

## Research Article

# Impact of Foliar Application of Zinc and Magnesium Amino-chelate on Bean Physiology and Productivity in Ghana

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Foliar application of fertilizers can guarantee nutrient availability to beans, leading to higher yield and seed quality. Different approaches including glycine have been used to improve mineral nutrient status of plants toward safer products and improved human health. However, limited research has been undertaken to understand the response of beans to amino Zn and Mg foliar fertilizer application in Ghana. This study was conducted to investigate the effect of zinc, magnesium, and combined zinc and magnesium foliar fertilizer application on two improved common bean (*Phaseolus vulgaris* L.) varieties locally referred to as *Adoye* and *Nsroma* in the forest (Fumesua) and forest-savannah transition (Akumadan) agro-ecological zones of Ghana during the 2018 and 2019 cropping seasons. The treatments were arranged in split-plot design with the two improved common bean varieties as the main plot, and foliar fertilizer options (zinc, 200 g/ha; magnesium, 224 g/ha; combined zinc and magnesium, 100 g/ha Zn and 112 g/ha Mg) and water spray (control) as the subplot treatments. The zinc and combined zinc and magnesium treatments had similar and significantly ( $P \leq 0.05$ ) higher plant height of 37.1 cm and 38.7 cm compared to the control and magnesium treatments. The results also showed that chlorophyll content was approximately 15.6% higher in plants treated with zinc plus magnesium compared to the other treatments. Similarly, stomatal conductance was significantly ( $P \leq 0.05$ ) increased by 35.6% with zinc plus magnesium treatment relative to the other treatments. The improved chlorophyll content and stomatal conductance in those treatments resulted in ~55.3–80.6% increase in crop biomass and seed yield. Crop performance parameters such as plant height, canopy spread, and chlorophyll content were significantly higher ( $P \leq 0.05$ ) at Akumadan, resulting in a greater seed yield of 1486.2 kg/ha compared to 1365.3 kg/ha at Fumesua. Combined application of zinc and magnesium appears to be a potential soil improvement strategy for common bean production in tropical soil environment of Ghana.

## 1. Introduction

Innovative plant nutrition strategies are required to address the multiple nutrient deficiencies that limit food production [1–3]. Soil degradation is a major hindrance to the optimum performance of agriculture production in Sub-Saharan Africa (SSA). Inadequate application of nutrients to agricultural soils, extensive soil erosion, bush burning, and other factors have resulted in about 65% soil degradation [4]. Soil degradation is a major contributing factor to low agricultural productivity and rising malnutrition in SSA, including Ghana [5]. The low soil fertility in SSA is compounded by the

low use of fertilizers in Africa (about 8 kg/ha), which is below the amount needed to compensate for lost or harvested nutrients [6]. Within this context, identifying and implementing innovative nutrient management strategies aimed at enhancing the resilience of common bean agro-ecosystems to nutrient stress which is a significant priority for sustainable bean production. Application of chemical fertilizers, in particular nitrogen (N) fertilizers, has had significant effect on growth and yield improvement in many agricultural crops [7]. However, mineral fertilization of crops has had negative effect on plant, human, and ecosystem health. Therefore, innovative strategies and

techniques are required in fertilizer formulation and application to achieve higher yields whilst maintaining or improving soil fertility. These strategies must also be friendly to human and environmental health [8].

The nutrient requirements of many crops depend on the stage of the crop [3]. The early vegetative stage, flowering, and pod and grain filling are stages with higher mineral nutrients requirement [3]. Crop yield is largely influenced by the availability of nutrients and water at those stages [9]. In many cases, these growth stages coincide with periods of inadequate nutrient supply from the soil mainly due to climatic factors [10]. Providing nutrients through foliar fertilization is very important for crop productivity during those periods of intensive nutrient demand [9, 11]. Due to the short growing cycle and high nutritional demand of common beans, the plant is sensitive to adverse soil and climate conditions [11]. Foliar fertilization offers an opportunity to meet an urgent need for nutrients within a short period of time [12]. In addition, foliar fertilization can serve as a preventive and curative measure to curb nutrient deficiency. There is a great advantage in foliar application of crops compared to soil application, since the nutrients are applied directly, allowing for specific and rapid response [13]. However, all plant species may not have proper responses to foliar feeding [10], and it is generally considered as complementary to soil fertilizer application. Recently, amino acid-based fertilizers, namely, amino chelates, are formulated for foliar feeding [1, 2], while their soil application also results in higher efficiency than general chemical fertilizers [10, 14] with no potential environmental pollution. Application of amino chelate fertilizers in soil or particularly in foliar spray has generally fewer deteriorating effects on soil salinity or on unbalancing soil nutrients [1, 3].

Common bean (*Phaseolus vulgaris* L.) remains a highly important crop for nutritional food security in Africa. Beans are a key source of protein, calories, vitamins, and minerals. The nutritional advantage of common beans can be further enhanced through biofortification. As they are fast growing and early maturing, they can be considered a climate-smart crop. Further, common bean has a broad temperature tolerance, making it an excellent climate-smart option for future agri-food systems. Although the production of beans appears to be gaining interest in Ghana, the actual yield from farmers' plots is low at 0.8 tons/ha relative to the potential yield of 2 tons/ha [15] and the situation has not changed. This is attributed to low soil fertility, particularly micronutrient deficiency and pest and disease infestation. Worldwide, it is estimated that about 50% of the soils used for grain production are deficient in plant-available Zn [16]. Also in Ghana, a review of the relevant agronomic literature shows high levels of micronutrient deficiencies in Ghanaian soils [17]. Zinc, iron, and magnesium are among the most deficient nutrients in Ghanaian soils [18] resulting in low crop productivity. Intensive farming and the continued removal of crop residues and low and unbalanced application of fertilizers are important in low soil fertility status and hindered plant production [14].

In several studies, it has been shown that bean growth and yield characteristics can be improved via foliar application of chemical and organic fertilizers [14]. Application of zinc is required for chlorophyll production, pollen function, fertilization, and germination [16]. Zinc has been noted to play an important role in plant metabolism such as gene expression, protein synthesis, carbohydrate metabolism, photosynthesis, and defense against plant disease [19]. Magnesium also plays essential role in photosynthesis, net assimilation, and relative growth and yield [20]. Carbohydrate, protein, and chlorophyll formation is significantly reduced in magnesium and zinc-deficient plants [20]. Therefore, a rapid and continuous supply of zinc and magnesium is needed for optimum growth and maximum yield of crops. This is particularly important in the case of common bean, since the plant is characterized by a small root system [21], nutrients should therefore be readily available to the plants for maximum production [22]. This study hypothesized that providing adequate foliar supply of zinc (Zn) and magnesium (Mg) amino chelate to common bean (*Phaseolus vulgaris* L.) would increase the biomass and seed yield of the crop. To achieve this, we investigated the influence of these nutrients on the crop's photosynthetic activity, biomass, and seed yield.

## 2. Materials and Methods

**2.1. Experimental Site.** The study was conducted during the 2018 and 2019 cropping seasons at the CSIR-Crops Research Institute experimental field at Fumesua (6°45'00.58' N; 1°31'51.28' W) in the semideciduous forest zone and Akumadan (7.3960° N, 1.9539° W) in the forest-savannah transition zone. The soil types in Fumesua and Akumadan are classified as Ferric Acrisol and Ferric Lixisol [23]. The top soils consist of grayish-brown sandy loam and dark brown to brown fine sandy loam soils at Fumesua and Akumadan, respectively [23, 24]. The study site is characterized by low soil fertility and poor moisture retention capacity. The climate is tropical, characterized by two wet periods within the rainy season, a major one between April and July, and a minor one between September and November. On average, the minimum and maximum temperatures range from 21 to 32°C. Table 1 presents initial soil characteristics of the study site. The soil has relatively low fertility [25] and it is the dominant soil type in the study areas that is under cropping. The cropping system in the research area is associated with continuous cropping under conventional tillage. Land preparation in the research area is also characterized by complete removal of crop residue. The crop before the start of the experiment was maize (*Zea mays* L.), which has been cultivated for two years. Seasonal temperature recorded during the course of the study was 27.65°C and 29.43°C in Fumesua and Akumadan in 2018 and 2019, respectively. Seasonal rainfall recorded during the course of the study was 681.8 and 660.2 mm in Fumesua and 627.6 and 593.3 mm in Akumadan in 2018 and 2019, respectively. Rainfall data were obtained from the Ghana Meteorological Agency.

TABLE 1: Initial soil chemical properties at the experimental sites.

Composition	Fumesua		Akumadan		Landon (1991) interpretation	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm	High	low
<i>Chemical characteristics</i>						
pH (H <sub>2</sub> O) (1 : 2:5)	4.53	4.14	4.81	4.35	>6.5	<5.8
Organic carbon (%)	1.55	1.31	1.83	1.67	>10.0	<4.0
Available phosphorus (mg/kg)	16.32	14.22	17.28	15.77	>50.0	<15.0
Total N (%)	0.15	0.13	6.23	5.33	>0.5	<0.2
<i>Exchangeable bases (cmol/kg)</i>						
Ca	1.8	1.71	2.67	2.14	>10.0	<4.0
Mg	1.27	1.21	1.27	1.33	>4.0	<0.5
K	0.12	0.10	0.71	0.21	>0.6	<0.2
Na	0.05	0.06	0.41	0.14	>1.0	<1.0

**2.2. Experimental Design and Treatment Application.** The study was conducted using a split-plot design replicated three times with common bean varieties released by the CSIR-Crops Research Institute as the main plots (*Adoye* and *Nsroma*). The subplots had zinc (200 g/ha) and magnesium (224 g/ha) and combined zinc and magnesium (100 g/ha Zn and 112 g/ha Mg) foliar fertilizers and a control (water spray). The concentration of the zinc and magnesium was considered as 6 : 1000. The zinc and magnesium fertilizers were sourced from Tecnokel and the products were liquid fertilized for foliar application. The guaranteed analyses of Tecnokel Amino Mg are magnesium oxide (MgO) water soluble (5.0% w/w) and “L” amino acids (6.0% w/w) and ethylenediamine tetracetic acid (EDTA) chelated. The guaranteed analyses of Tecnokel Amino Zn are zinc (Zn) water soluble 8.0% w/w and “L” amino acids 6.0% w/w and ethylenediamine tetracetic acid (EDTA) chelated. The zinc and magnesium foliar fertilizers were applied at the vegetative (V4: 4<sup>th</sup> trifoliolate unfolded at node 6 + branching) and flowering (R1: one open flower (early flower) on the plant) stages using a knapsack sprayer (15 litres). Common bean was planted at 20 cm intrarows and 50 cm interrows and the distance between treatments/plots and replicates was 1 and 1.5 m, respectively. The plot’s dimensions were 3 m by 4 m and harvest area was 1.5 m by 3 m. All treatments received a blanket application of P at 14 days after planting at the rate of 75 kg N/ha.

**2.3. Plant Height and Canopy Spread.** Ten (10) plants from the two central rows of each plot were randomly selected and tagged for height measurement at physiological maturity (R7: one pod at mature color). The average height of each plant was then calculated for each plot. Canopy spread was determined by measuring the widest point and the narrowest point of the canopy. The two values were added together and divided by two to calculate the average canopy spread.

**2.4. Chlorophyll Content and Stomatal Conductance.** Chlorophyll content (Chl) was measured on 10 fully expanded upper leaves exposed to solar radiation per plot/treatment using a portable chlorophyll meter (Model SPAD-502-PLUS, Konica Minolta, USA). Measurements were conducted at the vegetative (Vn: n<sup>th</sup> trifoliolate leaf unfolded

at node) and flowering stages (R2: 50% open flowers) using the chlorophyll meter for nondestructive determination of chlorophyll content. Concurrent with chlorophyll content, stomatal conductance (Gs) was measured on cloud-free days under natural light using a porometer (Model AP4, Delta-T Devices, Cambridge, UK) at the same growth stage. Measurements were conducted on middle portions of three fully developed leaves selected from innerrows per treatment/plot exposed to full sunlight and averaged.

**2.5. Biomass, Seed, and Pod Yield at Harvest.** The biomass was determined by cutting all the plants at whole net plot at ground level from each plot at harvest maturity (RH: 80% of pods at mature color). Harvested plant materials were put in large brown envelopes and oven-dried at 105°C for 45 min and subsequently dried to constant weight at 85°C [34]. At the harvest physiological maturity, bean plants were manually harvested from the two center rows of each plot. Seeds were threshed, weighed, and converted to seed yield at 12% moisture content and reported in kilograms per hectare. The total number of seeds per pod was recorded from five randomly selected plants at harvest and averaged for each treatment.

**2.6. Statistical Analysis.** Statistical analysis was carried out by using the univariate model of SPSS 22.0 (IBM Corp., Chicago, IL, USA) at a probability level of 5% ( $P \leq 0.05$ ). Differences between means were determined using Tukey’s honestly significant difference (HSD) test. The data analyzed were pooled across means for bivariate correlation analysis (two-tailed) using Pearson’s correlation coefficient.

### 3. Results and Discussion

**3.1. Plant Height and Canopy Spread.** No significant treatment interaction effect ( $P \leq 0.05$ ) was observed on plant height (Table 2), but nutrients and location independently influenced plant height. The highest plant height was consistently observed in plants that received foliar fertilization (36.6 cm) compared to unfertilized plants (25.5 cm), but some of the differences were not significant ( $P \leq 0.05$ ) (Figures 1(a) and 1(b)). Combined application of zinc and

TABLE 2: Analysis of variance for treatment effects and their interactions on plant height, canopy spread, chlorophyll content, and stomatal conductance.

Source of variation	Plant height	Canopy spread	Chlorophyll content		Stomatal conductance	
			Vegetative	Flowering	Vegetative	Flowering
Variety	ns	*	ns	ns	ns	ns
Nutrient	*	**	*	*	*	**
Location	*	**	*	*	*	**
Season	ns	ns	ns	ns	ns	ns
Variety × nutrient	ns	ns	ns	ns	ns	ns
Variety × location	ns	**	ns	ns	ns	ns
Variety × season	ns	ns	ns	ns	ns	ns
Nutrient × location	ns	*	ns	ns	ns	ns
Nutrient × season	ns	ns	ns	ns	ns	ns
Location × season	ns	ns	ns	ns	ns	ns

\*, \*\* indicate significant difference at  $P < 0.05$  and  $P < 0.01$ , respectively. ns indicates no significant difference at  $P < 0.05$ .

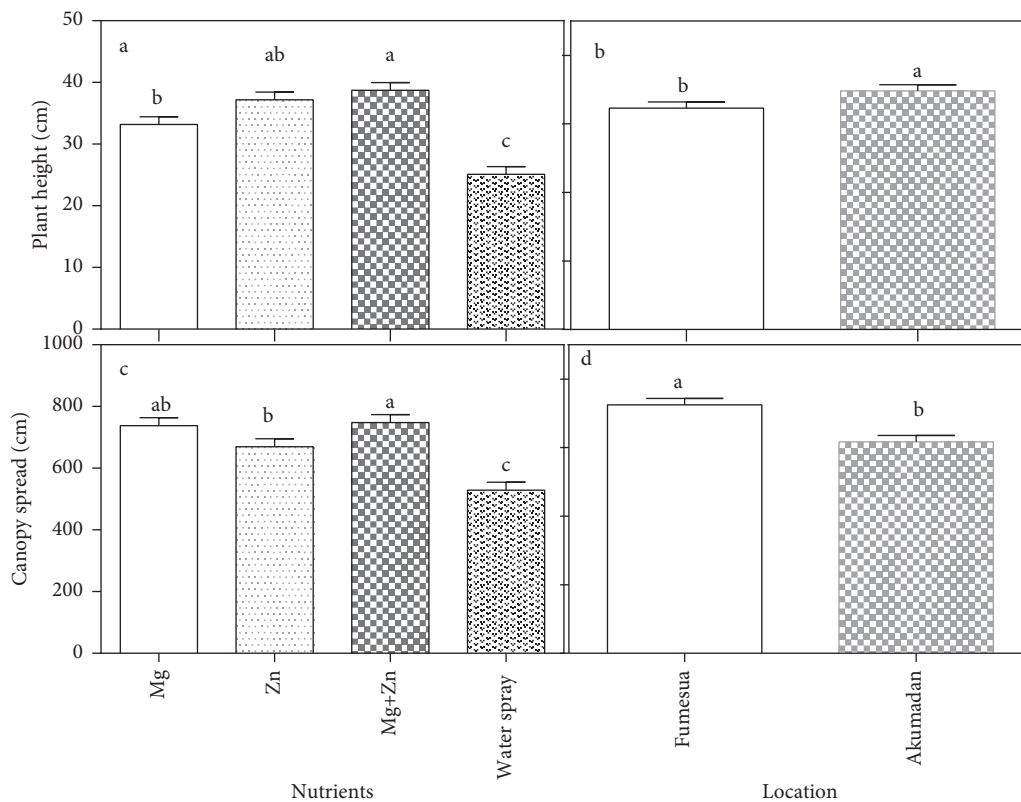


FIGURE 1: Effect of treatment on plant height and canopy spread. Bars with different letters in the figure are statistically different at  $P < 0.05$ . Error bars represent the standard error of means. Means comparison was done using Tukey HSD (honestly significant difference) ( $P < 0.05$ ).

magnesium foliar fertilizer significantly increased plant height by 16.72 and 54.2% compared to magnesium and water spray (control), respectively (Figure 1(a)). With respect to location, plant height was significantly increased by 8.5% at Akumadan compared to Fumesua (Figure 1(b)). Variety and location interactively affected canopy spread at  $P \leq 0.05$  (Table 2). The largest canopy spread was observed at Fumesua compared with Akumadan (Figure 2(d)). Soil fertility is fundamental in determining the productivity of a farming system; its management is important in contributing to agricultural sustainability. Crop growth, as shown by plant height and canopy spread, is influenced by radiation that is intercepted by the crop and the crop's ability to

convert that radiation into biomass. In this research, plant height and canopy spread increased with the application of zinc and magnesium foliar fertilizers, and the largest increase was observed when zinc and magnesium were applied together. According to [26], supplying a combination of zinc and magnesium to beans increased growth relative to sole application of either. The increase in plant height and canopy spread resulting from such treatment might be due to its positive influence on plant growth and dry matter partitioning [27]. Also, zinc and magnesium elements play an important role in cell division and cell lengthening which could also be responsible for the increase in plant height. Teixeira et al. [28] reported that foliar application of Zn and

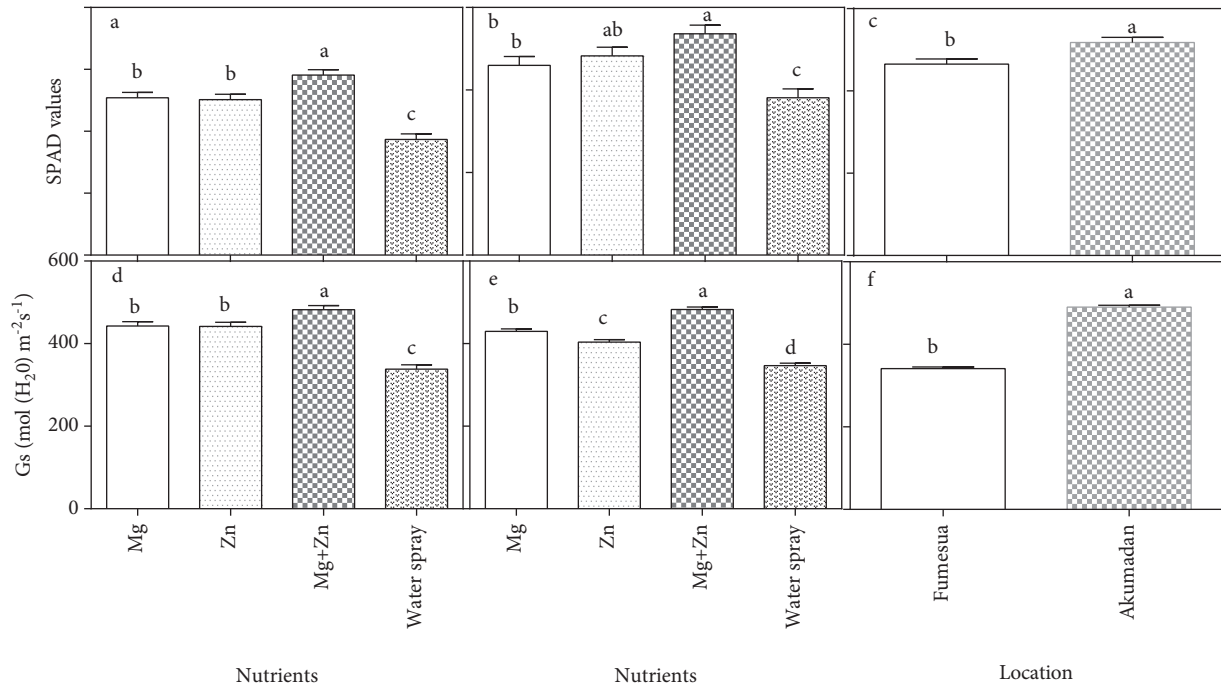


FIGURE 2: Impact of treatment on chlorophyll content at vegetative (a) and flowering (b) stages and stomatal conductance at vegetative (d) and flowering (e) stages at different locations. Bars with different letters in the figure are statistically different at  $P < 0.05$ . Error bars represent the standard error of means. Means comparison was done using Tukey HSD (honestly significant difference) ( $P < 0.05$ ).

Mg increased plant height in common bean due to its role in cell division and lengthening. The beneficial effect of the Zn and Mg amino chelates on the growth traits can also be due to their higher uptake and translocation efficiency rates [1, 14]. Plants can have higher nutrient uptake and efficiency by foliar feeding than soil application. The stimulatory effect of amino acids on plant growth has been also reported [29]. This finding is significant since an increased crop canopy influences the microenvironment of the crop, and this has a significant impact on the photosynthetic capacity and productivity [30, 31].

**3.2. Chlorophyll Content and Stomatal Conductance.** Combined application of zinc and magnesium had the highest chlorophyll content, ranging from 26.8 to 29.1 (Figures 2(a) and 2(b)). On average, combined application of zinc and magnesium increased chlorophyll content by 11.3, 13.9, and 21.5% compared to sole application of magnesium, zinc, and water spray, respectively (Figures 2(a) and 2(b)). Significant differences were also observed, but at a lesser magnitude, when zinc and magnesium foliar fertilizers were applied separately compared with the control. The chlorophyll content at Akumadan was significantly increased by 6.5% compared with Fumesua (Figure 2(c)). Stomatal conductance ( $G_s$ ) at both vegetative and flowering stages was significantly affected by nutrients and location (Table 2). At both measurement periods, no significant interaction was observed between treatments. On average, the highest  $G_s$  ( $482.86 \text{ mol} \cdot (\text{H}_2\text{O}) \text{ m}^{-2} \cdot \text{s}^{-1}$  and  $482.17 \text{ mol} \cdot (\text{H}_2\text{O}) \text{ m}^{-2} \cdot \text{s}^{-1}$ ) was under combined Zn and Mg application, while the lowest  $G_s$  ( $338.291 \text{ mol} \cdot (\text{H}_2\text{O}) \text{ m}^{-2} \cdot \text{s}^{-1}$  and

$346.86 \text{ mol} \cdot (\text{H}_2\text{O}) \text{ m}^{-2} \cdot \text{s}^{-1}$ ) was observed under water spray (control) (Figures 2(d) and 2(e)). Significantly higher ( $P \leq 0.05$ ) stomatal conductance values were recorded at Akumadan compared with Fumesua on the different sampling occasions (Figure 2(f)). The results show that combined application of magnesium and zinc had higher values of stomatal conductance compared to the other treatments. This shows the potential of this treatment to increase the photosynthetic capacity of crops. Our results show that stomatal conductance increased in response to the level of nutrients applied to the crop, and this supports findings of a previous study showing that stomatal conductance was reduced under suboptimal nutrient supply conditions [32]. Stomatal conductance in crops is largely influenced by nutrient supply, soil moisture content, and the microenvironment created by shading [33, 34]. The findings of this study suggest that combined application of zinc and magnesium fertilizer could increase the potential of common bean to counteract nutrient deficits that may occur during the critical growth stages of the crop. The results imply that foliar fertilization for bean nutrient management needs to be encouraged. The leaf chlorophyll content is positively correlated with the level of greenness, which is an indicator of nitrogen concentration in the leaf [35, 36]. In this investigation, the maximum leaf chlorophyll content was observed at the flowering stage, and analysis of variance showed significant differences only for nutrients in most cases. This result implies that the highest nutrient uptake occurred at flowering. This finding is significant, since the chlorophyll content of leaves is an important parameter of plant photosynthetic activity [37, 38]. This is more important because, irrespective of the fact that Zn and Mg are involved in the

TABLE 3: Analysis of variance for treatment effects and their interactions on number of pods per plant, number of seeds per pod, biomass yield, and seed yield.

Source of variation	No. of pods/plant	No. of seeds/pod	Biomass yield	Seed yield
Variety	ns	*	ns	*
Nutrient	**	*	**	**
Location	ns	ns	ns	**
Season	ns	ns	ns	ns
Variety × nutrient	*	ns	ns	ns
Variety × location	ns	ns	ns	ns
Variety × season	ns	ns	ns	*
Nutrient × location	ns	*	*	ns
Nutrient × season	ns	ns	ns	ns
Location × season	ns	ns	ns	ns

\*, \*\* indicate significant difference at  $P < 0.05$  and  $P < 0.01$ , respectively. ns indicates no significant difference at  $P < 0.05$ .

synthesis of stomatal conductance and chlorophyll molecules, there is limited research relating to this trait on common beans [39]. With respect to common beans, most studies that relate stomatal conductance and chlorophyll contents involve foliar concentrations of N [40, 41]. Irrespective of the variety tested, zinc and magnesium foliar fertilization had a significant impact on leaf chlorophyll content. The similar performance of the varieties could be attributed to the effect of Zn and Mg on common bean physiology. Zinc and Mg have been noted to influence plant metabolism such as gene regulation, protein synthesis, carbohydrate metabolism, and photosynthesis [19]. The effects can also be attributed to the fact that micronutrients such as Zn and Mg are key important elements in many enzymatic reactions leading to production of proteins, vitamins, leaf photosynthesis rates, and optimization of plant cell metabolism by amino acid [29], although the role of micronutrients in these formulations cannot be ignored.

**3.3. Yield and Yield Components.** Significant interaction ( $P \leq 0.05$ ) was observed between nutrients and location, while nutrients independently affected yield at physiological maturity (Table 3). Application of Zn plus Mg significantly ( $P \leq 0.05$ ) increased biomass yield by 40.90, 11.52, and 10.54% compared to water spray (22.6%/plant), zinc (34.2%/plant), and magnesium (33.9%/plant) treatments (Figure 3). Combined application of zinc and magnesium increased the number of pods per plant and seeds per pod by 23–30% relative to the water spray (control) (Figure 4). Sole application of zinc and magnesium had a significant ( $P \leq 0.05$ ) effect on the number of pods per plant compared to the control (Figure 4). Nutrients and location independently affected seed yield, but interactions were mostly not significant ( $P \leq 0.05$ ) (Table 3). The highest seed yield was obtained when zinc and magnesium were applied together, and this was significantly different ( $P \leq 0.05$ ) from the control (Figure 3(b)). Similarly, sole application of zinc (1535.04 kg/ha) and magnesium (1542.6 kg/ha) produced significantly greater ( $P \leq 0.05$ ) seed yield relative to the control (773.9 kg/ha). The highest seed yield was observed at Akumadan (Figure 4(c)). Irrespective of variety, the performance of the treatments followed a similar trend: foliar application of magnesium and zinc consistently recorded the

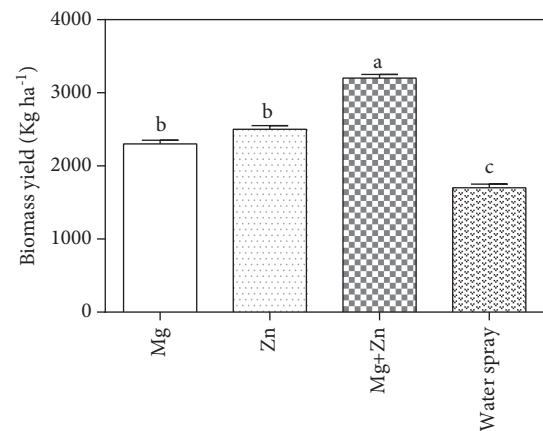


FIGURE 3: Impact of treatment on biomass yield. Bars with different letters in the figure are statistically different at  $P < 0.05$ . Error bars represent the standard error of means. Means comparison was done using Tukey HSD (honestly significant difference) ( $P < 0.05$ ).

most pods per plant and seeds per pod and highest seed yield in all studied locations compared to the control. Application of micronutrients, especially zinc and magnesium, increased number of stamens per plant [42] and this attribute of micronutrients could be responsible for the increase in the number of pods per plant observed in this study. This hypothesis is confirmed by the fact that common bean is a self-pollinated plant, so the increase in stamen activity will result in more fertile flowers and consequently more number of pods per plant. Teixeira et al. [28] observed that foliar application of Zn and Mg to common bean increased the number of pods per plant. Similarly, Banks [43] reported that the foliar application of Zn influenced yield and yield components of soybean and increased number of pods per plant. Higher bioavailability of nutrient elements associated with foliar application of a mixture of amino acids on beans is probably the main factor behind this yield improvements. The role of amino acids in phytohormone biosynthesis [29], cell membrane stability, and optimization of photosynthesis and metabolism [3] can also play key roles in higher yields achievement by amino chelates application in the present study. Therefore, application of a mixture of amino acids or in the form of chelate fertilizers, such as amino chelates, can have various beneficial effects on nutrient uptake, plant

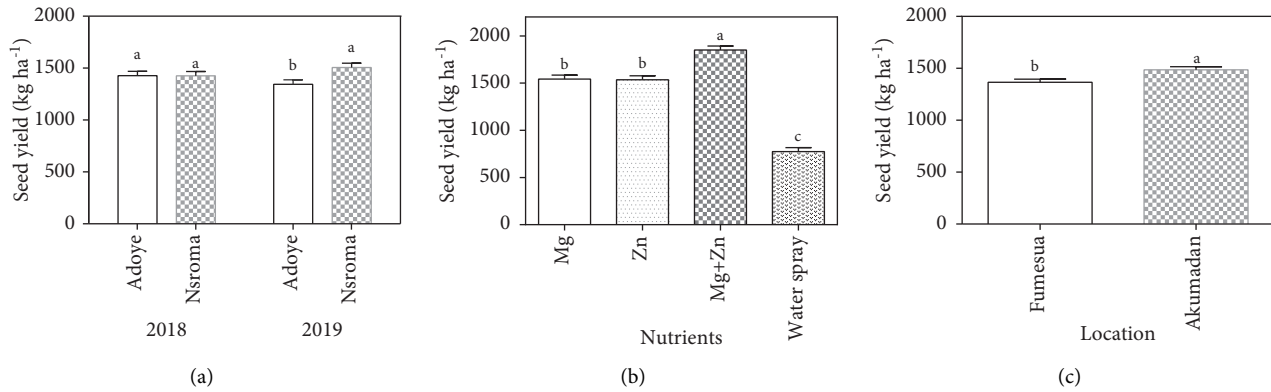


FIGURE 4: Impact of treatment on seed yield. Bars with different letters in the figure are statistically different at  $P < 0.05$ . Error bars represent the standard error of means. Means comparison was done using Tukey HSD (honestly significant difference) ( $P < 0.05$ ).

TABLE 4: Relationships between pods per plant (PP), seeds per pod (SP), biomass yield (BY), plant height (PH), leaf chlorophyll content (SPAD), and stomatal conductance (GS).

	PP	SP	BY	PH	SPAD	GS
SY	0.359**	0.583**	0.587**	0.516**	0.388**	0.532**
PP		0.337**	0.683**	0.503**	0.420**	0.505**
SP			0.409**	0.448**	0.308**	0.450**
BY				0.504**	0.599**	0.578**
PH					0.409**	0.430**
SPAD						0.348**

Correlation is significant at the \*\* 0.01 and \*0.05 levels (2-tailed).

growth, and production. Regarding the performance between varieties, the highest seed yield was observed in Nsroma in 2019 compared to Adoye. This finding may be associated with the capacity for nutrient uptake which is associated with genotypic variation that could change the efficiency of nutrient use by each variety [44]. The seed yield obtained in Akumadan was significantly higher compared with Fumesua across years. This can likely be attributed to the amount of rainfall received during the period. Rainfall can affect plant growth and productivity either negatively or positively by influencing the general plant health, particularly in rain-fed cropping systems [45]. The significant increase in seed yield, particularly when Mg and Zn foliar fertilizers were applied together, can be attributed to increased nutrient supply and the role it plays in chlorophyll synthesis, biomass accumulation, and higher photosynthetic activity [37, 38]. Similar improvement in yield following application of zinc and magnesium has been reported in other countries, including Egypt [46] and China [47]. The impact can be attributed to the role of the nutrient supply in crop growth, which involves photosynthesis and nitrogen assimilation.

**3.4. Correlation Analysis.** The Pearson's correlation coefficient values are shown in Table 4. Number of seeds per pod (SP) positively correlated with seed yield ( $r = 0.58$ ,  $P < 0.01$ ) and biomass yield ( $r = 0.40$ ,  $P < 0.01$ ). Biomass yield showed a positive correlation with seed yield ( $r = 0.587$ ,  $P < 0.01$ ). SPAD and Gs had significant positive correlations with yield

components and plant height, which translates to significant positive correlations with biomass and seed yield. Stomata conductance and chlorophyll content can explain more than 50% of the variation in seed and biomass yield and indicates the significant effect of photosynthesis activity and nutrient supply on bean crop productivity.

## 4. Conclusions

Foliar application of magnesium plus zinc on common beans increased plant height and biomass yield in both varieties and both locations to a significantly greater extent than the other treatments. Increased crop growth had a beneficial effect on chlorophyll content and stomatal conductance, which resulted in higher seed yield. These results suggest the potential for improved and more stable bean crop productivity when zinc and magnesium are applied together at 100 g/ha Zn and 112 g/ha Mg. This result highlights the stimulation effect of amino acid on growth and yield of common beans. The results reported in this study showed positive correlations between plant height, chlorophyll content, stomatal conductance, biomass, and seed yield. The results of this research can provide baseline information that can be utilized for future research, including crop modelling work aimed at developing fertilizer management strategies for different agro-ecological zones in Sub-Saharan Africa.

## Data Availability

All data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Authors' Contributions

Stephen Yeboah conceptualized the study, developed methodology, did formal analysis, investigated the study, and wrote the original draft. James Asibuo was responsible for funding acquisition, conceptualized the study, developed

methodology, reviewed and edited the manuscript, supervised the study, and did project administration. Patricia Oteng-Darko conceptualized the study, developed methodology, did formal analysis, and reviewed and edited the manuscript. Emmanuel Asamoah Adjei did formal analysis, investigated the study, and reviewed and edited the manuscript. Maxwell Lamptey did formal analysis, investigated the study, and reviewed and edited the manuscript. Eric Owusu Danquah did formal analysis, investigated the study, and reviewed and edited the manuscript. Boaz Waswa did funding acquisition, conceptualized the study, reviewed and edited the manuscript, and did project administration. Louis Butare was responsible for funding acquisition, conceptualized the study, reviewed and edited the manuscript, and did project administration.

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