Biological and Clinical Sciences Research Journal
eISSN: 2708-2261; pISSN: 2958-4728
www.bcsrj.com
DOI: https://doi.org/10.54112/bcsrj.v2023i1.616
Biol. Clin. Sci. Res. J., Volume, ***2023****: 616*
Original Research Article

OPTIMIZING MUNGBEAN YIELD AND NUTRITIONAL QUALITY: THE SYNERGISTIC IMPACT OF ZINC-ENRICHED SOIL APPLICATION AND AMINO ACID FOLIAR BOOST

MAQSOOD Z[1*], ZAFFAR M[2], AKBAR H[3], HUMAIYON M[4], ASAD M[5], ALI S[6], MUNIR A[5], IRFAN M[7], NAWAZ A[8], HASSAN W[9]

[1]Pulses Research Institute, AARI, Faisalabad, Punjab, Pakistan
[2]Chief Scientist, Sugarcane Research Institute, Faisalabad, Punjab, Pakistan
[3]Department of Engineering, Hamdard University Karachi, Sindh, Pakistan
[4]Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, Punjab, Pakistan
[5]Department of Agronomy, PMAS-Arid Agriculture University, Rawalpindi, Punjab, Pakistan
[6]Soil & Water Testing Laboratory, Jhang, Punjab, Pakistan
[7]Pulses Research Sub Station, Sahowali, Sialkot, Punjab, Pakistan
[8]Soil Chemistry Section, AARI, Faisalabad, Punjab, Pakistan
[9]Soil and Water Testing Laboratory for Research, Bahawalpur, Punjab, Pakistan
**Corresponding author email address:* zulkaifmaqsood@gmail.com

(Received, 25th September 2023, Revised 15th November 2023, Published 23rd December 2023)

Abstract: *Zinc is crucial for chlorophyll production, and soil variables affect its availability for plants by regulating its sorption and desorption, thereby affecting its content. Amino acids are crucial proteins in plants for development, growth, and overall functioning, acting as stress-response molecules that initiate the production and accumulation of certain amino acids in response to environmental stresses. The study was designed in CRD-factorial to check the solo and combined application of amino acids (0 ppm, 250 ppm, and 500 ppm) and zinc (0 ppm, 10 ppm, and 15 ppm) on biochemical, growth, and yield attributes of mung bean. The results showed that total amino acids and phenolics were increased in dose (amino acids 250 + zinc 10) compared to control. In addition, crop growth rate (CGR) was increased in dose (amino acids 500 + zinc 10) over control. The 100-seed weight was also increased in dose (amino acids 250 + zinc 10) compared to control. The crop growth and yield rate decreased by increasing the amino acids and zinc doses. It is suggested to apply the dose (amino acids 250 + zinc 10) for better growth and yield production of mung bean.*

Keywords: Zinc, Amino acids, Mung bean, Growth, Biochemical, Yield

Introduction

The search for effective and safe natural antioxidants is concentrated on food plants, especially spices and herbs (Yanishlieva et al., 2006). Amino acids are essential plant proteins in development, growth, and overall functioning (Hildebrandt et al., 2015). They act as stress-response molecules in plants, initiating the production and build-up of certain amino acids when faced with environmental stresses like drought, salinity, or extreme temperatures(Ali et al., 2019). These amino acids maintain cellular turgor pressure and water balance, enabling plants to withstand water scarcity and osmotic stress(Akıncı & Lösel, 2012). They also regulate gene expression and signal transduction pathways, ensuring plant resilience and survival in challenging environmental conditions(Ali et al., 2019).
Zinc is required for the carbonic enzyme that produces chlorophyll (Tavallali et al., 2009). Soil variables influence zinc availability for developing plants by regulating the sorption and desorption of zinc in the soil solution, affecting the zinc content (Alloway, 2009). Higher zinc content seeds serve several purposes during germination and the initial phases of establishment (Ozturk et al., 2006). Supplementing maize with zinc increases its photosynthetic rate, chlorophyll production, nitrogen metabolism, and resilience to biotic and abiotic challenges (Saboor et al., 2021).

Mungbean, known as *Vigna radiata* (L.), is a crucial grain legume crop in Asian agriculture, providing significant digestible protein to cereal-based diets (Pratap et al., 2021). In many industrialized and emerging nations, mungbean sprouts are often eaten as a salad vegetable (R. Nair & Schreinemachers, 2020). Mungbean yields remain modest despite significant advances in yield, which has limited its widespread usage as a substitute pulse crop in Asian agricultural practices (R. M. Nair et al., 2019). Apart from the abiotic restraints brought about by heat stress, drought, and soil adaptation, Insect pests and foliar diseases on farms and after harvest are the main causes of mung bean's productivity limitations (Pratap et al., 2019).
The primary usage of mungbean is as dried seed; however, it is also infrequently used as green pods and vegetable seeds (Mehandi et al., 2019). Mungbean has 24 to 28% protein, 1 to 1.5% fat, 3.6 to 4.5% fiber, 4.4 to 5.5% ash, and 60–65% carbohydrates by dry weight (HOSSEN, 2016). The amino acids cystine and methionine are low in sulfur in the seed protein, but lysine is abundant. In addition, the seeds are high in potassium, iron, phosphorus, calcium, and ascorbic acid (vitamin A) but low in salt. In general, mungbean is a great addition to diets centered on cereal, especially in Asia, where it is used in various ways (R. M. Nair et al., 2013). Can eat dried seeds whole or split, boil them, ferment them, or grind them into flour to use in soups,

[Citation: Maqsood, Z., Zaffar, M., Akbar, H., Humaiyon, M., Asad, M., Ali, S., Munir, A., Irfan, M., Nawaz, A., Hassan, W. (2023). Optimizing mungbean yield and nutritional quality: the synergistic impact of zinc-enriched soil application and amino acid foliar boost. *Biol. Clin. Sci. Res. J.,* **2023***: 616*. doi: https://doi.org/10.54112/bcsrj.v2023i1.616]

curries, cereals, desserts, and drinks that contain alcohol. In European traditions, beans are widely used as a fresh salad vegetable and are well-known for sprouting (Pasqualone et al., 2020).

Zinc and amino acids are necessary for mung bean to be resilient and survive in harsh environmental circumstances (Ahmed et al., 2023; Dev et al., 2023). Stress causes the production of important proteins called amino acids, which act as osmoprotectants to preserve the water balance and turgor pressure of cells (Majumder et al., 2010). Superoxide dismutase and peroxidase are examples of antioxidant enzymes that are activated by zinc, a micronutrient that cofactors for enzymes involved in stress response pathways (Marreiro et al., 2017). These enzymes help mung bean's stress tolerance by neutralizing reactive oxygen species (ROS) produced under stressful conditions. Zinc and amino acids promote long-term development and efficiency (Ali et al., 2019; Umair Hassan et al., 2020). This study was conducted to check the roles of amino acids and zinc on various biochemical activities, growth, and yield aspects of mung bean. We hypothesized that the combined application of amino acids and zinc could boost mung bean's biochemical activities, growth, and yield, Figure 1.

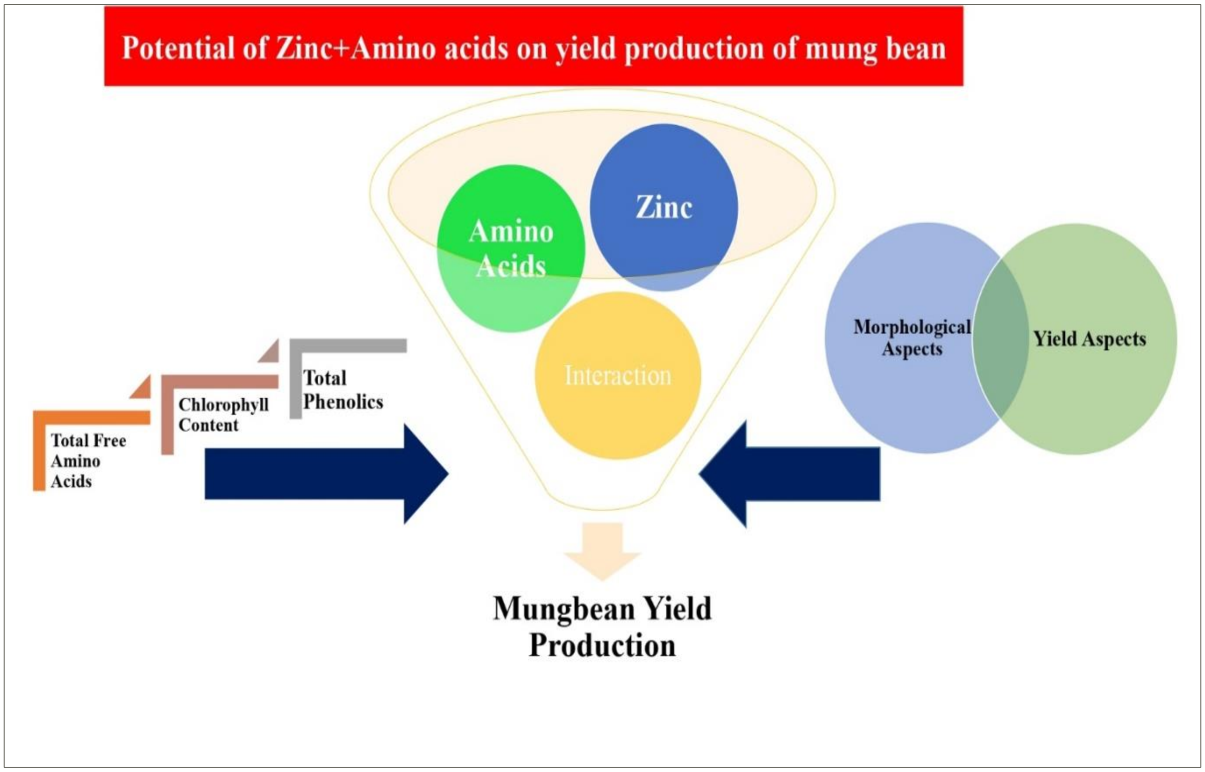

Figure 1. The combined effect of Zinc and Amino Acids on biochemical, morphological, and yield aspects of Mung bean

Methodology

This experiment was conducted in the greenhouse of Ayub Agricultural Research Institute in Faisalabad, Pakistan, in 2022. Soil samples ranging in depth from 0 to 15 cm were collected randomly, and a composite soil specimen was produced. The resulting specimens underwent physiochemical tests using standard procedures. The experimental soil's chemical and physical characteristics are displayed in Table 1, indicating that it is a sandy clay loam with a textured class. The mungbean seeds @ 10 seeds per pot were sowed in the pot's 22 x 20 cm soil. The research was set out in a CRD with four replications and two-component factorial designs. All agronomic operations were performed consistently and equally throughout the trial period in all treatments. The zinc was applied in the soil in the solution form at the seedling emergence, and amino acids were foliar applied at the pod setting stage, as shown in Table 2.

Table 1. Soil physiochemical analysis of the experimental site.

Soil Texture	Sandy clay loam
pH	7.7
Ec	0.26
P (ppm)	11.7
K (ppm)	144
Organic matter (%)	0.67

[Citation: Maqsood, Z., Zaffar, M., Akbar, H., Humaiyon, M., Asad, M., Ali, S., Munir, A., Irfan, M., Nawaz, A., Hassan, W. (2023). Optimizing mungbean yield and nutritional quality: the synergistic impact of zinc-enriched soil application and amino acid foliar boost. *Biol. Clin. Sci. Res. J.*, **2023***: 616*. doi: https://doi.org/10.54112/bcsrj.v2023i1.616]

Table 2. Doses of desired treatment (ppm) for soil and foliar application

Amino acids	Zinc
0	0
250	0
500	0
0	10
0	15
250	10
250	15
500	10
500	15

Data Collection

Height of plant (cm)

Following harvesting, 5 randomly chosen plants from each pot were measured for height.

Rate of crop growth (CGR)

The plants were picked between 130 and 140 DAS and oven dried to get a consistent dry weight. During this time, the CGR values were determined using the following formula: (W2 – W1) / (T2-T1) is the CGR. W1 = initial sampling weight after oven drying W2 is weight dried in the oven at the second sampling T1 is the initial sample time. T2 is the second sample time (Kataoka et al., 2003).

Content of chlorophyll in leaves (mg g-1)

Using the approach of (Palta, 1990), the chlorophyll content of leaves at 50% blooming was detected.

Pods per plant

One out of five randomly chosen plants, the number of pods plant^{-1} was counted from each pot, and the average was computed.

Weight (g) of 100 seeds

After manually removing 1000 seeds from each treatment, the weight of 100 seeds was determined.

Biological Yield (kg ha^{-1})

After harvesting, the weight of the entire plant—excluding the roots—was determined. It was stated in kg. The data was then converted to kg ha^{-1}.

Seed yield (kg ha^{-1})

The weight of the clean seed for pot^{-1} was presented in grams. The data was then transformed to kg ha^{-1}.

Biochemical analysis

The total free amino acid approach described by (Moerdijk-Poortvliet et al., 2022) was employed to calculate the total free amino acids. After 60 days, fresh leaves were homogenized in citrate buffer and centrifuged. The extraction samples were treated with a ninhydrin solution, and optical density at 570 nm was measured. The total phenolic content was calculated using the Julkenen-Titto (1985) technique described by (Ashraf et al., 2010).

Analytical statistics

The computer program Statistix 8.1 was utilized to study variamce by using 2-way Anova. The 0.05 probability threshold was utilized to distinguish between treatment differences using the (HSD) (Lee & Lee, 2018).

Results

Plant height (cm)

The data analysis outcomes demonstrated that the use of zinc, amino acid supplementation, and their combination significantly affected the height of the plant; however, the variation among treatments was non-significant (Table 8). The administration of 250 ppm of amino acids resulted in the maximum plant height of 49.28cm, followed by 500 ppm at 48.64cm. In contrast, the mungbean plant height was reduced because of greater amino acid dosages and the control. Applying 10 ppm of zinc resulted in the maximum plant height (55.62cm) while applying zinc at a rate of 0 ppm produced the most diminutive plant height (42.33 cm).

Table 3. Mung bean plant height (cm) as influenced by zinc and amino acid levels

Amino acids	Zinc			
	0	**10**	**15**	**Mean**
0	41.33p	54.34o	49.45q	48.37m
250	43.64q	55.78n	48.34qr	49.28m
500	42.33qr	56.74n	46.86q	48.64m
Mean	42.33l	55.62k	48.21m	

Crop growth rate (CGR)

Results from the crop growth rate analysis of variance showed that zinc, amino acids, and their interactions generated significant developments (Table 4). Applying zinc @ 10ppm resulted in the maximum crop growth rate (17.71), whereas the absence of zinc led to the lowest crop growth rate. Regarding the physical administration of amino acids, crop growth was at its highest level when 500 ppm of amino acids were administered. This was followed by 250 ppm of amino acids. The mungbean crop grew at the lowest rate when a control group was used.

Chlorophyll content

The treatment of zinc and amino acids and their combination had a noteworthy impact on the mungbean crop, as shown in Table 5. The variation among treatments is statistically significant, as shown in Table 8. The highest amount of chlorophyll detected was 45.05 with 250 ppm amino acids, while the control group showed the least chlorophyll. When zinc was applied, the plots with the

[Citation: Maqsood, Z., Zaffar, M., Akbar, H., Humaiyon, M., Asad, M., Ali, S., Munir, A., Irfan, M., Nawaz, A., Hassan, W. (2023). Optimizing mungbean yield and nutritional quality: the synergistic impact of zinc-enriched soil application and amino acid foliar boost. *Biol. Clin. Sci. Res. J.*, **2023***: 616*. doi: https://doi.org/10.54112/bcsrj.v2023i1.616]

highest chlorophyll content (46.99) were those where the zinc was applied @ 10ppm; the plots with the lowest chlorophyll were those without zinc. These findings were statistically equivalent. Regarding the interaction, zinc at 10 ppm and amino acids at 250 ppm showed the maximum chlorophyll concentration (48.6).

Table 4. Mung bean crop growth rate (%) as influenced by zinc and amino acid levels

Amino acids	**Zinc**			
	0	**10**	**15**	**Mean**
0	16.26 h	16.36h	16.53h	16.38h
250	17.4hi	17.73i	17.86ij	17.66i
500	17.73i	19.06l	17.5h	18.09k
Mean	17.13j	17.71k	17.29j	

Table 5. Mung bean's chlorophyll content is influenced by zinc and amino acid levels

Amino acids	**Zinc**			
	0	**10**	**15**	**Mean**
0	38.98m	45.67o	41.37n	42n
250	42.56n	48.65q	43.95p	45.05o
500	41.33n	46.67r	42.21n	43.40n
Mean	40.95m	46.99r	42.51n	

100-seed weight (g)

The examination of variation for the weight (g) of 100 seeds revealed that the mung beans' 100-seed weight was considerably impacted by the treatment of zinc, amino acids, and both (Table 6). Notably, the solo effects of both treatments were non-significant, while their interactions were significant, as shown in Table 8. The most excellent seed weight of 6.15g was produced by zinc treatment at a rate of 10ppm; the control produced the minimum seed weight of 5.55g. Regarding applying amino acids, the highest seed weight (5.85 g) was observed when applying 250 ppm of amino acids. Pots without adding zinc and amino acids (control) had the lowest 100 seed weight (5.75 g) concerning the interaction.

Table 6. Mung beans 100-seed weight (g) as influenced by zinc and amino acids levels

Amino acids	**Zinc levels**			
	0	**10**	**15**	**Mean**
0	5.46c	6.01f	5.78d	5.75d
250	5.65cd	6.12f	5.80d	5.85e
500	5.54c	6.32g	5.63cd	5.83e
Mean	5.55c	6.15f	5.73d	

Biological yield (kg ha^{-1})

The biological yield analysis of variance results showed that whereas giving zinc and amino acids alone produced substantial effects, combining them did not show such results, table 7. Interestingly, the solo and combined effects are statistically significant, as shown in Table 8. The highest biological output (1840.66) was achieved by administering zinc @ 10ppm. The lowest biological yield (1498.33) was noted without zinc. Pots sprayed with @250ppm of amino acids had the highest biological output (1721.33) of the mung bean crop, whereas the @15 ppm had the lowest biological yield (1664.33).

Table 7. Mung bean's biological yield (kg ha^{-1}) as influenced by zinc and amino acid levels

Amino acids	**Zinc**			
	0	**10**	**15**	**Mean**
0	1455l	1823q	1743n	1673.66o
250	1543n	1856s	1765p	1721.33q
500	1497m	1843rs	1654op	1664.33op
Mean	1498.33m	1840.66p	1720o	

Total free amino acids

Figure 2 shows how topically applying zinc and amino acids to the mungbean plant affects the plant's total free amino acid content. Statistical analysis showed that administering zinc, amino acids, and their combination significantly affected free amino acids. However, the treatment zinc showed non-significant variation, as shown in Table 8. The highest recorded total free amino acids (366.2) were found at 250 ppm, whereas the control sample (267.93) had the lowest free amino acids. The subsequent values (356.94) were statistically comparable at 500 ppm. When applying zinc, the highest total free amino acid content (332.59) was shown when applying zinc @ 10 ppm. On the other hand, the total free amino acid concentration was lowest at @15 ppm (328.73). Regarding the relationship, more significant zinc concentrations were associated with higher total free amino acid levels and amino acid concentrations of 250 ppm and 500 ppm; lower dosages of both led to lower total free amino acid levels. Numerous studies have demonstrated that foliar administration of amino acids raises the amounts of antioxidant molecules.

[Citation: Maqsood, Z., Zaffar, M., Akbar, H., Humaiyon, M., Asad, M., Ali, S., Munir, A., Irfan, M., Nawaz, A., Hassan, W. (2023). Optimizing mungbean yield and nutritional quality: the synergistic impact of zinc-enriched soil application and amino acid foliar boost. *Biol. Clin. Sci. Res. J.*, **2023***: 616*. doi: https://doi.org/10.54112/bcsrj.v2023i1.616]

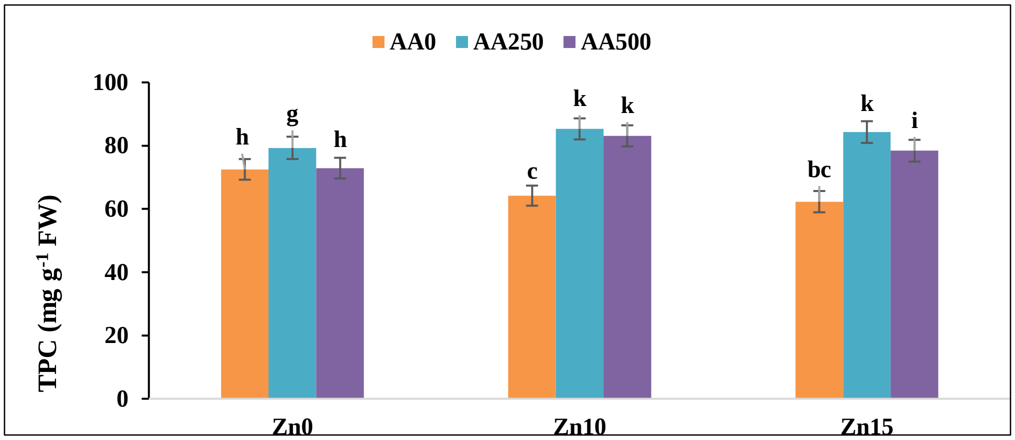

Figure 2. Effect of solo and combined zinc (Zn) and Amino Acids (AA) on total free amino acids of mungbean. Mean is the average of three replications ± S.E. The -way ANOVA was applied, and alphabet lettering showed significant and non-significant differences among treatments.

Total phenolic content

Zinc, amino acids, and their combination substantially impacted the groundnut crop's total phenolic content, as shown in Figure 3. However, the treatment zinc showed non-significant variation, as shown in Table 8. The highest phenolic content (77.56) was detected when zinc was supplied at 10 ppm; the lowest phenolic content (75.14) was seen at 15 ppm. Adding amino acids produced a maximum concentration of 82.99 at 250 ppm for total phenolic content. Regarding the interaction, applying amino acids at 250 ppm and zinc at 10 ppm produced the highest total phenolic content (88.33).

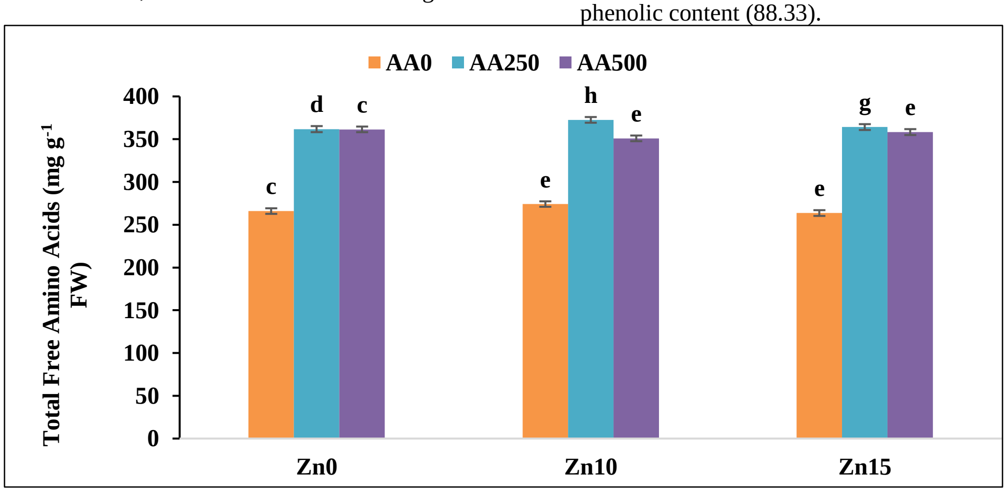

Figure 3. Effect of solo and combined zinc (Zn) and Amino Acids (AA) on total phenolics (TPC) of mungbean. Mean is the average of three replications ± S.E. The two-way ANOVA was applied, and alphabet lettering showed significant and non-significant differences among treatments.

Table 8. Two-way ANOVA values of all parameters as influenced by zinc and amino acids levels in Mungbean

Treatments	Plant Height	Crop Growth Rate	Chlorophyll	100-Grain Weight	Biological Yield	Total Free Amino Acids	Total Phenolics
Zinc (Zn)	*	ns	*	ns	*	ns	ns
Amino Acids (AA)	ns	ns	*	ns	*	**	*
Zn × AA	ns	ns	*	*	*	**	*

*** (Highly significant), * (Significant), ns (Non-significant)*

Discussion

The plant height of the mungbean crop rapidly declines with increasing concentrations of amino acids. Likewise, plants that received less zinc also grew to be shorter. Zinc exhibits excellent potential in heightening plant growth and building a crop stand(Cakmak et al., 2010). The increased plant height may be explained by Zinc's participation in several vital cellular processes in plants (Gupta et al., 2016). High Zn levels significantly impact several physiological processes during seed germination and the early development of seedlings (Bhantana et al., 2021). The mungbean plant grew taller when amino acids were applied. Our results corroborate those of (El Karamany et al., 2019; Farhangi-Abriz et al., 2017), who discovered that adding amino acids increased plant height compared to the control group.

The mungbean crop's growth rate decreased due to lower zinc levels. Amino acids strengthened the entire plant, accelerated the growth of immature plants, improved resistance to pests and diseases, and increased crop growth rate(Singh, 2013). The results indicate that the yield was significantly increased by this foliar spray of amino acids, even though it was applied in small amounts. Treatments with zinc increased crop growth rate favorably. The study found that most treatments of zinc and phosphorus significantly extended wheat shoots in water culture compared to the control group (Samreen et al., 2017).

Increased temperature endorsement (Soares et al., 2016) may be the reason for improved physiological characteristics brought on by foliar amino acid treatments, as seen by greater chlorophyll concentration than control seeds. When amino acid spray was applied to creeping bentgrass, it reduced chlorophyll degradation. It encouraged the formation of new cells, which resulted in an increase in chlorophyll in the leaves. Leaves with low zinc levels looked light green because less chlorophyll was present. A zinc deficit was shown to impact chlorophyll synthesis, as per the observations of (Roosta et al., 2018). Zinc, a crucial protein and enzyme component and co-factor for pigment biosynthesis, increases chlorophyll concentration (Umair Hassan et al., 2020).

The photosynthetic efficiency may have increased (Wei et al., 2022) due to increased enzymatic activity induced by the zinc treatment, which would have caused a thousand grains to weigh more. These findings correspond with (Liu et al., 2019). The study indicates that frequent application of amino acids during the vegetative stage of black cumin seeds can increase their weight per 100 seeds. Some specialists suggest that the extract's zeatin, a hormone linked to cytokinin, is responsible for the increased growth and output (Roberts, 2012; Torrey, 1976).

Hormones may encourage cell and tissue growth, development, and differentiation in plants, which might account for this. These outcomes are consistent with those of (Teixeira et al., 2018), who discovered that applying amino acids topically increased crop growth metrics. The application of zinc resulted in increased biological production and chlorophyll pigment concentrations. According to (Yilmaz et al., 1997), applying zinc increased grain production, consistent with our findings (Table 6).

Improved soil microclimate and enhanced photosynthetic activity are responsible for yield enhancement by applying zinc and amino acids (Morales et al., 2020). Foliar treatment of it yielded very substantial positive results for amino acid performance. The study found that amino acids were effective as growth bio-stimulants for the mungbean crop when administered at different intervals. Amino acids increase plant metabolism, aiding the growth of groundnut plants. These elements have increased dry matter accumulation, cell division, and elongation in plants, enabling them to overcome developmental obstacles and enhance growth characteristics(Ahanger et al., 2016).

The higher total phenolic content in mungbean leaves could be attributed to the higher phenolic concentration in plants treated with amino acids. Additionally, it may be possible that the increased internal phenolic content of mungbean leaves resulted from amino acids having a direct or indirect impact on metabolic processes (Mahmood et al., 2022). Because of these characteristics, amino acids can act as natural antioxidants and growth promoters (Omar et al., 2020). Our findings corroborate those of (Sreelatha and Padma, 2009), who found that total phenolic content was increased by amino acid treatment at critical phases. The nitrogen metabolism of maize plants is impacted by zinc deficiency (Al-Zahrani et al., 2021), and a noteworthy increase in phenolic content following zinc treatment was also documented. Zinc is a structural and catalytic component necessary for average growth and development (Table 9) (Maret & Li, 2009).

Conclusion

This study suggests that applying amino acids topically and zinc increased seed output. To maximize the output of the mungbean crop, a larger dosage of zinc, 15 ppm, and 200 ppm of amino acids, is advised. Given that the crop is suited for Faisalabad, it is necessary to assess several mungbean types in diverse farming environments throughout Punjab and Khyber Pakhtunkhwa. Future research may examine more significant dosages of zinc and more amino acid concentrations to get the best possible outcomes.

Declarations

Data Availability statement
All data generated or analyzed during the study are included in the manuscript.
Ethics approval and consent to participate
Approved by the department concerned.
Consent for publication
Approved
Funding
Not applicable

Conflict of interest

The authors declared the absence of a conflict of interest.

Author Contribution

ZULKAIF MAQSOOD
Conception of Study, Development of Research Methodology Design, Study Design,, Review of manuscript, final approval of manuscript
Supervision funding acquisition.
MUHAMMAD ZAFFAR
Data entry and Data analysis, drafting article
HUSSAIN AKBAR
Manuscript revisions, critical input.
MUHAMMAD HUMAIYON
Supervision funding acquisition.
MUHAMMAD ASAD
Coordination of collaborative efforts.
Supervision funding acquisition.
SAJID ALI

Study Design, Review of Literature
ARSHID MUNIR
Data entry and Data analysis, drafting article
MUHAMMAD IRFAN
Manuscript revisions, critical input.
ALLAH NAWAZ
Data entry and Data analysis, drafting article
WASEEM HASSAN
Study Design, Review of Literature

References

Ahanger, M. A., Morad-Talab, N., Abd-Allah, E. F., Ahmad, P., & Hajiboland, R. (2016). Plant growth under drought stress: Significance of mineral nutrients. *Water Stress and Crop Plants: A Sustainable Approach*, *2*, 649–668.

Ahmed, H. G. M.-D., Naeem, M., Faisal, A., Fatima, N., Tariq, S., & Owais, M. (2023). Enriching the Content of Proteins and Essential Amino Acids in Legumes. In *Legumes Biofortification* (pp. 417–447). Springer.

Akıncı, Ş., & Lösel, D. M. (2012). Plant water-stress response mechanisms. *Water Stress*, *25*, 42.

Al-Zahrani, H. S., Alharby, H. F., Hakeem, K. R., & Rehman, R. U. (2021). Exogenous application of zinc to mitigate the salt stress in Vigna radiata (L.) Wilczek—Evaluation of physiological and biochemical processes. *Plants*, *10*(5), 1005.

Ali, Q., Haider, M. Z., Shahid, S., Aslam, N., Shehzad, F., Naseem, J., Ashraf, R., Ali, A., & Hussain, S. M. (2019). Role of amino acids in improving abiotic stress tolerance to plants. In *Plant tolerance to environmental stress* (pp. 175–204). CRC Press.

Alloway, B. J. (2009). Soil factors associated with zinc deficiency in crops and humans. *Environmental Geochemistry and Health*, *31*(5), 537–548.

Ashraf, M. A., Ashraf, M., & Ali, Q. (2010). Response of two genetically diverse wheat cultivars to salt stress at different growth stages: leaf lipid peroxidation and phenolic contents. *Pak J Bot*, *42*(1), 559–565.

Bhantana, P., Rana, M. S., Sun, X., Moussa, M. G., Saleem, M. H., Syaifudin, M., Shah, A., Poudel, A., Pun, A. B., & Bhat, M. A. (2021). Arbuscular mycorrhizal fungi and its major role in plant growth, zinc nutrition, phosphorous regulation and phytoremediation. *Symbiosis*, *84*, 19–37.

Cakmak, I., Pfeiffer, W. H., & McClafferty, B. (2010). Biofortification of durum wheat with zinc and iron. *Cereal Chemistry*, *87*(1), 10–20.

Dev, P., Singh, U., Singh, L. N., Shivay, Y. S., Kumar, M., & Raiger, P. R. (2023). Zinc Biofortification of Mungbean (Vigna radiata L.) as Influenced by Varieties and Zinc Fertilization. *J. Environ. Agric. Sci*, *25*(1&2), 1–17.

El Karamany, M. F., Sadak, M. S., & Bakry, B. A. (2019). Improving quality and quantity of mungbean plant via foliar application of plant growth regulators in sandy soil conditions. *Bulletin of the National Research Centre*, *43*(1), 1–7.

Farhangi-Abriz, S., Faegi-Analou, R., & Nikpour-Rashidabad, N. (2017). Polyamines, affected the nitrogen partitioning, protein accumulation and amino acid composition of mung bean under water stress. *Journal of Crop Science and Biotechnology*, *20*, 279–285.

Gupta, N., Ram, H., & Kumar, B. (2016). Mechanism of Zinc absorption in plants: uptake, transport, translocation and accumulation. *Reviews in Environmental Science and Bio/Technology*, *15*, 89–109.

Hildebrandt, T. M., Nesi, A. N., Araújo, W. L., & Braun, H.-P. (2015). Amino acid catabolism in plants. *Molecular Plant*, *8*(11), 1563–1579.

HOSSEN, M. D. F. (2016). *COMBINED EFFECTS OF POTASSIUM AND BORON ON THE GROWTH, YIELD AND NUTRIENT CONTENTS OF MUNGBEAN*. Department of Agricultural Chemistry, Sher-e-Bangla Agricultural University ….

Kataoka, T., Kaneko, T., Okamoto, H., & Hata, S. (2003). Crop growth estimation system using machine vision. *Proceedings 2003 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM 2003)*, *2*, b1079–b1083.

Lee, S., & Lee, D. K. (2018). What is the proper way to apply the multiple comparison test? *Korean Journal of Anesthesiology*, *71*(5), 353–360.

Liu, C., Hu, C., Tan, Q., Sun, X., Wu, S., & Zhao, X. (2019). Co-application of molybdenum and zinc increases grain yield and photosynthetic efficiency of wheat leaves. *Plant, Soil and Environment*, *65*(10), 508–515.

Mahmood, S., Wahid, A., Azeem, M., Zafar, S., Bashir, R., Bajwa, M. O. S., & Ali, S. (2022). Tyrosine or lysine priming modulated phenolic metabolism and improved cadmium stress tolerance in mung bean (Vigna radiata L.). *South African Journal of Botany*, *149*, 397–406.

Majumder, A. L., Sengupta, S., & Goswami, L. (2010). Osmolyte regulation in abiotic stress. *Abiotic Stress Adaptation in Plants: Physiological, Molecular and Genomic Foundation*, 349–370.

Maret, W., & Li, Y. (2009). Coordination dynamics of zinc in proteins. *Chemical Reviews*, *109*(10), 4682–4707.

Marreiro, D. D. N., Cruz, K. J. C., Morais, J. B. S., Beserra, J. B., Severo, J. S., & De Oliveira, A. R. S. (2017). Zinc and oxidative stress: current mechanisms. *Antioxidants*, *6*(2), 24.

Mehandi, S., Quatadah, S., Mishra, S. P., Singh, I., Praveen, N., & Dwivedi, N. (2019). Mungbean (Vigna radiata L. wilczek): retrospect and prospects. In *Legume crops-characterization and breeding for improved food security* (pp. 49–66). IntechOpen London.

Moerdijk-Poortvliet, T. C. W., de Jong, D. L. C., Fremouw, R., de Reu, S., de Winter, J. M., Timmermans, K., Mol, G., Reuter, N., & Derksen, G. C. H. (2022). Extraction and analysis of free amino acids and 5′-nucleotides, the key contributors to the umami taste of seaweed. *Food Chemistry*, *370*, 131352.

Morales, F., Ancín, M., Fakhet, D., González-Torralba, J., Gámez, A. L., Seminario, A., Soba, D., Ben Mariem, S., Garriga, M., & Aranjuelo, I. (2020). Photosynthetic metabolism under stressful growth conditions as a bases for crop breeding and yield improvement. *Plants*, *9*(1), 88.

Nair, R. M., Pandey, A. K., War, A. R., Hanumantharao, B., Shwe, T., Alam, A., Pratap, A., Malik, S. R., Karimi, R., & Mbeyagala, E. K. (2019). Biotic and abiotic constraints in mungbean production—progress in genetic improvement. *Frontiers in Plant Science*, *10*, 1340.

Nair, R. M., Yang, R., Easdown, W. J., Thavarajah, D., Thavarajah, P., Hughes, J. d'A, & Keatinge, J. D. H. (2013). Biofortification of mungbean (Vigna radiata) as a whole food to enhance human health. *Journal of the Science of Food and Agriculture*, *93*(8), 1805–1813.

Nair, R., & Schreinemachers, P. (2020). Global status and economic importance of mungbean. *The Mungbean Genome*, 1–8.

Omar, A. E., Al-Khalaifah, H. S., Mohamed, W. A. M., Gharib, H. S. A., Osman, A., Al-Gabri, N. A., & Amer, S. A. (2020). Effects of phenolic-rich onion (Allium cepa L.) extract on the growth performance, behavior, intestinal histology, amino acid digestibility, antioxidant activity, and the immune status of broiler chickens. *Frontiers in Veterinary Science*, *7*, 582612.

Ozturk, L., Yazici, M. A., Yucel, C., Torun, A., Cekic, C., Bagci, A., Ozkan, H., Braun, H., Sayers, Z., & Cakmak, I. (2006). Concentration and localization of zinc during seed development and germination in wheat. *Physiologia Plantarum*, *128*(1), 144–152.

Palta, J. P. (1990). Leaf chlorophyll content. *Remote Sensing*

[Citation: Maqsood, Z., Zaffar, M., Akbar, H., Humaiyon, M., Asad, M., Ali, S., Munir, A., Irfan, M., Nawaz, A., Hassan, W. (2023). Optimizing mungbean yield and nutritional quality: the synergistic impact of zinc-enriched soil application and amino acid foliar boost. *Biol. Clin. Sci. Res. J.,* **2023***: 616*. doi: https://doi.org/10.54112/bcsrj.v2023i1.616]

Reviews, *5*(1), 207–213.
Pasqualone, A., Abdallah, A., & Summo, C. (2020). Symbolic meaning and use of broad beans in traditional foods of the Mediterranean Basin and the Middle East. *Journal of Ethnic Foods*, *7*(1), 39.
Pratap, A., Gupta, S., Basu, P. S., Tomar, R., Dubey, S., Rathore, M., Prajapati, U. S., Singh, P., & Kumari, G. (2019). Towards development of climate smart mungbean: challenges and opportunities. *Genomic Designing of Climate-Smart Pulse Crops*, 235–264.
Pratap, A., Gupta, S., Rathore, M., Basavaraja, T., Singh, C. M., Prajapati, U., Singh, P., Singh, Y., & Kumari, G. (2021). Mungbean. In *The beans and the peas* (pp. 1–32). Elsevier.
Roberts, J. A. (2012). *Plant growth regulators*. Springer Science & Business Media.
Roosta, H. R., Estaji, A., & Niknam, F. (2018). Effect of iron, zinc and manganese shortage-induced change on photosynthetic pigments, some osmoregulators and chlorophyll fluorescence parameters in lettuce. *Photosynthetica*, *56*, 606–615.
Saboor, A., Ali, M. A., Hussain, S., El Enshasy, H. A., Hussain, S., Ahmed, N., Gafur, A., Sayyed, R. Z., Fahad, S., & Danish, S. (2021). Zinc nutrition and arbuscular mycorrhizal symbiosis effects on maize (Zea mays L.) growth and productivity. *Saudi Journal of Biological Sciences*, *28*(11), 6339–6351.
Samreen, T., Shah, H. U., Ullah, S., & Javid, M. (2017). Zinc effect on growth rate, chlorophyll, protein and mineral contents of hydroponically grown mungbeans plant (Vigna radiata). *Arabian Journal of Chemistry*, *10*, S1802–S1807.
Singh, R. (2013). *Development of iron and zinc enriched mungbean (Vigna radiata* L.*) cultivars with agronomic traits in consideration*. Wageningen University and Research.
Soares, L. H., Neto, D. D., Fagan, E. B., Teixeira, W. F., dos Reis, M. R., & Reichardt, K. (2016). Soybean seed treatment with micronutrients, hormones and amino acids on physiological characteristics of plants. *African Journal of Agricultural Research*, *11*(35), 3314–3319.
Sreelatha, S., & Padma, P. R. (2009). Antioxidant activity and total phenolic content of Moringa oleifera leaves in two stages of maturity. *Plant Foods for Human Nutrition*, *64*, 303–311.
Tavallali, V., Rahemi, M., Maftoun, M., Panahi, B., Karimi, S., Ramezanian, A., & Vaezpour, M. (2009). Zinc influence and salt stress on photosynthesis, water relations, and carbonic anhydrase activity in pistachio. *Scientia Horticulturae*, *123*(2), 272–279.
Teixeira, W. F., Fagan, E. B., Soares, L. H., Soares, J. N., Reichardt, K., & Neto, D. D. (2018). Seed and foliar application of amino acids improve variables of nitrogen metabolism and productivity in soybean crop. *Frontiers in Plant Science*, *9*, 396.
Torrey, J. G. (1976). Root hormones and plant growth. *Annual Review of Plant Physiology*, *27*(1), 435–459.
Umair Hassan, M., Aamer, M., Umer Chattha, M., Haiying, T., Shahzad, B., Barbanti, L., Nawaz, M., Rasheed, A., Afzal, A., & Liu, Y. (2020). The critical role of zinc in plants facing the drought stress. *Agriculture*, *10*(9), 396.
Wei, C., Jiao, Q., Agathokleous, E., Liu, H., Li, G., Zhang, J., Fahad, S., & Jiang, Y. (2022). Hormetic effects of zinc on growth and antioxidant defense system of wheat plants. *Science of The Total Environment*, *807*, 150992.
Yanishlieva, N. V, Marinova, E., & Pokorný, J. (2006). Natural antioxidants from herbs and spices. *European Journal of Lipid Science and Technology*, *108*(9), 776–793.
Yilmaz, A., Ekiz, H., Torun, B., Gultekin, I., Karanlik, S., Bagci, S. A., & Cakmak, I. (1997). Effect of different zinc application methods on grain yield and zinc concentration in wheat cultivars grown on zinc-deficient calcareous soils. *Journal of Plant Nutrition*, *20*(4–5), 461–471.

[Citation: Maqsood, Z., Zaffar, M., Akbar, H., Humaiyon, M., Asad, M., Ali, S., Munir, A., Irfan, M., Nawaz, A., Hassan, W. (2023). Optimizing mungbean yield and nutritional quality: the synergistic impact of zinc-enriched soil application and amino acid foliar boost. *Biol. Clin. Sci. Res. J.*, **2023***: 616*. doi: https://doi.org/10.54112/bcsrj.v2023i1.616]