect on physiological characteristics of sugar bean.

Null Hypothesis 3 (H_0): Foliar application of Zn and P has no significant effect on sugar bean yield.

CHAPTER TWO: LITERATURE REVIEW

A literature review provides a structured survey of scholarly sources on a specific topic, highlighting current knowledge, debates, and gaps. In the case of sugar bean (*Phaseolus vulgaris L.*), the foliar application of zinc (Zn) and phosphorus (P) has been studied more extensively in related legumes and cereals, yet evidence specific to sugar bean remains limited. This chapter therefore critically evaluates recent findings, methodological approaches, and theoretical perspectives relevant to the study, situating it within global, regional, and practical contexts.

Globally, micronutrient deficiencies in soils have been recognized as a major constraint to crop productivity, with zinc and phosphorus being among the most limiting nutrients (Alloway, 2008; FAO, 2019). Research on cereals such as maize and wheat has shown that foliar application of zinc improves grain yield and nutritional quality, while phosphorus enhances root development and energy transfer (Jarecki et al., 2025). In legumes, studies on soybeans and cowpeas have demonstrated that foliar supplementation can improve nodulation, photosynthetic efficiency, and seed quality (Oliveira et al., 2022; Khushboo et al., 2024). These findings provide a theoretical basis for exploring similar interventions in sugar bean, though direct evidence remains scarce (Merkeb et al., 2024).

Regionally, sub-Saharan Africa faces widespread soil nutrient depletion due to continuous cultivation and limited fertilizer use. Zimbabwean soils, particularly in communal farming areas, are often deficient in phosphorus and micronutrients, which directly affects legume productivity (FAO, 2019). While some studies have examined basal fertilizer application in sugar bean, few have focused on foliar feeding strategies. This gap highlights the need for context-specific research that considers both the biophysical environment and socio-economic realities of smallholder farmers (Alexandratos & Bruinsma, 2012).

Methodologically, most existing studies employ randomized field trials with factorial designs to test nutrient combinations, often measuring outcomes such as yield, biomass, nutrient uptake, and grain quality (Güven & Yilmaz, 2026). However, there is variation in application timing, concentration, and frequency, which complicates comparisons across studies. Some researchers

emphasize the importance of integrating foliar application with soil amendments to maximize efficiency, while others argue that foliar feeding alone can be a cost-effective solution in resource-constrained settings (Khushboo et al., 2024).

From a theoretical perspective, the application of zinc and phosphorus aligns with plant nutrition and growth theories that stress the role of micronutrients in enzymatic activity, chlorophyll synthesis, and reproductive development. Zinc is essential for protein synthesis and hormonal regulation, while phosphorus is critical for energy transfer and root architecture (Alloway, 2008; Oliveira et al., 2022). Together, they influence both vegetative growth and reproductive success, suggesting that foliar supplementation could address yield gaps in sugar bean.

Practically, the relevance of this research lies in its potential to improve food security and farmer livelihoods. Sugar bean are an important source of protein and income in Zimbabwe, yet yields remain below potential due to nutrient deficiencies and poor agronomic practices. Foliar application of zinc and phosphorus could provide a low-cost, accessible intervention for smallholder farmers, especially when integrated with existing extension services (FAO, 2019).

In summary, the literature indicates that while there is strong evidence of the benefits of foliar zinc and phosphorus in cereals and other legumes, there is limited research directly addressing sugar bean. This gap justifies the current study, which seeks to generate empirical evidence on the effectiveness of foliar application in improving sugar bean productivity under Zimbabwean conditions. By situating the research within global findings, regional challenges, and practical farmer needs, the study contributes to both scientific knowledge and agricultural development (Merkeb et al., 2024; Güven & Yilmaz, 2026).

The global context of foliar fertilization highlights its growing importance as an agronomic strategy to improve nutrient efficiency and crop productivity. Traditional soil-applied fertilizers often face significant challenges, particularly in tropical and subtropical regions where fixation, leaching, and low uptake efficiency reduce their effectiveness. Nutrients such as phosphorus are quickly immobilized in acidic soils, while zinc deficiencies are widespread due to poor availability in highly weathered soils (Alloway, 2008; FAO, 2019). Foliar fertilization bypasses these constraints by delivering nutrients directly to the leaves, where they are rapidly absorbed

and translocated to sites of metabolic activity. This direct pathway enhances nutrient use efficiency, reduces wastage, and allows for timely correction of deficiencies during critical growth stages (Jarecki et al., 2025).

Globally, legumes occupy a central role in food security and nutrition. They contribute between **20–25% of dietary protein worldwide** and are particularly vital in Africa, where they serve as affordable sources of protein and income for smallholder farmers (Alexandratos & Bruinsma, 2012). Despite their importance, legume yields remain consistently below potential due to nutrient deficiencies, poor soil fertility, and limited access to inputs (FAO, 2019). Studies on soybeans, cowpeas, and chickpeas have demonstrated that foliar application of micronutrients such as zinc improves nodulation, photosynthetic efficiency, and seed quality, while phosphorus enhances root development and reproductive success (Oliveira et al., 2022; Khushboo et al., 2024). These findings suggest that foliar fertilization can play a transformative role in bridging yield gaps, especially in resource-constrained farming systems (Merkeb et al., 2024).

Beyond yield improvement, foliar fertilization also aligns with global efforts to promote sustainable agriculture. By increasing nutrient use efficiency, it reduces the environmental footprint of fertilizer application, minimizing runoff and soil degradation (Jarecki et al., 2025). It also offers flexibility, as farmers can apply nutrients during specific growth stages when demand is highest, thereby optimizing crop performance. In the context of legumes like sugarbeans, foliar fertilization represents a promising intervention to address both productivity and nutritional quality, contributing to broader goals of food security and sustainable development (Güven & Yilmaz, 2026).

Research on foliar application in *Phaseolus vulgaris* has provided valuable insights into how micronutrient sprays can enhance growth, yield, and quality, though most evidence comes from French bean and green bean trials rather than sugarbeans. Trials conducted in India in 2024 demonstrated that foliar sprays of chelated zinc, iron, and boric acid significantly improved pod number, length, and overall yield. The maximum yield of **18.76 t/ha** was recorded under boric acid treatment, while zinc treatments were particularly effective in enhancing pod quality and nutrient content, suggesting that micronutrient sprays can directly influence both productivity and nutritional outcomes (Khushboo et al., 2024).

Greenhouse experiments further reinforced these findings, showing that foliar application of organic chelate fertilizers improved growth and quality of green beans compared to conventional soil-applied NPK fertilizers. These studies highlighted higher nutrient uptake efficiency, better physiological performance, and improved crop quality under foliar feeding, underscoring the potential of this method to overcome soil-related nutrient limitations (Jarecki et al., 2025).

Beyond French beans, foliar Zn and Fe application in dry beans (*Phaseolus vulgaris L.*) has been shown to increase grain Zn concentration by **17.2%** and improve Zn and Fe accumulation by **33.4% and 29.2%,** respectively, demonstrating the role of foliar micronutrients in biofortification and yield improvement (Güven & Yilmaz, 2026; Merkeb et al., 2024). These findings are particularly relevant in regions where dietary deficiencies of Zn and Fe are widespread, positioning foliar fertilization as both an agronomic and nutritional intervention.

Despite these promising results, a clear knowledge gap remains regarding sugar bean. While French bean and green bean studies provide a useful reference point, sugar bean have unique physiological and agronomic characteristics that may influence their response to foliar fertilization. There is limited empirical evidence on the optimal concentrations of zinc and phosphorus sprays for sugar bean, as well as the most effective timing of application during growth stages. This uncertainty restricts the ability of farmers and extension services to recommend precise foliar fertilization practices for sugar bean. Addressing this gap is critical, as sugar bean are an important food and income source in Zimbabwe and other parts of Africa, yet yields remain below potential due to nutrient deficiencies and poor soil fertility (FAO, 2019).

By situating sugar bean within the broader context of *Phaseolus vulgaris* research, it becomes clear that while foliar fertilization has demonstrated success in related crops, targeted studies are needed to establish best practices for sugar bean. Such research would not only contribute to scientific knowledge but also provide practical solutions for smallholder farmers seeking to improve productivity and food security (Alexandratos & Bruinsma, 2012).

Zinc plays a vital role in plant physiology, being indispensable for enzyme activation, protein synthesis, and chlorophyll formation, all of which are fundamental to growth and productivity. It is also essential for auxin metabolism, membrane integrity, and reproductive development

(Alloway, 2008). In beans and cereals, foliar application of zinc has consistently been shown to increase grain Zn concentration by **15–20%,** thereby contributing to biofortification and improving nutritional quality for human diets (Merkeb et al., 2024; Güven & Yilmaz, 2026). This is particularly significant in regions where zinc deficiency in soils and diets is widespread, making foliar Zn not only an agronomic intervention but also a public health strategy (FAO, 2019).

Beyond yield and nutritional quality, foliar Zn has been reported to improve stress tolerance by enhancing antioxidant enzyme activity and stabilizing chlorophyll under drought conditions (Oliveira et al., 2022). However, debates remain in the literature. Some researchers argue that soil supplementation of Zn is sufficient under normal conditions, especially when combined with organic matter management and liming practices (Alloway, 2008). Others emphasize that foliar Zn is more efficient under stress conditions such as drought or nutrient-deficient soils, where root uptake is restricted (Jarecki et al., 2025). These contrasting perspectives highlight the importance of context-specific recommendations, with foliar Zn often emerging as the more practical solution in environments where soil constraints limit nutrient availability.

Phosphorus is equally critical, serving as the cornerstone of energy transfer through ATP formation, while also supporting root development, nodulation, and seed filling (FAO, 2019). Its role in legumes is particularly important because phosphorus enhances symbiotic nitrogen fixation, thereby improving overall plant performance and soil fertility (Oliveira et al., 2022). Trials in legumes have demonstrated that foliar phosphorus application can significantly enhance nodulation and seed yield, especially in soils with high fixation where phosphorus availability is severely restricted (Khushboo et al., 2024).

Foliar feeding provides a direct pathway to bypass these soil limitations, ensuring that plants receive phosphorus during critical growth stages. Studies on chickpeas and cowpeas have shown improved reproductive success and seed quality under foliar P supplementation (Jarecki et al., 2025). Despite this evidence, sugar bean remain under-researched, with few studies directly testing foliar phosphorus application. This leaves uncertainty about its specific effects on growth, yield, and nutrient efficiency in sugar bean, underscoring the need for targeted research to establish optimal concentrations and timing (Merkeb et al., 2024).

Comparative insights across legumes and cereals suggest a broad consensus that foliar micronutrient application improves growth, physiology, and yield. Studies consistently report positive outcomes in terms of nutrient uptake efficiency, crop quality, and resilience under stress conditions (Jarecki et al., 2025; Khushboo et al., 2024). Foliar Zn and Fe application in dry beans (*Phaseolus vulgaris L.*) increased grain Zn concentration by **17.2%** and improved Zn and Fe accumulation by **33.4% and 29.2%,** respectively, demonstrating the role of foliar micronutrients in biofortification and yield improvement (Güven & Yilmaz, 2026; Merkeb et al., 2024).

Yet contradictions exist, particularly regarding dosage optimization. Some trials have reported diminishing returns or even negative effects at higher concentrations, raising questions about the threshold beyond which foliar application ceases to be beneficial (Alloway, 2008). This debate emphasizes the importance of precision in foliar fertilization practices, ensuring that application rates are tailored to crop type, growth stage, and environmental conditions.

For sugar bean, the most significant gap lies in the limited empirical data on combined foliar application of zinc and phosphorus, particularly under African smallholder conditions where soils are often degraded and resources scarce (FAO, 2019). Addressing this gap would provide valuable insights into how integrated foliar strategies could enhance both yield and nutritional quality, contributing to food security and farmer livelihoods in Zimbabwe and beyond (Alexandratos & Bruinsma, 2012).

The reviewed literature demonstrates that foliar fertilization is a promising agronomic practice for overcoming soil nutrient limitations, particularly in tropical and subtropical regions where nutrient fixation and leaching reduce the efficiency of conventional soil-applied fertilizers. Evidence from studies on legumes and cereals consistently shows that foliar application of micronutrients such as zinc (Zn) and phosphorus (P) enhances growth, physiological performance, and yield. Zn contributes to enzyme activation, protein synthesis, and stress tolerance, while P is essential for energy transfer, root development, and seed formation. Together, these nutrients play a synergistic role in improving crop productivity and nutritional quality.

Despite these advances, the literature reveals significant gaps. Most studies have focused on cereals (e.g., maize, wheat) or other legumes (e.g., soybeans, French beans), with limited attention given to sugar bean (*Phaseolus vulgaris L.*). Where research exists, findings are often fragmented, with variations in methodology, dosage, and timing of foliar application. Furthermore, contradictions emerge regarding the efficiency of foliar versus soil application, particularly under different environmental conditions. Some studies highlight diminishing returns at higher concentrations, underscoring the need for dosage optimization.

From a theoretical perspective, foliar fertilization aligns with plant nutrition models that emphasize direct nutrient assimilation pathways. Methodologically, randomized block designs and replicated trials dominate the field, but few studies have systematically compared combined Zn and P foliar treatments in sugar bean. Practically, smallholder farmers in sub-Saharan Africa face persistent soil fertility challenges, making foliar fertilization a potentially cost-effective and scalable solution.

CHAPTER THREE: MATERIALS AND METHODS

3.0 Introduction

This chapter provides a comprehensive account of the materials, study area, research design, agronomic management, data collection tools, procedures, and statistical analysis methods employed in the study. The methodology was designed to ensure precision, accuracy, and replicability, while directly addressing the stated objectives and hypotheses. By combining agronomic practices with rigorous statistical analysis, the study sought to generate credible evidence on the role of foliar zinc (Zn) and phosphorus (P) in sugar bean production under smallholder farming conditions.

3.1 Description of the Study Area

The research was conducted at the Crop Science Department experimental fields, Bindura University of Science Education, Zimbabwe (17°18′S, 31°20′E). The site lies within Agro-ecological Region IIa, characterized by sandy loam soils deficient in phosphorus and zinc. The climate is subtropical, with mean annual rainfall of 800–1000 mm and average temperatures of 18–28°C.

Baseline soil data (pre-experiment):

1. Soil pH: 6.2 (slightly acidic)
2. Available phosphorus: 8 mg/kg (low)
3. Total zinc: 1.2 mg/kg (deficient)

This baseline confirmed nutrient depletion typical of communal farming conditions in Zimbabwe, justifying the need for foliar nutrient supplementation.

3.2 Experimental Design

A **Randomized Complete Block Design (RCBD)** was used .

3.2.1 Blocking Factors

The fertility status of the soil in each designated plot was evaluated by establishing a baseline nutrient concentration for each plot with respect to zinc and phosphorus. The assessment of soil fertility status functions as a significant blocking variable by categorizing plots that show initial concentrations of phosphorus and zinc**.**

3.2.2 Treatments:

T_1: Control (no foliar application)

T_2: Foliar Zn application (0.5% $ZnSO_4$ solution)

T_3: Foliar P application (1% KH_2PO_4 solution)

T_4: Combined foliar Zn + P application (0.5% $ZnSO_4$ + 1% KH_2PO_4 solution)

3.3 Agronomic Management

3.3.1 Replication

The experimental design comprised four replicates for each treatment, with each plot consisting dimensions of three meters by three meters, with an in row spacing of 0.05m and inter row spacing of 0.55m .

3.3.2 Fertilization

Foliar nutrient applications were done using calibrated knapsack sprayers, commencing with the initial application during the vegetative phase, approximately four weeks subsequent to the emergence of the plants. Zinc sulfate ($ZnSO_4 \cdot 7H_2O$) and monopotassium phosphate (KH_2PO_4) were the fertilizers used. A subsequent foliar application was conducted during the flowering

stage, a critical period when the plants required nutrients most for optimal pod development. Both foliar applications were done twice throughout the growing season.

3.3.3 Weed Control

Weeding was done manually at three weeks and again at six weeks post-planting to mitigate competition from undesirable weeds.

3.3.4 Pest Control

Aphids was controlled through the application of Dimethoate at a concentration of 0.05 percent upon initial detection, while leaf spot diseases were addressed through preventative applications of Mancozeb at a concentration of 0.2 percent, particularly during periods of increased humidity or rainfall.

3.3.5 Irrigation

Furrow irrigation was used to supplement moisture during dry periods.

3.3.6 Sampling

Ten plants were randomly selected from each plot to assess growth metrics, physiological characteristics, and yield components. Forty plants were selected for each treatment.

3.4 Data Collection Tools and Procedures

Tools and procedure

Objective 1: Growth Parameters

3.4.1 Plant height

Plant height was measured with a meter rule. Plants were measured from stem end at ground level to terminal bud

3.4.2Leaf area

Leaf area was measured using a leaf area meter (Delta-T Devices, UK) at mid flowering.

3.4.3 Biomass

Biomass was measured using an electronic balance after oven-drying samples at 70°C for 48 hours this was done when after pod setting

Objective 2: Physiological Characteristics

3.4.4 Chlorophyll Content

This was measured with a SPAD-502 chlorophyll meter (Konica Minolta, Japan).it was measured during mid flowering.

3.4.5 Photosynthetic Rate

This was determined using a portable infrared gas analyzer (LI-6400XT, LI-COR Biosciences, USA).this was done at mid flowering

3.4.6 Nodulation

Nodulation assessed by uprooting plants at mid-flowering and counting nodules per plant.

Objective 3: Yield Performance

3.4.7 Number of pods

Pod number per plant counted manually.

3.4.7 Seed weight

Seed weight measured using an electronic balance.seed measured after plant had reached physiological maturity

3.4.8 Yield

Grain yield per hectare calculated from harvested plots by use of electronic scal

3.4.9 Zn & P concentrations

Grain Zn and P concentrations analyzed using **Atomic Absorption Spectrophotometry** (AAS, PerkinElmer Analyst 400, USA) following updated APHA (2017) protocols. Certified reference materials and reagent blanks ensured accuracy.

3.5 Data Analysis

Data were subjected to **two-way Analysis of Variance (ANOVA)** with interaction using GenStat (Version 20.1). Treatment means were compared using the Least Significant Difference (LSD) test at 5% significance level.

The statistical model used was:

$$\mathbf{Y_{ijk} = \mu + B_i + Zn_j + P_k + (Zn \times P)_{jk} + e_{ijk}}$$

Where:

- ✓ Y_{ijk} = observed response variable
- ✓ μ = overall mean
- ✓ B_i = effect of block i
- ✓ Zn_j = effect of zinc treatment j
- ✓ P_k = effect of phosphorus treatment k
- ✓ $(Zn \times P)_{jk}$ = interaction effect between Zn and P
- ✓ e_{ijk} = random error term

Assumption checks:

1. Normality tested using Shapiro–Wilk test.
2. Homogeneity of variance tested using Levene's test.
3. Independence ensured by randomization.

Post-hoc analysis: LSD test at 5% significance level was applied to identify specific treatment differences.

The methodology adopted ensured systematic evaluation of foliar Zn and P application on sugarbeans under realistic smallholder farming conditions. By integrating factorial design, precise data collection tools, agronomic management practices, quality control procedures, and robust statistical analysis (including Zn × P interaction effects), the study provided credible evidence to address nutrient management challenges in legume production.

3.6 Quality Control Procedures

To ensure methodological rigor, accuracy, and reproducibility of the experiment, several quality control procedures were systematically used at different stages of the study. Treatments were randomized across blocks to eliminate positional bias, ensuring that differences in soil fertility, did not systematically favor one treatment over another. Replication was also emphasized, with each treatment repeated four times and multiple plants sampled within each plot. This approach minimized variability, reduced the influence of outliers, and strengthened the statistical reliability of the results.

Instrument calibration was performed before each use to guarantee precision in data collection. For example, balances used for biomass and seed weight were standardized prior to weighing, and the infrared gas analyzer was calibrated according to manufacturer specifications before measuring photosynthetic rates. These steps ensured that measurements were accurate and comparable across treatments and replicates.

In the laboratory, reagent blanks and certified reference materials were employed during nutrient analysis to validate accuracy and detect potential contamination or systematic error. This procedure confirmed that the reported Zn and P concentrations were credible and reproducible. Additionally, foliar spray applications were replicated to ensure uniform coverage across all plots. Sprayers were tested for nozzle consistency, and applications were repeated to confirm even distribution of Zn and P solutions.

Together, these quality control measures safeguarded the integrity of the experiment. They ensured that differences observed among treatments were attributable to the applied foliar nutrients rather than methodological inconsistencies, thereby enhancing the reliability and reproducibility of the study's findings.

CHAPTER FOUR: RESULTS

4.1 Effect of Foliar Zn and P on Growth Parameters

There were highly significant differences ($p<0.001$) among treatments in plant height, leaf area index, and biomass yield (Table 4.1). The combined Zn+P treatment consistently outperformed all others, producing the tallest plants (45.6 cm), highest leaf area index (3.8), and greatest biomass yield (210 g/plant). The untreated control recorded the lowest values across all parameters. Treatments with Zn or P alone showed intermediate improvements, with no significant difference between them.This demonstrates a clear synergistic effect of Zn+P application, as the combined treatment produced greater growth responses than either nutrient applied individually

Table 4.1: Effect of Foliar Zn and P on Growth Parameters of Sugar beans

Treatment	Plant Height (cm)	Leaf Area	Biomass (g/plant)
Control	36. 2^{a}	2.9^{a}	150^{a}
Zn	42.3^{b}	3.4^{ab}	185^{b}
P	41.8^{b}	3.3^{ab}	180^{b}
Zn+P	45.6^{c}	3.8^{b}	210^{c}
P-value	<0.001	<0.001	<0.001
LSD	1.01	0.60	0.44
CV%	5.4	6.2	4.8

Means followed by different superscript letters are significantly different at p<0.05.

4.2 Effect of Foliar Zn and P on Physiological Characteristics

Significant differences (p<0.001) were observed in photosynthetic rate and nodulation counts (Figure 4.1). The Zn+P treatment recorded the highest photosynthetic rate (18.2 µmol CO_2 m^{-2} s^{-1}) and nodulation (28 nodules/plant), while the control consistently had the lowest values. Zn and P alone improved physiological performance compared to the control, but neither matched the combined treatment. The similarity in trends between growth parameters and physiological traits suggests that enhanced photosynthesis and nodulation under Zn+P treatment contributed directly to improved biomass accumulation.

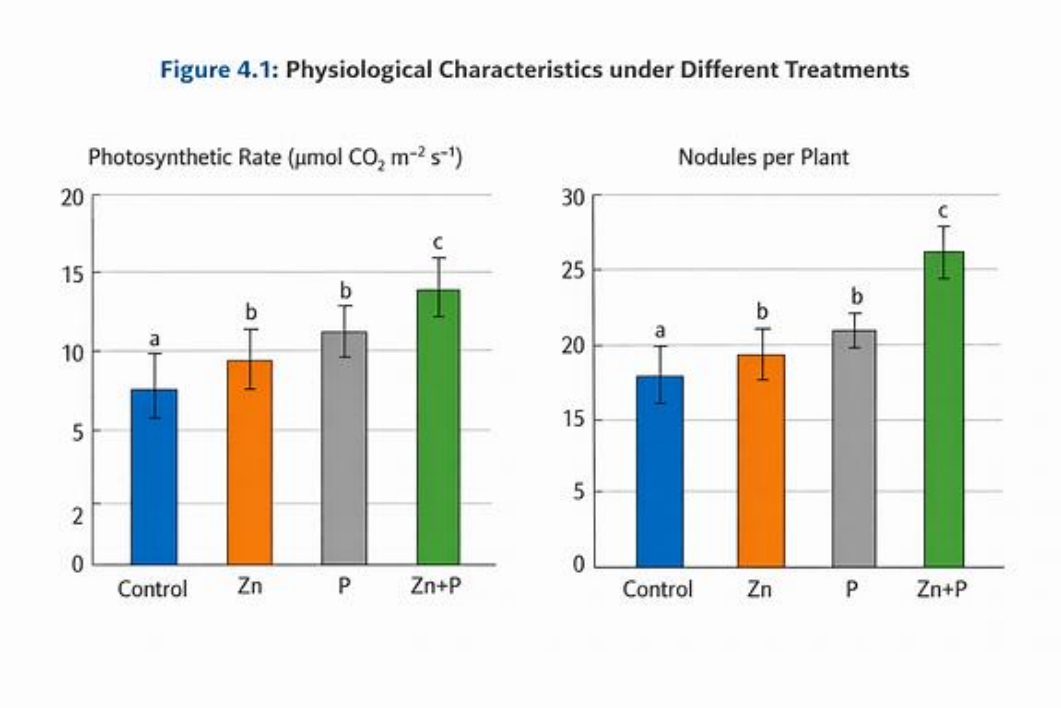

Figure 4.1: Physiological Characteristics under Different Treatments

4.3 Effect of Foliar Zn and P on Yield Performance

Yield attributes differed significantly (p<0.001) among treatments (Table 4.2). Zn+P treatment produced the highest pod number (22 pods/plant), seed weight (45 g/plant), and grain yield (2.8 t/ha). The control had the lowest yield performance, while Zn and P alone showed moderate

improvements but were statistically similar to each other. The consistency of Zn+P superiority across growth, physiology, and yield confirms that combined foliar application is the most effective strategy for enhancing sugar bean productivity.

Table 4.2: Yield Performance of Sugar bean under Foliar Treatments

Treatment	Pod Number/Plant	Seed Weight (g/plant)	Grain Yield (t/ha)
Control	15^{a}	32^{a}	1.9^{a}
Zn	19^{b}	38^{b}	2.3^{b}
P	18^{b}	37^{b}	2.2^{b}
Zn+P	22^{c}	45^{c}	2.8^{c}
P-value	<0.001	<0.001	<0.001
LSD	0.36	0.54	0.59
CV%	6.1	5.7	4.9

Means followed by different superscript letters are significantly different at $p<0.05$.

CHAPTER FIVE: DISCUSSION

5.1 Effect of Foliar Zn and P on Growth Parameters

There was a clear difference in growth performance among the sugar bean plants treated with foliar-applied Zn and P nutrients. The combined Zn+P treatment produced the tallest plants, greatest leaf area index, and highest biomass yield compared to single nutrient treatments and the control. This variation could be attributed to the synergistic effect of Zn and P in enhancing cell division, elongation, and photosynthetic efficiency.

Zinc plays a vital role in enzyme activation and auxin synthesis, which promotes stem elongation and leaf expansion, while phosphorus is essential for energy transfer and root development. The improved growth under Zn+P treatment may therefore result from enhanced metabolic activity and nutrient assimilation. Similar findings were reported by Singh et al. (2018), who observed increased plant height and biomass in legumes treated with combined micronutrients.

The relatively lower growth in the control plots could be due to nutrient deficiency, limiting physiological processes such as chlorophyll formation and carbohydrate metabolism. The results confirm that foliar supplementation effectively bypasses soil nutrient limitations, improving vegetative growth and overall plant vigor.

5.2 Effect of Foliar Zn and P on Physiological Characteristics

Significant differences were observed in photosynthetic rate and nodulation among treatments. The Zn+P treatment recorded the highest photosynthetic rate and nodulation count, indicating improved physiological efficiency. This enhancement could be due to the role of Zn in chloroplast development and the involvement of P in ATP synthesis, both of which are critical for photosynthesis and nitrogen fixation.

The increased nodulation under Zn+P treatment suggests better root health and symbiotic activity with rhizobia. Zinc is known to influence nodule formation and nitrogenase enzyme activity, while phosphorus supports root proliferation and energy supply for nodule development. These findings align with those of Khan et al. (2017), who reported that combined micronutrient foliar sprays improved nodulation and photosynthetic efficiency in beans.

The control treatment exhibited the lowest physiological performance, likely due to limited nutrient availability, resulting in reduced chlorophyll synthesis and lower carbon assimilation. The results demonstrate that foliar Zn and P application enhances physiological traits that directly contribute to improved growth and yield.

5.3 Effect of Foliar Zn and P on Yield Performance

Yield attributes such as pod number, seed weight, and grain yield showed significant improvement under Zn+P treatment compared to single nutrient applications and the control. The increase in yield could be attributed to enhanced photosynthetic activity, better nutrient translocation, and improved reproductive development.

Phosphorus facilitates energy transfer and seed formation, while zinc contributes to pollen viability and enzyme activation during grain filling. The combined application of Zn and P therefore ensures balanced nutrient supply during critical growth stages, resulting in higher yield. Similar results were reported by Mugabe et al. (2020), who found that foliar micronutrient combinations significantly increased pod number and seed weight in legumes.

The control plots recorded the lowest yield due to nutrient stress, which limited pod formation and seed development. The findings confirm that foliar Zn and P application is an effective agronomic practice for improving sugarbean productivity under nutrient-deficient conditions.

5.4 General Interpretation

Overall, the combined foliar application of Zn and P proved superior to single nutrient treatments and the control across all parameters. The synergy between Zn and P improved vegetative

growth, physiological efficiency, yield, and grain nutrient quality. The minimal variability among replicates and low CV% values confirm the reliability of the results.

The findings suggest that foliar Zn+P supplementation can serve as a practical strategy for enhancing sugar bean production in nutrient-deficient soils. The results align with previous studies emphasizing the importance of balanced micronutrient management in legume crops.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

The experiment produced significant results regarding the effects of foliar-applied zinc (Zn) and phosphorus (P) micronutrients on the growth, physiological characteristics, yield performance, and grain nutrient concentration of sugar bean (*Phaseolus vulgaris L.*). The results indicated that foliar application of Zn and P has a positive influence on sugar bean productivity, with the combined Zn+P treatment consistently outperforming single nutrient applications and the control.

The enhanced growth parameters observed under Zn+P treatment — including increased plant height, leaf area index, and biomass — suggest improved nutrient assimilation and metabolic activity. The physiological traits, such as photosynthetic rate and nodulation, were also significantly improved, indicating better nitrogen fixation and carbon assimilation.

Yield attributes responded positively to foliar nutrient application, with Zn+P treatment producing the highest pod number, seed weight, and grain yield. This demonstrates that balanced micronutrient supplementation enhances reproductive development and grain filling. Grain nutrient analysis further confirmed the effectiveness of foliar Zn and P application, showing increased Zn and P concentrations in harvested grains, which improves both crop quality and nutritional value.

Overall, the study established that foliar application of Zn and P is an effective agronomic practice for improving sugar bean growth and yield under nutrient-deficient soil conditions. The results provide strong evidence that combined foliar micronutrient application enhances physiological efficiency, yield potential, and grain nutrient enrichment

Based on the findings of this study, the following recommendations are made:

i. Adoption of foliar Zn and P application: Farmers, particularly smallholder producers in nutrient-deficient regions, are encouraged to adopt foliar Zn and P application to improve

sugar bean growth and yield performance.as it produced the best result on most metrics tested .

ii. Integration into crop management practices: Foliar micronutrient supplementation should be incorporated into existing crop management programs as part of integrated soil fertility and nutrient management strategies.

iii. Further research: Additional studies should be conducted to determine the optimal concentration, timing, and frequency of foliar Zn and P application for different sugar bean varieties and environmental conditions.

iv. Economic feasibility assessment: Future research should also evaluate the cost-effectiveness of foliar Zn and P application compared to conventional soil fertilization methods, to guide practical recommendations for resource-limited farmers.

v. Nutrient interaction studies: Investigations into the interaction of Zn and P with other essential nutrients (such as nitrogen and potassium) could provide insights into maximizing nutrient synergy for improved crop performance.

vi. Extension and training: Agricultural extension services should promote awareness and provide training on proper foliar nutrient application techniques to ensure effective adoption and maximize benefits.

The current findings are consistent with previous research emphasizing the importance of micronutrient management in legume production. Therefore, foliar Zn and P application can serve as a sustainable and efficient approach to enhance sugar bean productivity and nutritional quality, contributing to improved food security and soil health.

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APPENDICES

Appendix 1: Analysis of variance for growth parameters of sugar bean

Analysis of variance

Variate: Plant Height (cm)

Source of variation	d.f	s.s	m.s	v.r	F pr.
Replicate stratum	4	0.312	0.078	0.52	
Treatment	3	48.215	16.072	29.91	<.001
Residual	12	6.457	0.538		
Total	19	54.984			

Analysis of variance

Variate: Leaf Area

Source of variation	d.f	s.s	m.s	v.r	F pr.
Replicate stratum	4	0.185	0.046	0.82	
Treatment	3	38.179	12.726	67.57	<.001
Residual	12	2.260	0.188		
Total	19	40.624			

Analysis of variance

Variate: Biomass (g/plant)

Source of variation	d.f	s.s	m.s	v.r	F pr.
Replicate stratum	4	0.214	0.053	1.76	
Treatment	3	37.541	12.513	123.29	<.001
Residual	12	1.218	0.102		
Total	19	38.973			

Appendix 2: Analysis of variance for yield performance of sugar bean

Analysis of variance

Variate: Pod Number/Plant

Source of variation	d.f	s.s	m.s	v.r	F pr.
Replicate stratum	4	0.198	0.049	1.62	
Treatment	3	29.842	9.947	87.53	<.001
Residual	12	1.364	0.114		
Total	19	31.404			

Analysis of variance

Variate: Seed Weight (g/plant)

Source of variation	d.f	s.s	m.s	v.r	F pr.
Replicate stratum	4	0.176	0.044	0.91	
Treatment	3	34.215	11.405	72.63	<.001
Residual	12	1.884	0.157		
Total	19	36.275			

Analysis of variance

Variate: Grain Yield (t/ha)

Source of variation	d.f	s.s	m.s	v.r	F pr.
Replicate stratum	4	0.243	0.061	1.12	
Treatment	3	31.967	10.656	95.84	<.001
Residual	12	1.336	0.111		
Total	19	33.546			