Global Research Journal of Natural Science and Technology (GRJNST)
Volume: 04 - Issue 1 (2026)
p.ISSN: 2790-7643 e.ISSN: 2790-7651

Zinc, Iron and Boron Mediated Enhancement of Growth, Yield and Nutritional Quality of Cauliflower (*Brassica oleracea var. botrytis L.*) Across Diverse Agro-Ecological Zones of Punjab, Pakistan

Zia Chishti
Soil Fertility, Soil Fertility Research Institute, AARI, Faisalabad
Sumreen Siddiq (Corresponding Author)
Biochemistry Section, Post-Harvest Research Center, AARI, Faisalabad
drsumreensiddiq@yahoo.com
Muhammad Akram Qazi
Soil Fertility Research Institute, Lahore
Waqar Ahmad
Biochemistry Section, Post-Harvest Research Center, AARI, Faisalabad
Ali Hassan Malik
Soil Fertility, Soil Fertility Research Institute, AARI, Faisalabad
Ghulam Yaseen
Soil Fertility, Soil Fertility Research Institute, AARI, Faisalabad
Nadeem Raza
Soil Fertility, Soil Fertility Research Institute, AARI, Faisalabad
Samina Hameed
Soil Fertility, Soil Fertility Research Institute, AARI, Faisalabad
Fraza Ijaz
Fiber Crop Section, Agronomic Research Institute, AARI, Faisalabad
Saiqah Toor
Soil & Water Testing Laboratory, SFRI, AARI, Gujrat
Waqas Ashraf
Soil Salinity Research Institute, AARI, Pindi Bhattia
Muhammad Shakar
Soil Salinity Research Institute, AARI, Pindi Bhattian
Fahid Ihsan
Senior Scientist (Agronomy), AARI, Faisalabad
Hafiz Muhammad Abu Bakar Amin
Research Officer (Coordination), Punjab Agricultural Research Board (PARB), Lahore
Tayyaba Naz
Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad
Muhammad Mazhar Iqbal (Corresponding Author)
Department of Soil and Environmental Sciences, Faculty of Agriculture, University of Sargodha, Sargodha
mazhar.iqbal@uos.edu.pk

ABSTRACT

The balanced application of micronutrients along with macronutrients is essential to maintain soil health and enhance crop productivity. This practice also ensures the preservation of the nutritional quality of vegetables. Series of farmer field experiments were conducted for consecutive 5 years (2020-2025) to explore the effects of micronutrients such as zinc (Zn), iron (Fe) and boron (B) on the growth, yield and quality attributes of cauliflower in rice and

central cropping zones of Punjab, Pakistan. These experiments followed a randomized complete block design (RCBD) having five treatments. The treatments were included as: control (T_1 = Recommended doses of NPK @ 120-100-100 kg ha^{-1}) and various combinations of Zn, Fe and B viz T_2 toT_5 each with three replications. The micronutrient application rates for Zn, Fe and B were 5 kg ha^{-1}, 10 kg ha^{-1} and 1 kg ha^{-1} respectively. Among the tested treatments, T_5 recorded the highest marketable curd yield (58.06 t ha^{-1}), representing an 8.44% increase over the control (53.54 t ha^{-1}). Across agro ecological zones, T_5 increased marketable curd yield by 10.9% in the rice zone and 4.06% in the central zone relative to the control. The earliest curd initiation was observed in treatment T_5 (67.3 days) indicating its potential for early harvesting whereas the latest was recorded in T_1 (75.6 days), without micronutrient application. The maximum curd diameter (13.67 cm) and curd weight (650.27 g) were obtained under T_4 (B @ 1 kg ha^{-1}). In contrast, T_1 exhibited the lowest curd diameter (11.8 cm), curd weight (538.6 g), and yield (51.61 t ha^{-1}). Overall, the findings suggested that treatments T_4 and T_5 improved curd growth and productivity, whereas T_5 was most effective for achieving early curd initiation. Significant influence of micronutrient application on the gross income of farmers was noticed compared with the control treatment (NPK alone). The highest income (Rs. 8,153,400 ha^{-1}) was recorded under T_5, which was approximately 5.3% higher income than the control (T_1, Rs. 7,741,500 ha^{-1}). Integrated application of NPK + ZnFeB proved superior to the sole NPK treatment for improving the nutritional quality of the crop. Significant improvements were recorded in protein (2.74%), ash (0.96%), and dry matter (11.23%) contents in T_5, whereas crude fat and crude fiber exhibited non-significant response to micronutrient applications.

Keywords: *Cauliflower, Zinc, Iron, Boron, Sustainable Agriculture, Micronutrient fertilization, Dietary attributes*

INTRODUCTION

The cauliflower is a nutrient-rich and economically important vegetable crop that is grown throughout the world. The importance of the vegetable goes beyond its culinary importance to include its high vitamin, mineral, antioxidant, and dietary fiber content. Vegetable quality is an important characteristic of crop production as it is a determinant of the consumer choices, marketing, and sustainability. Considering the increased global demand for high-quality

vegetables along with concerns about food and nutritional security, increasing yield and nutrient content of the cauliflower has been the main aim in current crop production systems. Like other crops of the family, cauliflower is a heavy feeder of mineral elements, depleting the soil of both macronutrients and micronutrients (Kumar et al., 2021). Like other crops of the family, cauliflower is a heavy feeder of mineral elements, utilizing a significant amount of both macronutrients and micronutrients. Traditionally, production of vegetable crops has been largely dependent on the use of macronutrient fertilizers such as nitrogen (N), phosphorus (P), and potassium (K). Long-term fertilization systems lead to the re-organization of microbes such as archaea community through the regulation of the physiochemical nature of soil (organic content, NPK availability, EC, pH) and the activities of enzymes (Sun et al., 2025). However, micronutrients are just as important as macronutrients although in much smaller quantities (Rene et al., 2024).

Some basic micronutrients elements are iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), molybdenum (Mo), boron (B) and chloride (Cl) (Aftab and Hakeem, 2020). The deficiency of these elements in soils is commonly observed with time because of increased intensification of agriculture, soil degradation and improper fertilizer use. As a consequence, crops give lower yield and low-quality products. In case of cauliflower, the deficiency of micronutrients causes some physiological problems like curd browning (because of the lack of B), chlorosis (deficiency of Fe) and curd development (Maurya et al., 2025). Not only does this reduce market yield but also the quality of products. It was revealed that the lack of trace elements has a great influence on food security and safety (Sagwal et al., 2023; Shubham et al., 2023). Thus, the problem of micronutrient imbalance should be solved through correct fertilization strategy in order to get sustainable cauliflower production. These trace elements play an important role in enzyme activation.

Furthermore, micronutrient fertilization has a possibility of improving the nutritional content of the cauliflower curds that will help humans by filling up micronutrient deficiency in diets, this is related to the concept of biofortification in agronomy. Biofortification has emerged as an efficient approach to deal with the problem of hidden hunger, which is mainly caused due to deficiencies of Fe and Zn. However, the past fertilizer program initiatives have concentrated more on the improvement of the crop yield and not much importance was paid to the nutritional quality of the crops with respect to human health (Welch et al. 2013). Therefore, it becomes

necessary to conduct systematic studies in order to understand the effect of micronutrient fertilization on yield, nutrient uptake, and quality traits of cauliflower under varied agro-ecological environments. This study will explore the possibilities of micronutrient fertilization in improving the yield and nutritional quality of cauliflower.

MATERIALS AND METHODS

Field experiments have been performed during five consecutive rabi seasons ranging from 2020-21 to 2024-25 at farmers' field sites in Soil Fertility Research Institute, Lahore to find out the impact of the application of micronutrients to the soil on the growth, yield, and nutrient quality parameters of cauliflower. It is highly tolerant to various types of soils including sandy loam and clay. The physical and chemical characteristics of the soil determined following Estefan et al., (2013) and Qazi et al., (2021) in the field are depicted in Table 1.

Table 1: Physico-chemical characters of soil of the field areas

Soil Parameters	Values	
	Average	Range
EC_e (dS m^{-1})	2.1	1.2 - 3.2
pH_s	8.2	7.9 - 8.3
OM (%)	0.77	0.35 - 0.98
P (mg kg^{-1})	7.2	3.2 - 13.4
K (mg kg^{-1})	185	104 - 374
Zn (mg kg^{-1})	0.42	0.2 - 0.86
Fe (mg kg^{-1})	2.35	1.16 - 4.2
B (mg kg^{-1})	0.25	0.1 - 0.51

For experimentation the design of experiment was made on the basis of Randomized Complete Block Design having three replications. An important commercially available variety known as "Bonny" was chosen for transplantation in second fortnight of November in each year and five different treatments of nutrients were applied and given as under;

T_1 = Recommended doses of NPK (120-100-100 kg ha^{-1})

T_2 = Recommended doses of NPK + Zn @ 5 kg ha^{-1}

T_3 = Recommended doses of NPK + Fe @ 10 kg ha^{-1}

T_4 = Recommended doses of NPK + B @ 1kg ha^{-1}

T_5 = Recommended doses of NPK + ZnFeB 5-10-1 kg ha^{-1}

Cauliflower was sown at two locations at Rice Zone and Central Cropping Zone of Punjab Pakistan in second fortnight of November in each year. Full recommended doses of P, K and ½ N were applied at transplantation and other ½ N was applied after 30 days of transplantation. Micronutrients i.e. Zn, Fe and B were applied in soil at transplantation according to treatments. Sources of Zn, Fe and B were $ZnSO_4$, $FeSO_4$ and Borax respectively.

Protection of the crop was provided periodically, and the agronomic information was collected. Harvesting of the crop was done during the first half of March, and data on the yield and other characteristics were recorded. The quality attributes (crude protein, crude fat, crude fiber, ash %, dry matter) were analyzed using the procedures mentioned by AOAC (2005). Analysis of Variance (ANOVA) was performed with the help of Statistix 8.1 (Analytical Software, Tallahassee, FL, USA). Comparison of means was done using the LSD test.

RESULTS AND DISCUSSION

Soil physio-chemical properties

From the analysis before planting, it was found that the soil (Table 1) in the experimental field had slightly alkaline (mean pH of 8.2) properties, which is an indication of decreased solubility and availability of micronutrients. This, coupled with the low organic matter content (0.77%), made it difficult for plants to obtain sufficient micronutrients since organic matter helps to retain nutrients (Duiker, 2021). Fe (2.11 mg kg^{-1}), Zn (0.72 mg kg^{-1}), and B (0.36 mg kg^{-1}) were found to be deficient.

Zinc deficiencies are usually due to soils having a high pH, low organic matter, and high phosphorus, causing chlorosis, poor growth, and leaf abnormalities (Chhabra and Kumar, 2018). Micronutrient deficiency and imbalance during vegetative growth and curd formation phases are likely to negatively impact the growth and productivity since this plant is very sensitive to micronutrient balance (Dash 2003).

Growth and yield characteristics

Diverse treatments had a great effect on growth and yield attributes of cauliflower comprising number of days for curd initiation, curd diameter, curd weight and marketable curd yield (Table 2). Statistical analysis revealed that treatment effects on days for curd initiation ($p = 0.0236$), curd weight ($p = 0.035$) and curd yield ($p = 0.0215$) were statistically significant, but curd diameter was non-significant ($p = 0.405$). Treatment T5 (ZnFeB) showed earliest curd

initiation (67.3 days) and this was statistically earlier than other treatments whereas T_3 needed the greatest number of days for curd initiation (76.7 days). Early curd initiation in case of T_5 treatment showed fast translocation of photosynthetic products towards the curd and it assisted in early curd formation. Moklikar et al. (2018) also reported the minimum days for curd initiation in micronutrient application treatment. These results were in agreement with the findings of Lashkari et al., (2007).

Diameter of curd varied from 11.83 cm (no micronutrient applied) to 13.37 cm (T_4: B applied). The results are consistent with previous findings by Sani et al., (2018), Hassan at al., (2018), Kumar and Choudhary, (2002). Even though T_4 (B applied) treatment gave the maximum diameter of curd, there was no statistically significant difference ($p > 0.05$) between the treatments. This indicated that the treatments applied had minimal impact on this characteristic. The insignificant variation indicates that diameter of curd is a relatively stable character and could be influenced more by genetics and environmental factors than the treatments tested.

A marked improvement in curd weight was observed in the treatments. The highest weight of curd (650.2 g) was recorded in T_4, which was statistically similar to T_5 (648.7 g) but significantly higher than other treatments. The least curd weight (538.1 g) was obtained in T_1. Increased curd weight in T_4 and T_5 could be attributed to better nutrient utilization, increase in photosynthetic rate, and better translocation of assimilates to curd development, thus producing heavier and compact curds. Previous study in cauliflower Hassan et al., (2018) has reported that micronutrients (Boron) application increased curd weight.

There is a great variation in curd yield among treatments. The greatest curd yield (58 t ha^{-1}) was obtained from the application of micronutrients (ZnFeB) T_5. T_2 (56.2 t ha^{-1}) and T_3 (56 t ha^{-1}) had the second greatest curd yield respectively. The least curd yield (53.5 t ha^{-1}) was obtained in T1 where only application of NPK fertilizer was carried out. The greater yield obtained from the T_5 could be due to early curd formation along with greater weight of the curd. The findings show that the treatment T_5 has increased growth and yield performance. Such increase in curd yield as a result of application of micronutrients (ZnFeB) has been reported in other studies (Bairwa et al. 2020, Moklikar et al. 2018). Such effects were also reported by Hasan et al. (2025) showing that micronutrient supply increases the growth and yield of cauliflower. There were five treatments for increasing cauliflower yield through early curd initiation and obtaining maximum curd yield while T_4 was the best treatment in producing

large and heavy curds. It shows that the tested treatments positively affected cauliflower growth and yield but not curd diameter.



Figure 1: Average cauliflower yield (Tons ha^{-1}) as influenced by applied micronutrients

Table 2: Effect of applied micronutrient on growth and yield parameters of cauliflower

Treatment	Days taken to curd initiation	Diameter of the curd (cm)	Curd weight (g)	Curd yield (Tons ha^{-1})
T1 = NPK @120-100-100 kg ha^{-1}	75.7 a	11.833 b	538.1 d	53.5 b
T2 = NPK + Zn @5 kg ha^{-1}	75.7 a	12.70 ab	596 c	56.2 ab
T3 = NPK + Fe @10 kg ha^{-1}	76.7 a	12.76 ab	628.8 b	56 ab
T4 = NPK + B @1 kg ha^{-1}	72.3 ab	13.36 a	650.2 a	55.4 ab
T5 = NPK + ZnFeB @ 5-10-1 kg ha^{-1}	67.3 b	12.96 ab	648.7 ab	58 a
P-values	0.0236	0.405	0.035	0.215
LSD	2.31	1.72	1.87	2.35

Quality Attributes as Influenced by Applied Treatments

Crude Protein

Influence of different combinations of micronutrients showed a significant ($p = 0.005$) impact on the protein of the crop (Table 3). Treatment with the combination of micronutrient in T_5 (5-10-1 kg ha^{-1}) had the highest protein content (2.74%), which was significantly high than other treatments. Sole NPK treatment had the lowest protein content (2.20%). Individual applications of Zn, Fe, and B enhanced the protein content up to 2.42%, 2.53%, and 2.45% respectively, than the control. The highest protein content in the cauliflower curd was reported by Sarker et al. (2019) by the application of mixture of micronutrients. This could be due to the synergistic effect of Zn, Fe, and B on the N metabolism, enzyme activation, and protein synthesis.

Table 3: Effect of applied micronutrient application on quality attributes of cauliflower

Treatments	Protein (%)	Crude fat (%)	Crude fiber (%)	Ash (%)	Dry matter (%)
T1 = NPK @120-100-100 kg ha^{-1}	2.20 d	0.33	1.95	0.68 b	10.21 d
T2 = NPK + Zn @5 kg ha^{-1}	2.42 c	0.37	2.03	0.88 a	10.58 c
T3 = NPK + Fe @10 kg ha^{-1}	2.53 b	0.38	2.09	0.87 a	10.87 b
T4 = NPK + B @1 kg ha^{-1}	2.45 c	0.36	2.15	0.81 ab	10.78 b
T5 = NPK + ZnFeB @ 5-10-1 kg ha^{-1}	2.74 a	0.41	2.28	0.96a	11.23 a
P values	0.005	0.0001	0.0001	0.022	0.046
LSD (0.05)	0.0179	NS	NS	0.142	0.015

Crude Fat

The values for crude fat content ranged from 0.33 to 0.41% (Table 3), with the maximum content being recorded for the treatment where application of combined micronutrients was done (T_5). However, the differences between treatments were non-significant (NS), indicating minimal effect of micronutrient application on the quality parameter.

Crude Fiber

The values for the crude fiber content ranged from 1.95 to 2.28% among treatments (Table 3). Maximum crude fiber (2.28%) content was recorded for treatment T_5 (where NPK + ZnFeB application was done), while the minimum value of 1.95% was recorded for treatment T_1 (where no micronutrient application was done). The difference between treatments was non-significant, indicating that fiber content was relatively a constant genetic property of the crop.

Ash Content

Micronutrient application significantly affects ($p = 0.022$) ash content (Table 3). The maximum ash content (0.96%) was observed in treatment T_5 (ZnFeB), followed by T_2 (0.88%) and T_3 (0.87%), which received Zn and Fe, respectively. The minimum value of ash content (0.68%) was observed in T_1 where only NPK was applied without any micronutrient. Increase in ash percentage shows the efficient mineral uptake in the form of ash due to proper nutrient accumulation and translocation in plants.

Dry Matter

A significant difference ($p = 0.046$) in dry matter content was observed due to micronutrient application (Table 3). Supplementation of ZnFeB with NPK (T_5) resulted in the maximum dry matter content (11.23%), followed by T_3: Fe (10.87%), T_4: B (10.78%) and T_2: Zn (10.58%)

whereas the minimum value (10.21%) was found in treatment with NPK alone. An improvement in the dry matter content could be attributed to an efficient photosynthetic rate and nutrient utilization under balanced fertilization of both macro and micronutrient nutrients. The significant effect of micronutrient mixture application on dry matter production has been reported by Venkateswarlu et al., (2026).

The application of Zn, Fe, and B improved the proximate quality attributes of cauliflower with respect to crude protein, crude fat, crude fibre, ash, and dry matter depending on the agro-ecological zones of locations. This might be due to the significance of nutrients in enzyme activation, photosynthesis, carbohydrate, and protein synthesis, and the development of plant structure. For example, Zn has a major role in the activation and metabolism of many enzymes and helps to improve nutrient availability and growth of plants (Ummer et al., 2024). However, Fe has a major role in chlorophyll synthesis, electron transport, and photosynthesis metabolism, while B has a major role in cell wall synthesis, membrane stability, carbohydrate translocation, and reproductive process. It is notable here that some previous studies have revealed the sensitivity of cauliflower to Zn and B fertilizers, which have had a great impact on crop performance and nutrient availability (Shrestha et al., 2020; Bairwa et al., 2023). Likewise, the application of mixture of micronutrients has improved the quality and productivity of cauliflower when compared with unfertilized controls (Mori et al., 2020; Kumar et al., 2023).

Hence, the positive impact seen from various locations could be attributed to the increase in the availability and uptake of micronutrients. On the other hand, variations seen in agro-ecological zones could be attributed to the differences in soil pH, organic matter content, natural availability of micronutrients, and climatic factors (Shaukat, 2025). It has been recently demonstrated using multilocational trials that mixtures of ZnFeB improve the availability, uptake, and productivity of cauliflower, especially in micronutrient-deficient soils (Venkateswarlu et al., 2026).

Farmers' Earnings

The impact of using various micronutrients treatments on gross income of cauliflower has been found significant in comparison to the control treatment (NPK alone). The maximum income was recorded for treatment T_5, where the combination of ZnFeB along with the NPK dose recommended was used and the income was Rs. 8,153,400 ha^{-1} (Figure 2). The income

obtained from this treatment was about 5.3% more than the control treatment T_1 (Rs. 7,741,500 ha^{-1}), making it the most profitable nutrient management strategy.

It could be explained that the high income in case of combined treatment of micronutrients (T_5) was because of the synergism in plant's growth, physiology, and yield. Similar results have been found regarding the gross income, net income and the maximum benefit : cost ratio by Tirkey et al. (2024) using foliar application of micronutrients.

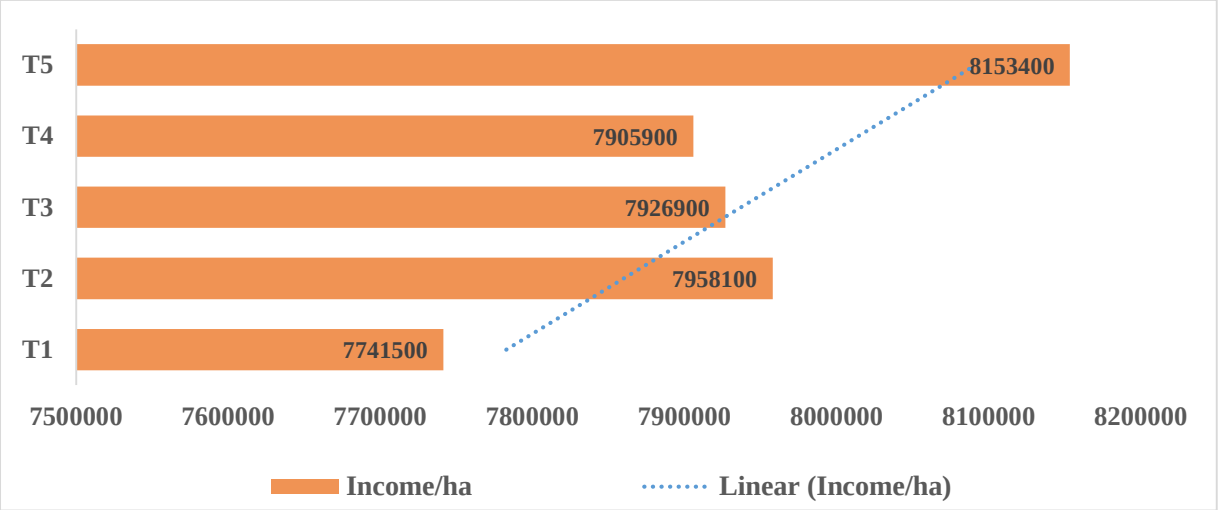


Figure 2: Effect of applied micronutrient on farmer income (per hectare)

CONCLUSION

Overall, the integrated application of NPK + Zn + Fe + B proved superior to the sole NPK treatment for improving growth, yield and the nutritional quality of the cauliflower crop. Among the treatments, T_5 exhibited the earliest curd initiation. Early curd initiation under T_5 suggests faster translocation of photosynthate towards the curd and it helped in early appearance of curd. The curd weight, yield and income were significantly higher in T_5 than the remaining treatments. These findings indicate that treatment T_5 effectively improved both crop growth, productivity and gross income of farmers. Significant improvements were observed in protein, ash, and dry matter contents, whereas crude fat and crude fibre exhibited non-significant responses. These findings suggest that balanced fertilization with both macro and micronutrients enhances nutrient uptake, metabolic processes, and biomass production, ultimately improving the overall quality of the crop. The supplementation of Zn, Fe, and B with recommended NPK dose likely promoted enzymatic activity, N assimilation, and mineral

accumulation lead to healthier growth and yield as well as better nutritional attributes compared with individual micronutrient applications.

Recommendations

Overall, the results demonstrate that the combined application of Zn, Fe, and B with the recommended NPK fertilizer is more economically beneficial than the application of individual micronutrients or NPK alone, making it an appropriate management practice for improving cauliflower income.

Acknowledgments

The authors highly appreciate the technical support provided by the supportive and ministerial staff of Soil Fertility Research Institute (SFRI) and Ayub Agricultural Research Institute (AARI) Punjab, Pakistan in experimentation and analysis of samples for completion of this study. The valuable contribution of the anonymous reviewers for enhancement of this paper before publishing is highly acknowledged.

Statements of Declaration

AI Tool Declaration: The authors have not used any AI tool in the writing of this paper.

Data Availability Statement: All data generated and/or analyzed during this experiment are included in this manuscript.

Ethics Approval and Consent Procedure: Approval granted by the department concerned.

Consent for Publication: Approval granted

Funding Acquisition: Not applicable

Conflict of Interest: Authors declare no conflict of interest.

Life Sciences Reporting: Under the head of Life Sciences, there was no threat observed in this current research paper.

Ethical Responsibility: This is an original research-based paper. This paper has neither been submitted nor sent anywhere else for publication.

Informed Consent: All the authors have read the full paper, approved it for submission and are accountable for the content of the manuscript.

REFERENCES

Aftab, T., & Hakeem, K. R. H. (Eds.). (2020). *Plant micronutrients: Deficiency and toxicity management*. Springer. https://doi.org/10.1007/978-3-030-49856-6

AOAC. (2005). *Official methods of analysis of AOAC International* (18th ed.). AOAC International, Gaithersburg, MD, USA. ISBN 0-935584-77-3.

Bairwa, P. L., Dixit, A., & Singh, V. (2023). Influence of macro and micronutrients on the yield and quality attributes of cauliflower (*Brassica oleracea* var. *botrytis* L.) cv. "Pusa Sharad." *International Journal of Plant & Soil Science, 35*(18), 465–475. https://doi.org/10.9734/ijpss/2023/v35i183311

Bairwa, P. L., Dixit, A., & Sahu, M. K. (2020). Effect of different micronutrients on growth and yield of cauliflower (*Brassica oleracea* var. *botrytis* L.). *International Journal of Chemical Studies, 8*(6), 3084–3089.

Chhabra, V., & Kumar, R. (2018). Role of zinc application on rice growth and yield. *Plant Archives, 18*(2), 1382–1384.

Duiker, S. W. (2021). Soil organic matter and nutrient availability. In *Soil organic carbon and feeding the future* (pp. 103–136). CRC Press.

Estefan, G., Sommer, R., & Ryan, J. (2013). *Methods of soil, plant, and water analysis: A manual for the West Asia and North Africa region* (3rd ed.). International Center for Agricultural Research in the Dry Areas. https://icarda.org/publications/11676/icarda-style-manual

Hasan, B. M. M., Pipil, M. H., Annee, I. J., Alam, M. N., Ali, R., & Karmokar, A. C. (2025). Effect of micronutrients on growth and yield of cauliflower (*Brassica oleracea* var. *botrytis* L.) under problematic soil environment. *International Journal of Biosciences, 26*(2), 169–178. http://dx.doi.org/10.12692/ijb/26.2.169-178

Hassan, M. R., Julie, S. N., Akber, A., Kundu, P. K., & Zaman, M. S. (2018). Influence of micronutrient (boron) for the growth and yield of cauliflower. *Journal of Bioscience and Agriculture Research, 18*(1), 1464–1469. https://doi.org/10.18801/jbar.180118.181

Kumar, A., Kumar, M., Singh, R., Prakash, S., & Singh, S. (2021). Growth and yield of cauliflower (*Brassica oleracea* L. var. *botrytis*) as influenced by integrated sources of nutrients and mulching. *Annals of Horticulture, 14*(1), 27–32. https://doi.org/10.5958/0976-4623.2021.00006.2

Kumar, M., Chaudhary, S. K., Shashikant, Shashibala, Kumar, R., Singh, S. K., Prabhakar, M. K., & Singh, P. K. (2023). Effect of boron and zinc on growth and yield attributes in early cauliflower (*Brassica oleracea* var. *botrytis* L.). *International Journal of Plant & Soil Science, 35*(6), 104–110. https://doi.org/10.9734/ijpss/2023/v35i62844

Kumar, S., & Choudhary, D. R. (2002). Effects of FYM, molybdenum and boron application on yield attributes and yield of cauliflower. *Crop Research, 24*(3), 494–496.

Lashkari, C. O., Makwana, A. N., & Meman, M. A. (2007). Effect of zinc and iron on growth and yield of cauliflower (*Brassica oleracea* var. *botrytis* L.) cv. Snowball-16. *Asian Journal of Horticulture, 2*(2), 277–279.

Maurya, H. K., Lata, R., Sundar, S., Mitra, D. S., & Meena, D. K. (2025). Physiological disorders of cauliflower and their management. *The Agriculture Magazine, 4*(5), 83–87.

Moklikar, M. S., Waskar, D. P., Maind, M. M., & Bahiram, V. K. (2018). Studies on effect of micronutrients on growth and yield of cauliflower (*Brassica oleracea* var. *botrytis*) cv. Sungro-Anandi. *International Journal of Current Microbiology and Applied Sciences, 7*(6), 2351–2358.

Mori, C. V., Patel, A. R., Patel, R. C., Patel, A. J., & Patel, D. S. (2020). Effect of different micronutrients and stage of their application on yield and quality of cauliflower (*Brassica oleracea* var. *botrytis*). *International Journal of Chemical Studies, 8*(4), 3712–3715. https://doi.org/10.22271/chemi.2020.v8.i4au.10222

Qazi, M. A., Khan, M. S. A., Ahmad, F., & Qamar, M. J. (2021). *SFRI-Guide-2: Soil and water analysis manual*. Directorate of Soil Fertility Research Institute, Department of Agriculture, Punjab. https://sfri.punjab.gov.pk/sfri-guides

René, N. K., Noel, G., Damien, A. A. H., & Sidiky, B. (2024). Effects of natural organic and mineral fertilizers on the growth and productivity of cabbage (*Brassica oleracea*) in Daloa Commune, West-Central Côte d'Ivoire. *International Journal of Agriculture and Biosciences, 13*(1), 46–52. https://doi.org/10.47278/journal.ijab/2024.085

Sagwal, A., Wadhwa, P., Shubham, & Kaushal, S. (2023). Essentiality of micronutrients in soil: A review. *International Journal of Plant & Soil Science, 35*(24), 56–65. https://doi.org/10.9734/ijpss/2023/v35i244297

Sani, M. N. H., Tahmina, E., Hasan, M. R., Islam, M. N., & Uddain, J. (2018). Growth and yield attributes of cauliflower as influenced by micronutrients and plant spacing. *Journal of Agriculture and Ecology Research International, 16*(1), 1–10. https://doi.org/10.9734/JAERI/2018/44192journaljaeri

Sarker, M. M. H., Moslehuddin, A. Z. M., Jahiruddin, M., & Islam, M. R. (2019). Direct and residual effects of micronutrients on crops in a pattern in floodplain soil. *Communications in Soil Science and Plant Analysis, 50*(18), 2245–2262. https://doi.org/10.1080/00103624.2019.1659295

Shaukat, F. (2025). Evaluation of zinc and boron fertilization on crop yield and nutrient uptake in salt-affected soils under greenhouse conditions. *Trends in Biotechnology and Plant Science, 3*(4), 79–86. https://doi.org/10.62460/TBPS/2025.013

Shrestha, S., Becker, M., Lamers, J. P. A., & Wimmer, M. A. (2020). Diagnosis of zinc and boron availability in emerging vegetable-based crop rotations in Nepal. *Journal of Plant Nutrition and Soil Science, 183*(4), 429–438. https://doi.org/10.1002/jpln.202000020onlinelibrary.wiley+7

Shubham, S. U., & Kaushal, R. (2023). Effect of nitrification inhibitors on quality, yield and economics of cauliflower cv. PSB K1 in Typic Eutrochrept under mid hills of North Western Himalayas. *Journal of Plant Nutrition, 46*(17), 4096–4109. https://doi.org/10.1080/01904167.2023.2220741

Sun, S. K., Li, M., Zhao, L. L., & Liu, S. J. (2025). Archaeal abundance as a negative indicator of soil fertility. *Asian Journal of Agriculture and Biology, 2025*, e2025058. https://doi.org/10.35495/ajab.2025.058

Tirkey, A., Shankar, D., & Kaushik, S. (2024). Effect of foliar spray of micronutrients on yield and benefit–cost ratio of cauliflower (*Brassica oleracea* var. *botrytis* L.) under polyhouse. *International Journal of Plant & Soil Science, 36*(8), 985–991. https://doi.org/10.9734/ijpss/2024/v36i84930

Ummer, K., Ali, L., Hafeez, H. T., Ahmed, F., Nisar, I., Iqbal, M. A., Zaib, H., Rashid, S., & Waqas, M. (2024). Impact of Zn-lysine chelation foliar application in wheat plants under drought stress. *Agrobiological Records, 16*, 19–32. https://doi.org/10.47278/journal.abr/2024.008

Venkateswarlu, M., Thiyageshwari, S., Abhirami, P., Selvi, D., Suganya, S., & Anandham, R. (2026). Development and factorial evaluation of micronutrient mixtures to enhance soil fertility, nutrient uptake, and cauliflower yield. *Discover Agriculture, 4*, 117. https://doi.org/10.1007/s44279-026-00589-1

Welch, R. M., Graham, R. D., & Cakmak, I. (2013). *Linking agricultural production practices to improving human nutrition and health* (Expert paper for the ICN2 Second International Conference on Nutrition Preparatory Technical Meeting, Rome, Italy, 13–15 November 2013). Food and Agriculture Organization of the United Nations. http://www.fao.org/3/a-as574e.pdf