RESPONSE OF MICRONUTRIENT APPLICATIONS ON HYBRIDS OF COLOURED CAPSICUM

Thesis

by

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(H-2021-51-D)

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CERTIFICATE-I

This is to certify that the thesis titled, **"Response of Micronutrient Applications on Hybrids of Coloured Capsicum"** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy Vegetable Science** in the discipline of **Horticultural Sciences** to Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) - 173 230 is a bonafide research work carried out by **Mr. Bonde Kuldeep Jagannath (H-2021-51-D)** son of Sh. Jagannath Tryambak Bonde under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been fully acknowledged.

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CERTIFICATE - II

This is to certify that the thesis titled, **"Response of Micronutrient Applications on Hybrids of Coloured Capsicum"** submitted by **Mr. Bonde Kuldeep Jagannath (H-2021-51-D)** son of Sh. Jagannath Tryambak Bonde to the Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP) – 173 230, India in partial fulfilment of the requirements for the degree of **Doctor of Philosophy Vegetable Science** in the discipline of **Horticultural Sciences** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

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LIST OF ABBREVIATIONS

ANOVA	:	Analysis of Variance
B:C	:	Benefit Cost Ratio
CD	:	Critical Difference
cm	:	Centimeter
CV	:	Coefficient of Variation
cv.	:	Cultivar
df	:	Degree of Freedom
dS	:	Deci Siemens
DW	:	Dry weight
e.g.	:	For example
et al.	:	Co-workers
etc.	:	Et cetera
FAO	:	Food and Agriculture Organization
FW	:	Fresh weight
FYM	:	Farm Yard Manure
g	:	Gram
ha	:	Hectare
HP	:	Himachal Pradesh
i.e.	:	That is
IARI	:	The Indian Agricultural Research Institute
ICAR	:	The Indian Council of Agricultural Research
IIVR	:	The Indian Institute of Vegetable Research
K	:	Potassium
kg	:	Kilogram
L	:	Litre
LAI	:	Leaf Area Index
m	:	Meter
m^2	:	Meter square
mg	:	Milligram

ml	:	Millilitre
mm	:	Millimeter
N	:	Nitrogen
NHB	:	National Horticulture Board
NS	:	Non-significant
OC	:	Organic carbon
OD	:	Optical Density
P	:	Phosphorus
PDI	:	Percent Disease Index
PGR	:	Plant growth regulator
ppm	:	Parts per million
pH	:	Potential of Hydrogen
q	:	Quintal
RDF	:	Recommended Dose of Fertilizers
S	:	Siemens
SE	:	Standard Error
SS	:	Sum of Square
t	:	tonne
TSS	:	Total Soluble Solids
USDA	:	The United States Department of Agriculture
WSF	:	Water Soluble Fertilizers
viz.	:	*Videlicet*
YSP UHF	:	Dr. Yashwant Singh Parmar University of Horticulture and Forestry

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Chapter-1

INTRODUCTION

Capsicum (*Capsicum annuum* L.) belonging to the family Solanaceae, often known as sweet pepper or bell pepper, is a prominent vegetable crop grown globally for its vibrant colour, flavour and nutritional value. It was first grown in the American tropics and is now grown all over the world for fresh, dried and processed food products. Capsicum originated in Mexico, with the secondary centre of origin in Guatemala and Central America (Heiser and Smith 1953). Capsicum was introduced to India by the British during the 19^{th} century, specifically in the Shimla hills of Himachal Pradesh and the Nilgiri hills of Tamil Nadu (Greenleaf 1986). It was soon widely cultivated in India's hilly regions for commercial purposes and its association with Shimla led to it being popularly called "Shimla Mirch."

Capsicum flourishes in temperate to subtropical climates, with optimal growth occurring at temperatures between 20°C and 30°C and night temperatures ideally between 15°C and 18°C. The plants require full sun and well-drained soil with a pH of 6.0 to 7.0. They are susceptible to frost and extreme temperatures, which can adversely affect fruit development and yield. The capsicum cultivation typically spans 7 to 10 months under field and protected conditions respectively (Jones et al. 2018).

In India, bell pepper occupies an area of 0.39 lakh hectares with the production of 6.31 lakh MT and productivity of 15.91 MT/ha (Anonymous 2024a). In India, capsicum is mainly grown in West Bengal, Haryana, Jharkhand, Karnataka, Madhya Pradesh, Himachal Pradesh, Jammu and Kashmir and Maharashtra. It is extensively grown on an area of 2.96 thousand hectares with the production of 51.77 lakh MT and productivity of 17.48 MT/ha in Himachal Pradesh (Anonymous 2024b). Capsicum is widely grown as a cash crop in the sub-temperate regions of Solan, Sirmaur, Mandi, Bilaspur, Chamba and the lower areas of Shimla district in Himachal Pradesh during the summer and rainy seasons. The off-season production yields substantial profits by supplying capsicum to the neighbouring plains (Singh et al. 2020).

According to USDA Food Data Central, a 100 g serving of fresh capsicum delivers a range of nutrients, including 4.3 g of carbohydrates, 1.3 g of proteins and 0.4 g of fats, amounting to 25.5 calories. It is also a rich source of vitamin A, with 683 IU per 100 g and contains 0.06 mg of Vitamin B1, 0.03 mg of riboflavin Vitamin B2 and 175 mg of Vitamin C. Additionally, capsicum offers 10 mg of calcium, 1.2 mg of iron and 22 mg of phosphorus. Beyond these nutrients, capsicum is also known for its antioxidant properties and dietary fibre content, which contribute to overall health and well-being. Capsicum fruits are enjoyed both raw and cooked and are also used in traditional medicine. They are believed to help alleviate symptoms of asthma, coughs, sore throats and toothaches. Singh et al. (2010) have highlighted the medicinal benefits of capsicum, noting its anti-inflammatory and antioxidant properties. Ascorbic acid in capsicum has antioxidant properties and may help prevent cancer, cardiovascular diseases, stroke, atherosclerosis and cataracts (Maldonado et al. 2002).

Research indicates that red and yellow bell peppers have higher levels of vitamins and antioxidants than green bell peppers. These coloured varieties require protected environments to achieve their full colouration, as they do not develop optimal hues in open fields (Smith et al. 2015). Capsicum is a major vegetable cultivated under protected structures due to its adaptability and the benefits of such cultivation, including enhanced quality and extended growing seasons. The growing demand from the fast food, hotel and catering industries for their superior visual appeal, flavour and nutritional content has made coloured bell peppers highly sought after in urban markets (Brown et al. 2020). This has increased farmer interest and made capsicum an important off-season crop with significant economic value for both fresh market sales and processing (Kumar et al. 2016).

The levels of beneficial compounds like vitamin C (ascorbic acid) can be influenced by various factors such as growing conditions, nutrient management, genotype and fruit maturity in capsicum (Buczkowska et al. 2016). To maximize fruit yield and quality, capsicum cultivation requires adequate fertilization and irrigation. A well-balanced mix of macro and micronutrients is not only crucial for plant development but also supports environmental health (Chen 2006).

Plant nutrients are essential for sustainable agriculture, playing a crucial role in ensuring optimal plant growth and productivity. The quantity and quality of crop yields can be significantly affected by an insufficient supply of essential nutrients, leading to deficiency symptoms in plants. These nutrient deficiencies in plants are closely linked to soil imbalances, which, in turn, are often reflective of human nutritional inadequacies. Addressing these deficiencies is critical for both agricultural productivity and public health. Therefore, it is essential to accurately diagnose nutrient shortages and implement appropriate corrective measures, such as soil amendments or targeted fertilization, to restore soil health and improve plant growth. Additionally, integrating advanced soil testing and monitoring techniques can help in early detection and prevention of nutrient imbalances, ensuring sustainable agricultural practices.

Macronutrients are crucial for plant growth and development and capsicum plants show positive responses to balanced fertilizer applications, with high demand for nitrogen (N), phosphorus (P) and potassium (K). Micronutrients have been extensively recognized for their vital role in boosting crop productivity, making a substantial impact on agricultural yields (Tripathi et al. 2015). Micronutrients are necessary substances that are needed in extremely small amounts for overall growth of plants but, are equally essential for various plant metabolic activities.

Boron, zinc and calcium are three important essential nutrients which help in various plant metabolic processes. These nutrients play a vital role in enhancing the chemical composition and overall health of vegetable crops, acting as catalysts in various organic processes within plants (Karthick et al. 2018). These nutrients are essential for plant growth, development and metabolism. However, their deficiencies can lead to physiological disorders and diseases, ultimately affecting both the quality and quantity of vegetable yields (Sharma and Kumar 2016). In recent years, micronutrient deficiencies have become more prevalent due to factors such as intensive farming practices, soil erosion, nutrient loss through leaching, liming of acidic soils and unbalanced fertilizer use, particularly with NPK fertilizers, without adequate nutrient replenishment (Aske et al. 2017). These deficiencies can lead to reduced crop yields and compromised quality, ultimately impacting food security and agricultural sustainability. Addressing these issues is crucial for enhancing nutrient management strategies and ensuring optimal plant health and productivity.

Boron is crucial for cell growth and development, particularly in the meristematic regions of plants. Boron is important for both flower development and initial fruit, or seed set and maintaining the structural integrity of cell wall and cell membranes (Zhang et al. 2014). In capsicum, boron aids in fruit development by enhancing calcium metabolism and nitrogen absorption (Pandav et al. 2016). It also contributes to carbohydrate metabolism, root elongation and photosynthesis (Islam et al. 2018). Boron deficiency can lead to poor fruit set, reduced fruit size and lower yields, with symptoms such as rosetting, brittle and curled leaves and fruit distortion (Bubarai et al. 2017; Harris and Lavanya 2016).

Zinc is essential for plant growth and development, facilitating hormone synthesis, carbohydrate formation and key cellular functions like protein metabolism, gene expression and photosynthesis (Pankaj et al. 2018). It is crucial for ribosome integrity and supports starch formation, seed maturation and seedling vigour (Sainju et al. 2003; Trivedi and Dhumal 2013). Additionally, zinc is involved in reproductive processes, enzymatic activities and sulphur and nitrogen metabolism (Pandav et al. 2016). Zinc deficiency leads to chlorosis, premature leaf drop, stunted growth and leaf distortion, affecting overall plant health and productivity (Alloway 2008). Adequate zinc levels are therefore vital for maximizing crop yield and quality in capsicum.

The interaction between zinc and boron has shown significant benefits for crops in vegetable crops. The combined application of these micronutrients led to increased mature fruit numbers, enhanced fruit quality with higher total soluble solids and improved content of ascorbic acid (Salam et al. 2011). Additionally, the application of zinc and boron together has resulted in increased plant height, more leaves and a greater number of fruits per plant (Ali et al. 2015).

Calcium is essential for plant health, playing a crucial role in cell wall formation and stability, which is vital for maintaining structural integrity and supporting overall growth (Marschner 2011). It regulates various cellular processes, including enzyme activity, membrane permeability and signal transduction (White and Broadley 2003). Additionally, calcium influences root development, nutrient uptake and plant disease resistance (Harris et al. 2012). Deficiencies in calcium can lead to poor root growth, weakened cell walls and increased disease susceptibility, ultimately impacting plant health and yield.

Addressing macro and micro nutrient deficiencies in plants has led to the development of advanced agro techniques, with foliar application emerging as a highly effective method. Macro and micronutrients can be applied either to the soil or sprayed onto foliage, but numerous studies have demonstrated that foliar applications significantly enhance both nutrient levels and crop yield (Bindraban et al. 2015). Foliar fertilization involves directly applying one or more essential plant nutrients to the aerial parts of plants, complementing traditional soil fertilization methods (Sabbe and Hodges 2010). This technique is widely recognized for its ability to deliver nutrients quickly and efficiently, improving plant nutritional status and enhancing crop yield and quality with relatively low costs and infrastructure requirements (Fernández et al. 2013). One key advantage of foliar fertilization is the rapid absorption of sprayed nutrients through leaf surfaces, which helps correct nutrient deficiencies during critical growth stages (Fageria et al. 2009). Timely foliar application has been shown to boost both crop yield and post-harvest quality, making it a viable strategy for increasing essential nutrients like zinc, boron and calcium in crops.

In addition to improving yields, foliar application can enhance resistance to stress and contribute to better overall crop health, particularly when soil conditions limit nutrient uptake (Fernández et al. 2013). This method has been extensively researched and is increasingly adopted in modern agriculture as an efficient, cost-effective strategy to enhance nutrient content in crops. Thus, foliar application can be used as a method of increasing level of essential elements like zinc, boron and calcium in capsicum crop.

The interaction between boron, zinc and calcium significantly boosts capsicum's physiological efficiency and stress tolerance. Together, these nutrients synergistically enhance fruit development, increase yield and improve both the physical and chemical properties of capsicum, resulting in superior crop yield quality.

In light of the information discussed above, the research, titled **"Response of Micronutrient Applications on Hybrids of Coloured Capsicum"** was undertaken to explore the role of nutrient applications in enhancing the growth, yield and quality of coloured capsicum hybrids with the following broad objectives:

OBJECTIVES:

- To study the effect of boron, zinc and calcium application on growth and yield of coloured capsicum hybrids
- To study the effect of boron, zinc and calcium application on quality of coloured capsicum hybrids
- To study the economics of the different treatments

Chapter-2

REVIEW OF LITERATURE

Capsicum, particularly coloured hybrids, are not only valued for their culinary uses but also for their nutritional benefits, including high levels of vitamins and antioxidants. The global demand for capsicum has risen due to its association with health-conscious diets, making it an important cash crop in many regions. The successful cultivation of capsicum hybrids is closely linked to adequate micronutrient supply, which enhances their yield and quality.

The study of micronutrients and their impact on plant growth, yield and quality has garnered significant attention in agricultural research, particularly in the context of increasingly intensive farming practices (Alloway 2008). Essential nutrients, including boron, zinc and calcium, play critical roles in various physiological and biochemical processes within plants. Their deficiency can lead to adverse effects on crop health and productivity, emphasizing the need for effective nutrient management strategies (Sharma and Kumar 2016). Micronutrients can be applied through various methods, including soil applications, fertigation and foliar sprays. Among these, foliar application has emerged as a particularly effective technique, allowing for targeted nutrient delivery directly to the plant’s leaves. This method facilitates rapid uptake of nutrients, addressing deficiencies quickly and improving overall plant health (Sabbe and Hodges 2010). Thus, foliar application of boron, zinc and calcium can significantly enhance the growth, yield and overall quality of capsicum. By improving nutrient uptake efficiency and addressing specific deficiencies at critical growth stages, these micronutrient applications can contribute to optimal plant development and increased fruit production.

This review aims to synthesize current research findings on the role of micronutrient applications in enhancing the growth, yield and quality of coloured capsicum hybrids. The pertinent and significant literature related to the current investigation titled **“Response of Micronutrient Applications on Hybrids of Coloured Capsicum”** has been reviewed under the following sub-headings:

2.1 Effect of boron, zinc and calcium application on growth and yield of coloured capsicum

2.2 Effect of boron, zinc and calcium application on quality of coloured capsicum

2.3 Economics of the different treatments

2.1 Effect of boron, zinc and calcium application on growth and yield of coloured capsicum

The application of essential micronutrients like boron, zinc and calcium plays a crucial role in enhancing the growth and yield of crops. These nutrients are involved in key physiological processes that improve plant health, productivity and resistance to environmental stress. Boron is vital for cell wall integrity; calcium is essential for cell structure and membrane stability and zinc facilitates enzyme activation and protein synthesis. Their combined application can lead to synergistic effects, improving nutrient uptake, fruit set and overall yield.

Understanding the impact of boron, zinc and calcium on plant growth is essential for optimizing nutrient management strategies to maximize crop productivity and quality. The effects of these essential micronutrients on plant growth and yield have been widely researched and their significance is thoroughly analyzed and discussed in detail below:

Afrin et al. (2024) conducted an experiment at the Horticulture Farm, Sher-e-Bangla Agricultural University, Dhaka, Bangladesh, from July 2022 to June 2023, using a Randomized Complete Block Design with three replications. The study evaluated three levels of plant growth regulators (No PGR, 200 ppm GA_3 and 100 ppm NAA) and three levels of micronutrients (No micronutrients, 200 ppm boron and 200 ppm zinc) to find out the effect on growth, yield and quality of Brinjal (*Solanum melongena* L.). The combination of 200 ppm GA_3 with 200 ppm zinc resulted in the highest plant height, leaf area (471.33 cm^2), SPAD value (52.95), flowers per plant (65.33), fruits per plant (58.38), yield (3312.8 g) and lipid content (0.35 %). The 100 ppm NAA with 200 ppm Zinc treatment produced the highest dry weight (158.80 g), individual fruit weight (67.33 g) and fiber content (12.28 %).

Ahmed et al. (2024) conducted an experiment to study the effect of iron and zinc on the growth and yield of chili at the Horticulture Research Farm, University of Agriculture, Peshawar, Pakistan. The study evaluated four levels of iron (0 %, 0.25 %, 0.5 %, 0.75 %) and zinc (0 %, 0.25 %, 0.5 %, 0.75 %) using a Randomized Complete Block Design with three replications. Results revealed that iron and zinc had significant effects on almost all the parameters. The highest branches per plant, leaf chlorophyll content, fruit length, number of fruits per plant, single fruit weight, root length, ascorbic acid content and yield (t ha^{-1}) were recorded with 0.75 % iron application, while the maximum plant height was observed at 0.5 % iron. Similarly, 0.75 % zinc application led to the best performance across all measured parameters. Untreated plants took the longest time to flower and set fruit. Therefore, applying 0.75 % iron and zinc was recommended for optimal chili growth and yield in the Peshawar valley.

Chhaba et al. (2024) conducted an experiment on tomato cv. 'Abhilash' at the Department of Horticulture, Suresh Gyan Vihar University, Jaipur, during the *kharif* season. The study, arranged in a Factorial Randomized Block Design with three replications, included sixteen treatment combinations of Boron (0, 0.1, 0.2 and 0.3 %) and Zinc (0, 0.1, 0.2 and 0.3 %). The interaction of Boron @ 0.2 % + Zinc @ 0.2 % significantly enhanced growth and yield traits. This combination resulted in the highest plant height (39.17 cm, 72.11 cm, 98.99 cm at 45, 60 and 75 DAT), maximum leaves per plant (162.30), minimum days to 50 % flowering (24.52) and the maximum yield (3.83 kg plant^{-1} and 134.10 t ha^{-1}). Fruit attributes like length (4.40 cm), diameter (5.54 cm), volume (131.82 cm^{3}) and weight (126.40 g) were also superior.

The field experiment conducted by Haleema et al. (2024) at Agriculture Research Institute, Tarnab, Peshawar, aimed to enhance tomato yield and reduce physiological disorders through foliar application of calcium, zinc and boron. The study tested four levels of calcium (0, 0.3, 0.6, 0.9 %), three levels of boron (0, 0.25, 0.5 %) and three levels of zinc (0, 0.25, 0.5 %) applied foliarly at flowering, fruit set and 15 days after fruit set. Results showed that 0.6 % calcium improved yield, reduced flower drop and increased fruit Ca content, while 0.9 % calcium reduced blossom end rot and fruit cracking. Foliar boron at 0.25 % improved flowering and production and 0.5 % boron enhanced Ca and B content, minimizing blossom end rot. Zinc at 0.5 % increased yield, fruit B and Zn content, while reducing blossom end rot and fruit cracking. The combination of micronutrients effectively improved yield and reduced physiological disorders in tomatoes.

Pagard et al. (2024) conducted a greenhouse experiment at Agricultural Sciences and Natural Resources University, Khuzestan, Iran to assess the effects of boron application on bell pepper plants through fertigation and foliar methods. The study involved seven treatments: a control, fertigation with boric acid (0.5, 1 and 2 g/L) and foliar application (0.5, 1 and 2 g/L), each with three replications. The experiment used Lorca bell peppers in a completely randomized design. Results indicated that both fertigation and foliar applications improved plant growth compared to the control. However, increasing boric acid concentration in foliar application reduced fruit count, fresh weight, yield and width. The best results for fruit weight, length, width and count per plant were observed with the lowest boric acid concentration (0.5 g/L) applied either by fertigation or foliar methods.

Singh (2024) investigated the effects of foliar zinc and iron applications on sweet pepper growth and fruit production at the Vegetable Research Farm, Dr. YS Parmar University of Horticulture and Forestry, Nauni-Solan, Himachal Pradesh, India. The study was conducted over two consecutive *kharif* seasons (2021 and 2022) using a Factorial Randomized Block Design with three replications. The 20 treatments included five levels of zinc sulphate ($ZnSO_4$) and four levels of iron sulphate ($FeSO_4$).The results revealed that treatment T_{11} ($ZnSO_4$ at 0.50 % and $FeSO_4$ at 0.40 %) produced the highest growth and fruit traits, including branches per plant (8.07), plant height (81.53 cm), fruit weight (29.60 g) and yield per plant (949.26 g). It also had the best fruit set percentage (83.08 %), number of pickings (8.36) and yield per hectare (421.89 q). Conversely, treatment T_{20} ($ZnSO_4$ at 1.00 % and $FeSO_4$ at 0.60 %) led to delayed first picking (73.49 days), increased internodal length (5.33 cm), longer harvest duration (82.00 days) and higher incidences of fruit rot (10.96 %) and anthracnose (10.18 %). T_{11} also showed the highest zinc and iron content in both leaves and fruits.

Vera-Maldonado et al. (2024) in a review article discussed that Boron (B) is an essential micronutrient involved in key plant metabolic processes, including the synthesis of cell walls and plasma membranes, carbohydrate and protein metabolism and ribonucleic acid (RNA) formation. It interacts with other important nutrients like calcium (Ca), nitrogen (N), phosphorus (P), potassium (K) and zinc (Zn). Specifically, B enhances cell wall integrity by forming boron-Ca-pectin complexes, which are vital for structural development in plants. Its synergy with Zn improves RNA synthesis, enzyme activation and nutrient absorption, while Zn can also mitigate boron toxicity. These interactions highlight boron's crucial role in optimizing nutrient uptake and boosting crop yields, emphasizing the need for effective fertilization strategies.

Dwivedi et al. (2023) conducted an experiment during 2021-2022 in a naturally ventilated polyhouse at the Horticulture Farm of ITM University, Madhya Pradesh to evaluate the effectiveness of mineral nutrients- calcium (Ca), sulfur (S) and molybdenum (Mo), in combination with nanomaterials, specifically nano-zinc (nano-Zn), nano-iron (nano-Fe) and nano-magnesium (nano-Mg), on capsicum (cv. Rani) productivity. The study found that combining calcium with nano-Zn or nano-Mg, particularly in treatments N_1M_1 (nano-Zn and $CaCl_2$ at 1000 ppm each) and N_3M_1 (nano-Mg and $CaCl_2$ at 1000 ppm each), significantly improved capsicum productivity. This enhanced performance was attributed to more efficient nutrient uptake and utilization, resulting from the positive interactions between Ca-Zn and Ca-Mg.

Kalmykova et al. (2023) studied the impact of microelements on sweet pepper crop, particularly through foliar application, as a key technique to improve yield and quality. Conducted from 2014-2019 in the Lower Volga region of Volgograd State Agrarian University, Russia the research highlighted that foliar feeding during the budding phase is crucial. The recommended treatment includes spraying with solutions of boric acid (0.29 g a.i./1 L of water) and ammonium molybdate (0.10 g a.i./1 L of water), with a water consumption rate of 1 L per 10 m^2. These applications significantly boosted plant growth, yield and fruit quality.

The experiment to study the influence of capsicum hybrids to micronutrients under naturally ventilated polyhouse was conducted by Kishor et al. (2023) during the *rabi* seasons of 2021-22 and 2022-23 at the Vegetable Research Farm, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur. The study used a split-plot design with 45 treatment combinations, replicated thrice. The study involved three hybrids of capsicum (Indira, Swarna and Bomby) and five different micronutrient application methods (control -no micronutrients application, soil application of Zn, Fe and B, fertigation of EDTA of Zn and Fe and Solubor at 15 days interval, foliar application of vegetable special @ 5 g/L at 15 days interval, foliar application of chelated combo micronutrients @ 1 g/L at 15 days interval). Based on the results, the capsicum hybrid Indira with foliar application of vegetable special @ 5 g/L at 15 days interval recorded the highest growth parameters, including plant height, number of branches, stem diameter and improved overall quality of capsicum. Among the micronutrient treatments, foliar application of vegetable special @ 5 g/L resulted in the highest growth and quality parameters in capsicum.

A field study conducted by Mondal et al. (2023) at the Bangladesh Institute of Nuclear Agriculture, Rangpur, during the *rabi* season of 2021-22, evaluated the effects of different varieties and foliar boron application on green chili growth and yield, using a split-plot design with three replications. Various concentrations of boron were applied as foliar sprays, with nine treatments: T_1= 0.5 g/L at the vegetative stage, T_2= 1.0 g/L at the vegetative stage, T_3= 0.5 g/L at the vegetative stage + 1.0 g/L at the fruiting stage, T_4= 1.0 g/L at both stages, T_5= 1.5 g/L at the vegetative stage, T_6= 1.5 g/L at both stages, T_7= 2.0 g/L at the vegetative stage, T_8= 2.0 g/L at both stages and T_9= Control. Among the nine foliar boron treatments, the application of 2.0 g/L at both the vegetative and fruiting stages (T_8) resulted in the highest fresh chili yield (21.22 t ha^{-1}).

Saha et al. (2023) conducted a pot experiment at Bihar Agricultural University, Sabour, to evaluate the effects of farmyard manure, zinc and boron on the fruit yield and nutrient uptake in brinjal. The study employed a factorial randomized complete block design with two levels of FYM (none and 5 Mg ha^{-1}), four levels of Zn (none, 5 kg Zn ha^{-1} as basal, 10 kg Zn ha^{-1} as basal and 5 kg Zn ha^{-1} basal plus foliar application of Zn twice at 0.5 % ($ZnSO_4.7H_2O$) and three levels of B (none, 1 kg and 2 kg ha^{-1}). Results showed that 10 kg Zn ha^{-1}, along with basal and foliar applications, significantly increased fruit yield compared to lower Zn levels. Foliar spraying enhanced Zn uptake by 2.0 - 2.25 fold and 2 kg B ha^{-1} also doubled B uptake, with higher efficiency recorded at 1 kg B ha^{-1}. Basal Zn and B applications, along with foliar Zn, were recommended to address deficiencies in brinjal.

The influence of micronutrients, particularly zinc (Zn) and boron (B), on tomato growth and yield parameters, was evaluated in a field experiment by Saha et al. (2023) Conducted during the winter season from November to February over two consecutive years at the College of Horticulture, Bihar Agricultural University, Noorsarai, Bihar, the study utilized graded doses of Zn (soil and soil + foliar applications) and B (soil application) with or without FYM. The results revealed that Zn and B significantly increased fruit yield and growth parameters, with the highest yield improvement of 27.6 % over control achieved by combining Zn (soil + foliar), B (2.0 kg ha^{-1}) and FYM. Additionally, the maximum fruit length (53.0 cm) and highest number of fruits per plant (26.9) were observed with this combined treatment, highlighting the effectiveness of higher Zn doses.

A study was conducted to check the response of bio stimulants and micronutrients for growth, yield and quality attributes in chilli (*Capsicum frutescens* L.) during the *rabi* season of 2022-2023 at the Main Experiment Station, ITM University, Gwalior by Singh et al. (2023). The experiment followed a Randomized Completed Block Design with three replications to evaluate the effects of three bio stimulants (Neem, Moringa, Hibiscus) combined with Boric acid (0.50 %). Among the treatments, T_7 (Neem + Moringa + Hibiscus leaves extract 0.25 % + Boric acid 0.50 %) performed the best, recording highest primary branches (4.35), maximum plant height (58.29 cm) and maximum number of fruits per plant (10.40). T_7 also produced the highest average fruit weight of 0.496 g.

Yadav et al. (2023a) highlighted zinc as a vital micronutrient for bell pepper plants, essential for enzyme activation, protein synthesis and auxin production, which supports growth and flowering. Zn deficiency leads to smaller leaves, chlorosis and reduced fruit yield. Its interaction with boron and calcium enhances nutrient uptake, with Zn aiding calcium absorption and boron improving Zn mobility. This synergy strengthens cell walls, improves fruit set and reduces physiological disorders. Proper Zn application boosts yield and enhances stress resistance in pepper plants.

Yadav et al. (2023b) conducted a study at the Agricultural Research Farm, Department of Horticulture, School of Agriculture, Jaipur (Rajasthan), during 2022-23. The experiment, laid out in a Randomized Block Design, included ten treatments: Control (T_0), boric acid at 0.2 % (T_1), 0.4 % (T_2) and 0.6 % (T_3); copper sulphate at 0.2 % (T_4), 0.4 % (T_5) and 0.6 % (T_6) and zinc sulphate at 0.2 % (T_7), 0.4 % (T_8) and 0.6 % (T_9), each replicated three times. The study revealed significant effects of different treatments on chilli growth and yield. Boric acid at 0.4 % (T_2) recorded maximum plant heights (31.64 cm), (49.98 cm) and (75.98 cm) at 45, 60 and 75 DAT, respectively; maximum branches per plant (14.54); flowers per cluster (16.67); fruits per plant (45.43); fruit girth (2.99 cm); minimum days to 50 % flowering (38.85); days to first harvest (45.10); maximum fruit length (8.27 cm); fruit weight (11.25 g); yield per plant (504.84 g); yield per plot (12.12 kg); green chilli yield (15.89 t ha^{-1}) and dry red chilli yield (2.58 t ha^{-1}). Inferior results were observed in the control (T_0).

Anita (2022) studied the impact of crop management practices on capsicum cv. Sweet Banana at the Vegetable Research Farm, Dr. YS Parmar University of Horticulture and Forestry, Nauni-Solan. The experiment, conducted in a Factorial Randomized Block Design with nine treatments replicated thrice, evaluated three nutrient levels: no nutrient application, boric acid @ 0.1 % and calcium chloride @ 0.5 %. Maximum values for growth and yield parameters were observed with boric acid @ 0.1 %, including plant spread (42.35 cm), fruit length (12.60 cm), diameter (34.05 mm), weight (25.90 g), fruit set percentage (71.64% and yield per hectare (366.75 q). This treatment also recorded the maximum number of fruits per plant (31.50) and harvest duration (105.26 days), with the minimum days to first picking (50.43 days). The maximum plant height (90.72 cm) and internodal length (6.63 cm) were recorded with calcium chloride @ 0.5 %.

Khatri et al. (2022) conducted a study to assess the effects of foliar applications of zinc and boron on the performance of tomato variety Manisha at Agriculture and Forestry University, Rampur Chitwan, Nepal. The research utilized a Randomized Complete Block Design with five treatments and four replications, including a control (T_0), two levels of chelated zinc (T_1: 30 ppm and T_2: 60 ppm) and two levels of borax (T_3: 30 ppm and T_4: 60 ppm), applied in two instalments (15 and 35 days after transplanting). The results indicated a significant increase in several parameters, including plant height (86 cm), number of leaves (52.47), branches (8.21), clusters (19.32), fruits (22.73), fruit diameter (5.58 cm), fruit weight (59.71 g) and yield (56.56 t ha^{-1}) with the foliar application of 30 ppm chelated zinc. Additionally, early flowering (23.70 days) was also observed at 30 ppm borax in the study.

Field experiments were conducted by Turhan et al. (2021) during the summer seasons of 2018 and 2019 at the experimental field of Bursa Uludag University, Turkey, to assess the effect of foliar zinc application on red pepper plants. Four Zn doses (control, 0.05 %, 0.10 % and 0.20 %) were applied as zinc sulphate ($ZnSO_4.7H_2O$). Results showed positive effects of Zn on plant height and crop canopy percentage, with the tallest plants recorded from the 0.10 % Zn application. Zn treatments at 0.10 % and 0.20 % significantly increased fruit weight, fruit diameter and fruit height compared to control. The highest fresh fruit yield and paste yield were also observed with 0.10 % and 0.20 % Zn, with paste yield increasing by 33 % at 0.10 % Zn.

A screening experiment was conducted at a farmer's field in Thalavadi, Erode district, Tamil Nadu, by Behera and Chitdeshwari (2021) under protected cultivation to evaluate the growth, root traits and yield of six capsicum hybrids in response to zinc fertilization. The two treatments tested were control (no Zn) and 37.5 kg $ZnSO_4$/ha on six capsicum hybrids: Indra, Priyanka, Inspiration, Massilia, Bachata and Local Green. The experiment was laid out in a Randomized Block Design with three replications and the results showed that zinc fertilization significantly enhanced plant height, root growth, fruit development and yield.

The hybrid Indra recorded the highest plant height (83 cm), root length (37 cm), root volume (13 cc), fruit weight (133 g), fruit length (9.17 cm), pericarp thickness (0.67 cm), dry matter production (65.0 g/pot) and fresh fruit yield (4.70 kg/pot), followed by Inspiration and Bachata with 37.5 kg $ZnSO_4$/ha.

Islam et al. (2021) conducted an experiment at the Bangladesh Agricultural Research Institute, Gazipur, during the *rabi* season of 2020-2021 to evaluate the effects of foliar boron application on the growth, seed yield and quality of sweet pepper (cv. BARI Mistimorich-1). Boron was applied at 0 ppm (control), 150 ppm, 200 ppm, 250 ppm, 300 ppm and 350 ppm using boric acid (17.5 % B). The highest number of fruits per plant (4.50), fresh fruit weight (80.25g), seed count per fruit (161) and germination rate (78.25 %) were recorded with 250 ppm. The tallest plants were obtained with 150 ppm. Seed quality, including root length, shoot length and vigour index, was superior at 200 ppm. The maximum fruit length (7.70 cm) and fresh weight (75.25 g) were achieved with 350 ppm boron application.

Kamalakannan et al. (2021) conducted a field experiment in Vanniyarpalayam village, Cuddalore district, Tamil Nadu, from February to May 2020, using the chilli hybrid Mahyco Sierra to evaluate the effects of macro and micronutrient fertilization in sandy clay loam soils. The treatments included various combinations of inorganic fertilizers: Complex fertilizer (17:17:17) at 0.5 % foliar spray, DAP at 0.5 % foliar spray and Borax at 0.5 % foliar spray, arranged in a randomized block design and replicated three times. The experimental results showed that the highest yield parameters were achieved with the application of RDF combined with Complex fertilizer (17:17:17) @ 0.5 % foliar spray + DAP @ 0.5 % foliar spray + Borax @ 0.5 % foliar spray. The highest yield parameters included flowers per plant (110.20), days to 50 % flowering (27), fruits per plant (91.26), fruit length (14.18 cm), fruit girth (5.44 cm), fruit weight (6.51 g), seeds per fruit (123.14), 1000-seed weight (6.42 g) and a fruit yield (170 q ha^{-1}).

The study on effects of zinc and boron on the growth and yield of Chilli was conducted by Khan et al. (2021) at the Agriculture Research Institute, Swat, Pakistan during the summer of 2016, using a Randomized Complete Block Design with two factors and three replicates. The experiment evaluated four levels of boron (0, 1.0, 2.0 and 3.0 kg ha^{-1}) and three levels of zinc (0, 1.5 and 3.0 kg ha^{-1}). Results showed that foliar application of boron significantly improved all parameters, with the highest values recorded @ 3.0 kg ha^{-1} : fruits per plant (117.01), fruit length (8.98 cm), fruit weight per plant (622.21 g) and yield

(2.71 t ha^{-1}). For zinc, the optimal application @ 3.0 kg ha^{-1} resulted in fruits per plant (113.99), fruit length (9.45 cm), fruit weight (660.19 g) and yield (2.85 t ha^{-1}). Thus, foliar applications of boron and zinc @ 3.0 kg ha^{-1} were recommended for better chilli production in Swat's agro-climatic conditions.

Kumar (2021) conducted a field investigation at Banaras Hindu University, Uttar Pradesh, to assess the effects of ammonium molybdate (AM) and B-20 (Boron) on the growth, yield and quality of green chili cv. Kashi Anmol. The experiment, laid out in a randomized block design with nine treatments, revealed that the combination of AM @ 0.4 % and B-20 @ 0.09 % significantly improved plant height, number of primary branches and flowering characteristics such as days to first flower and 50 % flowering. Yield attributes, including fruit number, fruit length, weight and seed count, also showed significant enhancement under this treatment. This combination further led to improved green chili yield per plant and total yield per hectare. The results suggest that ammonium molybdate @ 0.4% + Boron-20 @ 0.09% is the most effective and remunerative treatment for enhancing chili productivity.

Siva Prasad et al. (2021) conducted a greenhouse experiment (2016-17) and two field trials (2017-18) in the eastern dry zone of Karnataka to examine effect of zinc on tomato growth and yield. The highest plant height was observed in treatment T_9 (T_2 + $ZnSO_4$ @ 20 kg ha^{-1} soil application + 0.25 % $ZnSO_4$ foliar spray) in zinc-rich soils. This treatment significantly increased the number of fruits per plant across all pickings compared to other treatments. T_9 also enhanced the fruit weight per 5 plants (8.6 kg), outperforming other treatments in overall yield.

Belyaev et al. (2020) conducted a study in the Volgograd region, Russia, to examine the effects of boric acid and other microelements on yellow pepper growth and yield, through pre-sowing treatment and foliar applications. The research demonstrated that applying boric acid (0.05 % solution) significantly improved seed germination energy and seedling development, increasing germination by 18.4 % compared to the control. Boric acid also enhanced plant growth parameters such as plant height (110 mm), plant dry weight (5.58 g) and leaf area (20 cm^2). The foliar application of boric acid resulted in a 48.08 % increase in yield, showing substantial positive effects on productivity.

A field experiment was conducted by Ghosh et al. (2020) at the Agriculture Farm of Visva-Bharati, Sriniketan, during *rabi* seasons of 2015-16 and 2016-17 to evaluate the impact of micronutrients and growth regulators on chilli. Five levels of micronutrients (control, 0.1 % $ZnSO_4$ 0.2 % $ZnSO_4$, 0.1 % H_3BO_4, 0.2 % H_3BO_4) and growth regulators (control, 28-Homobrassinolide and Putrescine at different concentrations) were applied via foliar spray. Results showed that 0.2 % $ZnSO_4$ significantly improved plant height, dry matter accumulation, number of branches, leaf area index and crop growth rate, while 28-Homobrassinolide (0.5 ppm) further enhanced growth and yield parameters. The highest fruit yield per plant was achieved with 0.2 % $ZnSO_4$ and 0.5 ppm 28-Homobrassinolide.

Kumar et al. (2020) conducted a study at Veer Kunwar Singh University, Bihar, to evaluate the effect of different concentrations of zinc (0.25 % and 0.75 %) in the form of zinc sulphate and boron (0.15 % and 0.25 %) in the form of borax, alone and in combination on chilli cv. NP-46A. The experiment included nine treatments, including a control (water spray), replicated thrice in a Randomized Block Design. Combined foliar spray of 0.75 % zinc and 0.25 % boron at 45 and 65 days after transplanting significantly enhanced growth and yield, producing the highest green and dry yield. Zinc (0.75 %) alone also effectively improved growth and yield compared to the control.

A field experiment was conducted by Kurubetta et al. (2020) at the Horticulture Research and Extension Station, Haveri, Karnataka, during the *kharif* seasons of 2016, 2017 and 2018 on medium deep black clay soil using a Randomized Complete Block Design with thirteen treatment combinations, replicated three times. The treatment (T_7) involving RDF along with calcium, magnesium and sulphur @ 25 + 25 + 25 kg ha^{-1} consistently produced the highest dry chilli yields, recording 1056 kg ha^{-1} in 2016, 571 kg ha^{-1} in 2017 and 799 kg ha^{-1} in 2018, significantly outperforming the other treatments over the three years.

Malik et al. (2020) conducted a study during the *kharif* seasons of 2017 and 2018 at SKUAST-Kashmir to assess the effect of foliar micronutrient application on the growth, yield, quality and seed yield of chilli cv. Kashmir Long-1 under temperate conditions. The trial consisted of eight treatments, including T_1= control, T_2= $FeSO_4$ @0.2 %, T_3= $CaNO_3$ @0.2 %, T_4= Boron @ 0.1 %, T_5 =Mixture of all (T_2+T_3+T_4), T_6 (spray of T_5 except $FeSO_4$ @0.2 %), T_7 (Spraying of T_5 except $CaNO_3$ @0.2 %) and T_8 (spraying of T_5 without Boron @0.1 %), replicated thrice in a Randomized Block Design. Foliar applications were done at 60, 90 and 120 days after transplanting. Pooled analysis showed that treatment T_5 (a mixture of $FeSO_4$, $CaNO_3$ and boron) performed best, improving plant height (70.02 cm), branches

(8.51), plant spread (36.13 cm), fruit number (47.80), dry fruit yield (52.61 q ha^{-1}), fruit weight (6.64 g), fruit length (10.52 cm) and seed yield (9.61 q ha^{-1}).

Mayorga-Gómez et al. (2020) in a review article discussed that the application of calcium during bloom and early fruit development in bell peppers can effectively prevent calcium deficiency disorders such as blossom-end rot. Calcium is essential for cell wall integrity and regulates various physiological functions during the plant's growth. Deficiencies are most common when the demand for calcium surpasses supply, particularly during the rapid expansion phase of fruit growth. Studies indicate that timely calcium application helps ensure sufficient calcium uptake throughout fruit development, reducing the risk of disorders like BER, thus improving both yield and fruit quality in bell pepper production.

Nawrin et al. (2020) studied the effects of boron (B) and vermicompost (VC) on the growth, yield and nutrient accumulation in chili. The highest plant height (22 cm), leaf count (73), leaf area (502.53 cm² per plant), dry weight (22.27 g per plant), fruit length (8.97 cm), fruit number (6/plant) and fruit yield (11.76 g per plant) were recorded with B @ 0.5 kg/ha + VC @ 5 t ha^{-1}. Nutrient concentrations in the fruits also varied significantly ($p<0.05$). The highest levels of P, K, S, Cu, Fe and Mn were found with B @ 0.5 kg ha^{-1} + VC @ 5 t ha^{-1}, while the highest N and Zn were in B @ 1.5 kg ha^{-1} + VC @ 5 kg ha^{-1}.

An investigation to study the effect of nutrient application of nitrogen and boron on the yield of tomato was conducted at the experimental farm of the Rama University, Kanpur, during 2017-18 by Tiwari and Shukla (2020). The experiment was laid out in a Randomized Block Design with three replications, consisting of 16 treatment combinations. The treatments included varying levels of Nitrogen (0 %, 0.10 %, 0.15 % and 0.20 %) and Boron (0 %, 0.15 %, 0.20 % and 0.25 %). Results indicated that N_3 (0.20 %) and B_3 (0.25 %) produced the highest significant values for all yield attributes of tomato. Therefore, it was recommended that researchers and vegetable growers in Central Uttar Pradesh should spray nitrogen @ 0.20 % and boron @ 0.25 % to achieve optimum yield of tomato.

Mosleh and Rasool (2019) conducted an experiment to evaluate the effect of boron and sugar alcohols on the growth, yield and seed quantity of pepper (cv. California Wonder). The experiment was conducted in a Factorial Randomized Complete Block Design with three replications at the College of Agriculture, University of Baghdad. The experiment involved two factors: boron (boric acid at 0, 50 and 100 mg L^{-1}) and sugar alcohols (sorbitol and mannitol), along with a control (water spray). Results showed that boron at 100 mg L^{-1} significantly improved plant height (58.60 cm), number of branches per plant (7.52), leaf area (1129.9 dcm^2 per plant), fruit count per plant (49.43) and total yield (148.64 ton ha^{-1}). The best combination for maximizing yield was 100 mg L^{-1} boron with 30 g L^{-1} mannitol.

A study aimed to determine the effects of different levels of zinc and GA_3 on the yield attributes of tomato was undertaken by Rahman et al. (2019). The experiment involved three levels of zinc: Z_0 (control), Z_1 (0.5 kg ha^{-1}) and Z_2 (1 kg ha^{-1}), as well as four levels of gibberellic acid (GA_3): G_0 (control), G_1 (50 ppm), G_2 (75 ppm) and G_3 (100 ppm). It was conducted using a Randomized Complete Block Design with three replications. Results showed significant effects of zinc and GA_3 on all observed parameters. The combined treatment Z_1 @ 0.5 kg ha^{-1} + G_2 @ 75 ppm) produced the best results, with the highest flower clusters per plant (14.67), flowers per cluster (13.00), fruits per cluster (11.00), fruits per plant (83.33), fruit weight per plant (3.027 kg) and a yield of 92.54 tons per hectare.

Salim et al. (2019) conducted two field experiments in 2017 and 2018 at the Experimental Farm of Ain Shams University, Egypt, using the red pepper (*Capsicum annuum* L.) cultivar “Hot Chili”. The experiments employed a split plot design with three replicates, applying foliar treatments of calcium chloride (0, 1000 and 2000 ppm) and boric acid (0, 200 and 400 ppm) at 30, 45 and 60 days after transplanting. Results showed that all foliar applications, individually or in combination, significantly enhanced vegetative growth, fruit setting percentage and fruit yield. The combination of 2000 ppm calcium chloride with either 200 or 400 ppm boric acid resulted in the highest plant height, number of branches, fresh and dry shoot weights and fruit yield per plant and per hectare.

Singh et al. (2019) conducted an experiment at the Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, during 2016-2017 to study the effect of boron and zinc on plant growth and yield in tomato. The study followed a Factorial Randomized Block Design with sixteen treatment combinations, using four levels of boron (0 %, 0.2 %, 0.3 %, 0.4 %) and zinc (0 %, 0.4 %, 0.5 %, 0.6 %). The highest plant height (98.94 cm), maximum number of primary and secondary branches per plant (8.27 and 2.38 respectively) and maximum fruit yield per plant (1170.50 g) was recorded with the combination of 0.6 % zinc + 0.4 % boron. The combination of 0.6 % zinc and 0.4 % boron also significantly increased the total yield, achieving 520.22 q ha^{-1}.

Agarwal (2018) conducted field experiments to standardize agro-techniques for enhancing capsicum productivity at the Field Research Laboratory in Partapur, Nubra Valley, Ladakh. The study assessed the effects of different growing environments (underground trench, polycarbonate greenhouse, polytunnel and open field) and micronutrient sprays (zinc, boron, manganese, magnesium and copper) on the yield and quality of capsicum varieties California Wonder, Pusa Deepti and Yolo Wonder. The results showed that growing environments significantly affected capsicum marketable traits. The highest fruit yield was recorded in the triple-layer polycarbonate greenhouse at 634.0 g plant^{-1}, a 115 % increase over the open control (294.0 g plant^{-1}). Two sprays of zinc (100 ppm) or boron (100 ppm) under greenhouse conditions yielded 840.96 g plant^{-1}, surpassing the control (768.43 g plant^{-1}). Significant interaction effects were noted between micronutrients and variety for marketable traits.

An experiment was conducted by Chowdhury et al. (2018) at Sher-e-Bangla Agricultural University, Dhaka, to assess the impact of commercially available liquid fertilizers on local chilli germplasm. The study, arranged in a Randomized Complete Block Design with four replications, involved three treatments: F_0 (Control), F_1 (Calsol: Zn 0.12 %, B 0.34 %, Ca and other nutrients) and F_2 (Wuxal: Zn 0.005 %, B 0.01 % and other nutrients). Fertilizers were applied at 21 ml per 7 liters of water on 168 m² every 15 days, starting 30 days after transplanting and continued for 120 days. The study revealed that liquid fertilizer application significantly enhanced the growth and yield of local chilli germplasm. Calsol (F_1) treatment produced the highest plant height (59.5 cm), number of branches (33), leaves (78.4) and flowers (68.7) per plant. It also resulted in the greatest fresh fruit weight (81.3 g), dry fruit weight (15.7 g), single fruit weight (2.6 g) and fruit length (76.2 mm). Additionally, F_1 yielded the most fruits per plant (214.8), 1000 seed weight (3.5 g) and yield (17.6 t ha^{-1}). In contrast, the control (F_0) showed lower values across all parameters, with a total yield of 12.8 t ha^{-1}.

Haleema et al. (2018) investigated the effect of foliar application of calcium, boron and zinc on tomato (cv. Riogrande) growth and fruit production in 2013 at the University of Agriculture Peshawar, Pakistan to optimize concentrations for enhanced growth and yield. Using a Randomized Complete Block Design with three replicates, treatments included calcium chloride (0, 0.3, 0.6, 0.9 %), boric acid (0, 0.25, 0.5 %) and zinc sulphate (0, 0.25, 0.5 %) applied as foliar sprays three times. Calcium chloride at 0.6 % increased plant height

(88.04 cm), primary branches (2.63), secondary branches (7.15), leaf area (65.52 cm^2) and fruits per plant (66.15). Boric acid at 0.25 % improved plant height (88.14 cm) and fruit number (67.78), while zinc sulphate at 0.5 % increased plant height (86.53 cm) and fruits per plant (63.78). Combined foliar application of Ca (0.6 %), B (0.25 %) and Zn (0.5 %) significantly enhanced tomato growth and yield.

An experiment was conducted at the Crop Farm, Eastern University, Sri Lanka by Harris et al. (2018) to evaluate the effect of foliar application of boron (B) and magnesium (Mg) on the growth and yield of green chili cv. MIPC-1. The study involved various treatments, including (T_0) Control; (T_1) B = 50 ppm; (T_2) B = 100 ppm; (T_3) B = 150 ppm; (T_4) Mg = 50 ppm; (T_5) Mg= 100 ppm; (T_6) Mg = 150 ppm; (T_7) B (50 ppm) + Mg (50 ppm); (T_8) B (100 ppm) + Mg (100 ppm) and (T_9) B (150 ppm) + Mg (150 ppm). The highest plant growth and yield parameters, including plant height (98 cm), number of branches (18), number of leaves (25), number of flowers (29), total dry weight (66 g) and unripe fruit yield (333 g), were achieved with a foliar application of 100 ppm boron and magnesium. This treatment resulted in a three-fold yield increase compared to the control, making it the most effective treatment for improving chili growth and yield.

A field experiment on tomato variety Arka Rakshak was conducted by Nagar et al. (2018) at the College of Agriculture, Bikaner (Rajasthan), using five levels of zinc sulphate (0, 50, 100, 150 and 200 ppm) and three spray timings (20, 40 and 60 days after transplanting), resulting in 15 treatment combinations. The study was laid out in a Factorial Complete Randomized Design with three replications. Zinc sulphate application significantly enhanced plant height, number of branches, flowers, chlorophyll content, fruit length, fruit weight, fruits per plant and overall yield. The highest growth and yield parameters, along with maximum net returns of ₹ 800412.82 and a cost-benefit ratio of 1:2.66, were achieved with three sprays of zinc sulphate at 200 ppm.

Zeist et al. (2018) conducted a study at Universidade Estadual do Centro-Oeste in Guarapuava, Paraná, Brazil, using a randomized complete block design with three replicates and nine plants per plot. The treatments included isolated and combined foliar applications of fertilizers: boron (0.01 %), calcium chloride (0.04 %) and the plant regulator ‘Stimulate’. Applications were made biweekly on the leaves from the start of flowering- (December 2013) till March 2014. The results showed that foliar application of boron enhanced photosynthetic yield and increased the number of marketable fruits. However, calcium and ‘Stimulate’ did not significantly improve gas exchange or fruit yield. However, foliar spraying with calcium improved the firmness of the commercial fruits from the beginning of flowering.

A field experiment was conducted at the Vegetable Research Field of the Horticulture Research Centre, Gazipur, by Ahmed et al. (2017) during the *rabi* seasons of 2009-12 to determine the optimal doses of boron and zinc for maximizing capsicum yield. The study included sixteen treatment combinations with four levels of boron (0, 1, 2 and 3 kg ha^{-1}) and zinc (0, 2, 3 and 4 kg ha^{-1}), alongside a blanket dose of NPKS (150:65:120:20 kg ha^{-1}) and cow dung @10 t ha^{-1}. The experiment utilized a Randomized Complete Block Design factorial with three replications. Results showed that the combination of 2.0 kg ha^{-1} boron and 3.0 kg ha^{-1} zinc produced the highest mean number of fruits per plant (11.1), maximum fruit length (9.29 cm), fruit diameter (7.34 cm) and individual fruit weight (122 g), leading to a yield of 31.8 t ha^{-1} with an 84.8 % increase over the control. The combined applications of zinc and boron outperformed their individual applications in the study.

An experiment was conducted in a naturally ventilated polyhouse at the Hi-tech Horticulture Unit, Rajasthan College of Agriculture, Udaipur by Ameta et al. (2017). The study aimed to assess the growth and yield response of capsicum cultivar "Indira" to various applications of humic acid and micronutrients. Seven treatments were arranged in a Randomized Complete Block Design with three replications. The analysis of variance revealed significant differences among all studied traits. The T_7 treatment, consisting of RDF, soil application of humic acid (10 kg ha^{-1}), foliar humic acid (0.1 %) and a micronutrient mixture (0.5 % Zn, 0.2 % B, 0.5 % Mn), proved statistically superior. This treatment increased plant height (103.91 cm), number of branches (9.33), leaf area (391.30 cm^2), fruit weight (174.28 g), number of fruits per plant (22.07), fruit volume (376.57 cc), specific gravity (0.58 g/cc) and yield per plant (3.85 kg).

Avinash et al. (2017) conducted a field experiment during *kharif* 2015 to evaluate the effect of foliar application of humic acid fortified with zinc and boron on capsicum growth and yield. The study used a Randomized Complete Block Design with 16 treatment combinations. Results showed that the treatment with Recommended Dose of Fertilizers, Farm Yard Manure and three foliar sprays of 0.50 % zinc-fortified humic acid (from poultry manure) significantly enhanced plant height, branch and leaf numbers, SPAD meter readings, dry matter, fruit yield (54.23 t ha^{-1}) and fruit set.

Harris and Puvanitha (2017) conducted an experiment at the Eastern University, Sri Lanka, to assess the effects of foliar applications of H_3BO_3 and $CuSO_4$ on tomato growth and yield. The study, arranged in a Randomized Complete Block Design with eight replications, tested 10 treatments, including various concentrations of H_3BO_3 and $CuSO_4$, alone and in combination. Foliar sprays were applied thrice at 10-day intervals, starting 40 days after transplanting. Results showed that $CuSO_4$ at 150 and 250 ppm increased plant height, while H_3BO_3 at 250 ppm and its combination with $CuSO_4$ improved leaf number. $CuSO_4$ at 250 and 350 ppm and the combination of H_3BO_3 (250 ppm) + $CuSO_4$, boosted root length H_3BO_3 at 150 and 250 ppm increased fruit yield, while 350 ppm of H_3BO_3 improved fruit count.

Rayudu et al. (2017) conducted an experiment to study the effect of zinc and boron on growth, yield and quality of tomato (*Solanum lycopersicum* L.) Hybrid-Titano 1001 under protected cultivation at the Institute of Agricultural Sciences, Bhagwant University, Ajmer, during 2016-2017. The study, laid out in a Randomized Block Design with three replications and nine treatments, tested various combinations- T_0 (control), T_1 (Zn- 1.5 g/L), T_2 (Zn- 2.0 g/L),T_3 (B- 1.25 g/L + Zn- 1.5 g/L),T_4 (B- 1.25 g/L + Zn- 2.0 g/L), T_5 (B- 1.25 g/L), T_6 (B- 1.5 g/L), T_7 (B- 1.5 g/L + Zn- 1.5 g/L) and T_8 (B- 1.5 g/L + Zn- 2.0 g/L). The treatment T_3 (B- 1.25 g/L + Zn- 1.5 g/L) showed significant improvements in plant height (238.48 cm), number of leaves (203.93), clusters (10.80), fruits per cluster (6.73), fruit yield per plant (7.38 kg), fruit yield per hectare (135.32 t ha^{-1}), total soluble solids (4.80 °Brix) and shelf life (28.27 days) under Ajmer conditions.

Buczkowska et al. (2016) conducted a study from 2010- 2012 at University of Life Sciences in Lublin, Poland to evaluate the effects of foliar calcium (Ca) feeding on the yield of sweet pepper ‘Caryca F1’. Calcium was applied in different forms- $Ca(NO_3)_2$, Insol Ca and Librel Ca- on 3rd or 5th dates of the month at a 1 % concentration. The study revealed a significant increase in marketable fruit yield with Ca feeding, ranging from 4.26 to 4.63 kg/m^2, compared to the control yield of 3.80 kg/m^2.

Rana (2015) conducted a study on cabbage during the *rabi* seasons of 2016-17 and 2017-18 at the Experimental Farm, Department of Vegetable Science, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan (HP). The experiment, designed as a Randomized Complete Block Design (Factorial), involved 14 treatment combinations with two levels of biofertilizers (B_0: No biofertilizers and B_1: Azotobacter + PSB + KSB) and seven levels of micronutrients (M_0: No micronutrient, M_1: Boric acid @ 0.5 %, M_2: Zinc sulphate @ 0.5 %, M_3: Ferrous sulphate @ 0.5 %, M_4: Manganese sulphate @ 0.5 %, M_5: Ammonium molybdate @ 0.5 % and M_6: Multiplex @ 0.5 %). The treatment B_1M_6 (biofertilizers + Multiplex @ 0.5 %) showed the highest plant spread (42.38 cm), net head weight (870.00 g) and yield (322.10 q ha^{-1}). B_1M_2 (biofertilizers + Zinc sulphate @ 0.5 %) recorded the maximum vitamin C content (59.97 mg/100 g) and leaf zinc content (47.17 ppm), while B_1M_3 (biofertilizers + Ferrous sulphate @ 0.5 %) had the highest soil iron (17.15 mg/kg) and leaf iron (173.30 ppm). Based on growth, yield and quality parameters, treatment B_1M_6 (biofertilizers + Multiplex @ 0.5 %) was identified as the best treatment for cabbage.

A field trial was conducted by Kalroo et al. (2014) near Umerkot, Pakistan to assess the effect of different levels of chelated zinc (zinc sulphate) on chilli (cv. Talhari) growth and fruit yield. Zinc was applied as a foliar spray at concentrations of 1, 2, 3, 4 and 5 ml/L water, with a control group. Zinc at 5 ml/L water significantly increased the number of fruits per plant (481.33), fruit length (5.50 cm), fresh fruit yield per plant (705 g) and total yield (16.35 t ha^{-1}). Zinc also enhanced growth, with 5 ml/L producing a plant height (85.66 cm), plant spread (77 cm), branches per plant (13) and early flower emergence at 56.33 days. However, there was no significant yield difference between 5 ml/L and 4 ml/L, indicating that 4 ml/L (16.09 t/ha) is the optimal concentration for economic yield.

Kazemi (2014) conducted a study at Islamic Azad University, Karaj, Iran, to evaluate the effects of foliar application of humic acid (HA) and calcium chloride ($CaCl_2$) on the growth, yield and quality of tomato plants. The experiment, arranged as a Completely Randomized Block Design with four replications, tested HA (15 and 30 ppm) and $CaCl_2$ (10 and 15 mM) alone and in combination. Results showed that foliar application of HA (30 ppm) and $CaCl_2$ (15 mM) significantly enhanced vegetative and reproductive growth, chlorophyll content, yield and fruit quality. The combination of HA (30 ppm) + $CaCl_2$ (15 mM) produced the highest yield (25.36 t ha^{-1}), TSS (5.14 °Brix), vitamin C (25.14 mg), lycopene (2.14 mg) and fruit firmness (3.91 kg/cm^2) while reducing blossom-end rot incidence to 5 %.

Manas et al. (2014) conducted a study to evaluate the effect of foliar application of humic acid (0.05 %), zinc (0.05 %) and boron (0.02 %) on biochemical changes related to the productivity of pungent pepper cv. Bullet. The pot experiment was arranged in a randomized block design with three replications and carried out in the net house at Bidhan Chandra Krishi Viswavidyalaya, Bengal. The results demonstrated that foliar application of humic acid, zinc and boron significantly enhanced plant growth and yield of pungent pepper. Among the treatments, the combined application of HA + Zn + B produced the highest plant height (64.03 cm), number of leaves per plant (58.57), leaf area (1.80 cm^2) and number of branches (75.11). Additionally, the same treatment resulted in the best yield components, including the highest number of fruits per plant (9.80), fruit length (7.30 cm) and fruit weight (81.60 g for 20 fruits).

Shadia (2014) conducted a study over two consecutive autumn seasons at the Desert Research Centre, Cairo, Egypt. It aimed to evaluate the effects of different application methods (soil addition and foliar spray) of microelements (iron and zinc) on the growth, yield and chemical composition of sweet pepper (cv. California Wonder). The experiment included eighteen treatments: nine soil addition treatments (including controls) with iron (25 and 30 kg fed^{-1}) and zinc (15 and 20 kg fed^{-1}), plus nine foliar spray treatments with 50 and 100 ppm of Fe-EDTA and Zn-EDTA, also including control treatments. Treatments were applied at 30, 45 and 60 days after transplanting. The foliar spray method proved superior to soil addition, yielding better results. The highest levels of iron and zinc as foliar sprays significantly enhanced growth parameters, including plant height, number of branches, fresh and dry weight, leaf area, fruit number fruit length, diameter, fruit weight and total yield.

A field trial on chilli (cv. Bogra local) was conducted by Shil et al. (2013) at the Spice Research Centre, Bogra, Bangladesh, during the *rabi* seasons of 2005-2008. The study aimed to evaluate the response of chilli to zinc and boron and determine their optimum doses for maximum yield. Four levels of zinc (0, 1.5, 3.0, 4.5 kg ha^{-1}) and boron (0, 1.0, 2.0, 3.0 kg ha^{-1}) were applied with a blanket dose of NPK (130:60:80 kg ha^{-1}), S (20 kg ha^{-1}) and Mg (10 kg ha^{-1}) in a Randomized Complete Block Design. Results showed that combined applications of zinc and boron were superior to individual ones, with the highest yield (1138 kg ha^{-1}) at Zn @ 3 kg ha^{-1} + B @ 1 kg ha^{-1}.

Fernandez and Brown (2013) in a review article explored the efficacy of foliar-applied nutrients like boron, zinc and calcium in improving the growth, yield and quality of crops. Boron enhances fruit set and prevents physiological disorders, while zinc supports enzymatic functions and chlorophyll production, promoting healthier plants. Calcium strengthens cell walls and prevents common fruit disorders, such as blossom-end rot. The research emphasizes that foliar applications of these micronutrients improve nutrient uptake and translocation, leading to increased productivity. It also highlights the importance of environmental conditions and plant characteristics in influencing the effectiveness of foliar sprays.

Barche et al. (2011) conducted an experiment on tomato cv. Rashmi at the Allahabad Agriculture Institute-Deemed University, Allahabad. The study evaluated the effect of micronutrients on plant growth and yield using 11 treatment combinations, including boric acid, zinc sulphate, copper sulphate and multiplex (a micronutrient mixture) at 100 and 250 ppm, along with a control. The experiment was arranged in a Randomized Block Design with three replications. The treatment T_8 (boric acid + zinc sulphate + copper sulphate @ 250 ppm each) showed the best results, with maximum plant height (80.4 cm), branches per plant (34.7), flowers per inflorescence (9.13), fruits per plant (35.67) and fruit yield (1.18 kg plant^{-1} and 375.94 q ha^{-1}). In contrast, the lowest values for all parameters were observed in the control (T_0).

El-Said (2009) conducted two field experiments at El-Baramon Experimental Station, Dakahlia Governorate, Egypt, during 2007 and 2008 to examine the effect of boron foliar application and different nitrogen fertilization combinations on sweet pepper (cv. California Wonder). Foliar application of boron at 100 ppm combined with 75 % mineral and 25 % organic nitrogen significantly increased plant height, branch number, fresh and dry weight, fruit set percentage, fruit number per plant, average fruit weight and total yield per feddan, as well as fruit length, diameter, flesh thickness, dry weight, total soluble solids and vitamin C content.

A field experiment was conducted by Patil et al. (2008) at the University of Agricultural Sciences, Dharwad, during 2005-06 and 2006-07 to study the impact of foliar application of micronutrients on the growth and yield of tomato (cv. Megha). Eight micronutrient treatments- Boron, Zinc, Molybdenum, Copper, Iron, Manganese, a mixture of Boron, Zinc, Manganese and Iron (100 ppm each) with Molybdenum (50 ppm) and a commercial formulation (Multiplex) were tested against a control in a randomized block design with three replications. Based on the two-year average, boric acid application at 100 ppm resulted in the highest number of primary branches (18.30), yield per plant (2.07 kg) and fruit yield (30.50 t ha^{-1}). The next best treatment was the micronutrient mixture, which produced a fruit yield of 27.98 t ha^{-1}, significantly outperforming the control and other treatments.

El-Mohsen et al. (2007) conducted field experiments during the 2005 and 2006 summer seasons at the National Research Center, Cairo, Egypt to evaluate the response of sweet pepper (cv. California Wonder) to foliar applications of Fe, Mn and Zn. The study tested eight treatments, including individual and combined applications of Fe, Mn and Zn at 1 g and 2 g concentrations, compared to a control (sprayed with tap water). Results showed that the foliar application of Fe 1g/L + Mn 1g/L + Zn 1g/L led to the tallest plants, highest number of leaves and branches and greatest fresh and dry leaf weights. This treatment also resulted in the highest total yield and nutrient content (N, P and K).

2.2 Effect of boron, zinc and calcium application on quality of coloured capsicum

The application of boron, zinc and calcium significantly influences the quality of agricultural produce, particularly in enhancing the nutritional and physical attributes of crops. Boron is crucial for carbohydrate metabolism and reproductive growth, directly affecting fruit set and development. Zinc plays a key role in enzyme activation and protein synthesis, contributing to improved nutritional value, while calcium ensures structural integrity and membrane stability, reducing physiological disorders like blossom-end rot.

The combined use of these micronutrients not only boosts yield but also improves fruit quality, shelf life and resistance to stress. Understanding their impact is essential for achieving high-quality produce in commercial agriculture. Numerous studies have investigated the impact of these essential micronutrients on the quality of capsicum and the following section provides a detailed examination of their relevance and impact as under:

Ahmed et al. (2024) conducted a study on effect of iron and zinc on the growth and yield of chili at the Horticulture Research Farm, University of Agriculture, Peshawar, during the summer of 2022. The experiment tested four levels of iron (0, 0.25, 0.5 and 0.75 %) and four levels of zinc (0, 0.25, 0.5 and 0.75 %). The highest vitamin C content (106.23 mg/100g) was recorded with the application of 0.75 % zinc, followed by 100.42 mg/100g with 0.5 % zinc. When plants were sprayed with 0.75 % iron, the vitamin C content reached 103.8 mg/100g and 100.9 mg/100g with 0.5 % iron. These findings highlight the positive impact of both zinc and iron applications on enhancing vitamin C content in chili plants.

Kumar et al. (2024) conducted an experiment to evaluate the impact of micronutrients and bio-capsules on the quality of capsicum under protected conditions during the *rabi* seasons of 2022-23 and 2023-24 at the Horticulture Research Field, SHUATS, Prayagraj. The study employed a Completely Randomized Design with 15 treatments and 3 replications. Results showed that treatment T_{14} (boron, zinc, molybdenum, copper, iron and manganese with bio-capsules containing PGPR) significantly enhanced various quality attributes, including total soluble solids (7.94 °Brix), ascorbic acid content (147.82 mg/100g) and acidity (4.89 %). T_{14} was the most effective treatment, likely due to the synergistic effect of bio-capsules and micronutrients, which balanced the carbon-to-nitrogen (C:N) ratio. This combination improved nutrient availability and plant metabolism, leading to increased carbohydrate accumulation in the fruit and subsequently higher levels of total soluble solids and ascorbic acid.

Pagard et al. (2024) investigated the effects of boron supply on bell pepper plants through fertigation and foliar application. The experiment included seven treatments: a control group, boric acid via fertigation (0.5, 1 and 2 g/L) and foliar application (0.5, 1 and 2 g/L), with three replications under controlled greenhouse conditions, using Lorca bell peppers in a completely randomized design. Results indicated that both fertigation and foliar application significantly enhanced all measured characteristics compared to the control. Higher concentrations of boric acid improved chlorophyll a, b, total chlorophyll, leaf carotenoid content, soluble sugars, total soluble solids, titratable acidity, total phenols and fruit ascorbic acid content, with the highest values observed at 2 g/L foliar application.

An experiment by Rabbi et al. (2024) conducted in the net house of Bangladesh Institute of Nuclear Agriculture, Satkhira, Bangladesh, assessed the impact of zinc application (5 and 10 kg ha^{-1}) on tomato fruit quality and nutrient acquisition under salt stress. The study revealed that salt stress reduced vitamin C, protein, lycopene and nutrient uptake (N, P, K, Ca, Mg, Zn, Fe). However, applying 10 kg Zn ha^{-1} improved all these parameters in both saline and non-saline conditions. Additionally, a higher Zn application reduced Na content in the fruit and lowered the Na/K ratio. The findings suggest that Zn enhances tomato fruit quality and nutrient absorption, mitigating the adverse effects of salinity.

Sobczak et al. (2024) investigated the effects of foliar spraying with 0.03 % salicylic acid (SA), 0.7 % calcium nitrate (Ca) and a combination of both (SA + Ca) on the growth, yield and fruit quality of peppers grown in mineral wool substrate. Control plants were treated with water. The study involved two red-fruited sweet pepper cultivars, ‘Aifos’ and ‘Palermo’, known for their distinct fruit shapes. Individual treatments of SA and Ca did not affect the dry matter content of the fruit. However, fruits from plants treated with SA, Ca, or the combination exhibited juicier flesh compared to the control, with the least bitterness in the SA + Ca treatment. Sensory analysis revealed no significant differences in fruit odour, texture or taste between the SA and Ca treatments and the control.

Al-Ogaidi and Alwan (2023) explored the effects of mineral micronutrients (Fe, Zn, Mn, Cu) on the yield and qualitative traits of sweet pepper cultivated in calcareous soil under a protected system. Conducted in a greenhouse at University of Baghdad, Iraq during the 2020-2021 season, the experiment used $FeSO_4$, $ZnSO_4$, $MnSO_4$ and $CuSO_4$, applied through irrigation and foliar spraying. Fe irrigation resulted in the highest vitamin C content (23.57 mg/100g), while foliar spraying with Fe + Mn + Cu yielded the highest total soluble solids (5.8). The study also showed the highest chlorophyll index (74.68) in the Fe + Cu spray treatment. The results underscore the benefits of micronutrient applications in improving fruit quality and productivity of sweet pepper in nutrient-deficient, calcareous soils.

The study by Saha et al. (2023) conducted at Bihar Agricultural University, Bihar, evaluated the effects of zinc (Zn) and boron (B) fertilization on the quality parameters of tomato. The experiment involved the application of Zn at different levels (5 and 10 kg ha^{-1}) and B (1 and 2 kg ha^{-1}) with or without farmyard manure (FYM). The results showed significant improvements in the biochemical quality of tomatoes. The highest carotene content (6.9 mg/100g) was observed with combined Zn and B application, along with FYM. Similarly, the ascorbic acid content increased by 64.7 %, reaching 25.2 mg/100g, compared to the control. The Zn and B applications significantly enhanced fruit quality, with the Zn_3 (5 kg Zn ha^{-1} + foliar spray) and B_2 (2 kg B ha^{-1}) treatments showing the best outcomes. These findings indicate that Zn and B, along with FYM, can effectively improve the quality of tomato fruits.

Anita (2022) studied the impact of crop management practices on quality of capsicum cv. Sweet Banana at the Vegetable Research Farm, Dr. YS Parmar University of Horticulture and Forestry, Nauni-Solan. The experiment, conducted in a Factorial Randomized Block Design with nine treatments replicated thrice, evaluated three nutrient levels: no nutrient application, boric acid @ 0.1 % and calcium chloride @ 0.5 %. Nutrient application significantly influenced the quality of capsicum cv. Sweet Banana. Calcium chloride @ 0.5 % produced maximum total soluble solids (8.86 °Brix), ascorbic acid content (139.02 mg $100g^{-1}$), calcium content (131.79 mg $100g^{-1}$) and calcium uptake (14.42 kg ha^{-1}). Maximum boron content in fruits (3.36 mg $100g^{-1}$) and minimum anthracnose incidence (6.61 %) and fruit rot severity (6.60 %) were recorded with boric acid @ 0.1 %.

Behera et al. (2021) conducted an experiment at Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu which involved three treatments: Control, 50 kg $FeSO_4$ and 37.5 kg $ZnSO_4$ per hectare as a basal soil application, using six capsicum hybrids. Leaf samples were collected at the fruiting stage to analyze antioxidant enzyme activities, while fruit samples were assessed for biochemical constituents. The application of $FeSO_4$ and $ZnSO_4$ significantly increased the biochemical content in fruits and antioxidant enzyme activity in leaves. Zinc (Zn) and iron (Fe) fertilization raised titrable acidity in all hybrids. $ZnSO_4$ application yielded higher total soluble solids (5.90 °Brix) than $FeSO_4$ and Zn also boosted ascorbic acid content more effectively (8.70 mg/100 g) than Fe (8.47 mg/100 g).

Turhan et al. (2021) conducted an open-field study at Bursa Uludag University, Turkey, to evaluate the effects of foliar zinc (Zn) applications on red pepper plants. Four doses of Zn (0.0 %, 0.05 %, 0.10 % and 0.20 %) were applied as zinc sulphate ($ZnSO_4.7H_2O$). The highest fruit dry matter was achieved with 0.10 % and 0.20 % Zn applications, while the highest soluble solids content was recorded at 0.20 % Zn. These findings suggest that foliar application of Zn is beneficial for improving fruit quality in red pepper cultivation, enhancing both dry matter and soluble solids content.

Belyaev et al. (2020) conducted a study at the Russian Academy of Sciences Volgograd, Russia, to investigate the effects of boric acid and other microelements on the growth and yield of yellow peppers, using pre-sowing treatments and foliar applications. The application of microelements positively influenced the quality of sweet pepper fruit, with copper, boron and manganese being particularly effective in enhancing dry matter and sugar content during the pre-sowing treatment. The highest levels of vitamin C were consistently found in the variants treated with boron, copper, manganese and molybdenum across all years of research, highlighting the significance of these microelements in improving pepper quality.

The field experiment conducted by Kurubetta et al. (2020) was carried out at the Horticulture Research and Extension Station, Haveri, Karnataka, during the *kharif* seasons of 2016, 2017 and 2018, on medium deep black clay soil. The study utilized a Randomized Block Design consisting of thirteen treatment combinations, replicated three times. Pooled results over the three years indicated that the highest fruit colour of 205 ASTA units was observed with treatment T_8 (RDF + Ca + Mg + S @ 25 + 50 + 50 kg ha^{-1}), which was at par with treatment T_7 (Ca + Mg + S @ 25 + 25 + 25 kg ha^{-1}). Although capsaicin and oleoresin percentages were statistically non-significant, treatments T_7 and T_8 exhibited numerically higher values compared to other treatments.

Malik et al. (2020) conducted an investigation during *kharif* 2017 and 2018 at SKUAST-Kashmir to evaluate the effect of foliar micronutrient application on the quality of chili (cv. Kashmir Long-1) under temperate conditions. The experiment consisted of eight treatments, with T_5 ($FeSO_4$ @ 0.2 %, $CaNO_3$ and boron @ 0.1 %) yielding the highest oleoresin content (6.34 %) and vitamin C content (67.60 mg/100g), followed by T_7, which used the same spray as T_5 but without $CaNO_3$.

A pot experiment was conducted by Nawrin et al. (2020) in the net house of the Department of Soil, Water and Environment, University of Dhaka, Bangladesh to examine the effects of boron (B) and vermicompost (VC) on the growth, yield and nutrient accumulation in chili. The highest nutrient concentrations in fruits, including S (0.20 %), Cu (8.0 mg kg^{-1}), Fe (410 mg kg^{-1}) and Mn (0.80 mg kg^{-1}), were observed with B @ 0.5 kg ha^{-1} + VC @ 5 t ha^{-1} treatment. Additionally, total N (0.41 %) and Zn (3.50 mg kg^{-1}) were found in the B @ 1.5 kg/ha + VC @ 5 t ha^{-1} treatment.

Rahman et al. (2019) conducted a study to evaluate the effects of different zinc (Zn) levels and gibberellic acid (GA_3) on the yield and quality of tomatoes. The experiment, set up in a Randomized Complete Block Design with three replications, involved three levels of zinc: Z_0 (control), Z_1 (0.5 kg ha^{-1}) and Z_2 (1 kg ha^{-1}), along with four levels of GA_3. The results showed that both Zn and GA3 significantly influenced all measured parameters. The best outcomes for total soluble solids (8.00 %), β-Carotene (0.3967 mg/100g) and vitamin C (114.1 mg/100g) were achieved with Zn @ 0.5 kg ha^{-1} + GA_3 @ 75 ppm). This combination was recommended for further testing under different field conditions.

Salim et al. (2019) from Ain Shams University, Cairo, Egypt conducted two-season research in 2017-2018 to assess the effects of foliar application of boric acid and calcium chloride ($CaCl_2$) on hot pepper plants (*Capsicum annuum* L. cv. Hot Chili). Treatments comprised both single and combination doses of boric acid at 0, 200 and 400 ppm and $CaCl_2$ at 0, 1000 and 2000 ppm. The findings demonstrated that, in comparison to the control, $CaCl_2$ and boric acid greatly increased fruit carotenoid and vitamin C content, leaf nutrient concentrations (N, P and K) and SPAD readings. The greatest concentrations of $CaCl_2$ (2000 ppm) and boric acid (400 ppm) provided the maximum values for all quality parameters, except vitamin C in the first season.

Akladious and Mohamed (2018) conducted a study at Ain Shams University, Cairo, Egypt, to evaluate the effects of calcium nitrate and humic acid on the quality and biochemical attributes of pepper under salt stress. The experiment included two concentrations of calcium nitrate (60 mg kg^{-1} and 120 mg kg^{-1}) and humic acid (750 mg kg^{-1} and 1500 mg kg^{-1}), applied individually and in combination. The combination of calcium nitrate (60 mg kg^{-1}) and humic acid (1500 mg kg^{-1}) significantly improved the quality of pepper fruits. Capsaicin content increased to 15.72 mg g^{-1} DW, β-carotene reached 281 mg kg^{-1} FW and lycopene content rose to 278 mg kg^{-1} FW. Total phenols were also higher in this treatment, reaching 183.3 mg gallic acid/100g FW and total flavonoids were elevated to 18.52 mg quercetin/100g FW. Antioxidant activity increased to 82.2 %, indicating a substantial enhancement in fruit quality and biochemical traits.

Ali and Zaino (2018) conducted an experiment at the Technical Institute Khabat, Erbil Polytechnic University, in a plastic house during the spring of 2015. Using a Factorial Randomized Complete Block Design with three replicates, they studied the effects of boron and zinc foliar applications (0, 150 and 250 ppm) on the chemical characteristics of the leaves and fruits of Flavio F_1 hybrid sweet pepper plants. Results showed that boron foliar application significantly increased the levels of potassium, calcium, sodium, iron, manganese, copper, boron and zinc in the leaves and fruits. In contrast, zinc foliar application significantly reduced calcium and iron levels while increasing sodium, manganese, copper, boron and zinc. Overall, boron had a stronger effect on nutrient content than zinc.

Chowdhury et al. (2018) conducted an experiment at the Department of Agricultural Botany, Sher-e-Bangla Agricultural University, Dhaka, from October 2015 to July 2016, to evaluate the impact of commercially available liquid fertilizers on local chili germplasm. The results showed that Calsol: Zn 0.12 %, B 0.34 %, Ca and other nutrients) significantly enhanced vitamin C content in green chili fruits to 75.28 mg/100 g and in dry chili to 39.47 mg/100 g, as well as protein content to 3.9 %.

Ziest et al. (2018) found that biweekly foliar sprays of calcium (0.01 %) from the start of flowering improved bell pepper firmness. The study demonstrated that calcium application enhances fruit quality, particularly by increasing the firmness of commercial bell peppers.

An experiment to study the effect of zinc and boron on growth, yield and quality of tomato Hybrid-Titano 1001 under protected cultivation was conducted by Rayudu et al. (2017) at the Bhagwant University, Ajmer, Rajasthan. Zinc and boron were used in different concentrations and the trial was set up in a randomized block design with three replications and nine treatments. The highest Total Soluble Solids (TSS) content of 4.80 ºBrix was observed in treatment T_3 (boron 1.25g/L and zinc 1.5g/L), followed by 4.47 ºBrix in T_4 (boron 1.25g/L and zinc 2.0g/L). Additionally, the longest shelf life of 28.27 days was recorded in T_3, followed by 26.53 days in T_4, demonstrating the positive effects of zinc and boron.

Buczkowska et al. (2016) investigated the impact of calcium (Ca) feeding on the fruit quality of sweet pepper 'Caryca F1' at the University of Life Sciences in Lublin, Poland. The foliar application of $Ca(NO_3)_2$ significantly reduced the occurrence of blossom-end rot (BER) in fruits, with only 4.3 %- 5.2 % of fruits showing BER symptoms, compared to 14.4 % in the control group. Additionally, $Ca(NO_3)_2$ application positively influenced the accumulation of vitamin C and carotenoids in the fruits, enhancing their nutritional quality. Reduced Ca spraying proved to be advantageous in terms of improved fruit quality and higher concentrations of beneficial compounds like carotenoids in this study.

Kumar et al. (2016) in a review article discussed that micronutrients such as zinc, iron and boron play crucial roles in improving the fruit quality of pepper. Zinc enhances enzyme activity and protein synthesis, leading to better growth and fruit development. It also helps increase vitamin C content in pepper fruits. Iron is essential for chlorophyll formation and supports enzyme systems that influence respiration and nitrogen fixation, contributing to better fruit size and colour. Boron aids in carbohydrate translocation, cell wall formation and reproductive processes, significantly enhancing fruit set, size and quality. Foliar applications of these micronutrients have been shown to increase nutrient content, total soluble solids (TSS) and vitamin C, resulting in overall improved fruit quality in pepper.

Harris and Vellupillai (2015) conducted an experiment at the Eastern University of Sri Lanka to evaluate the effects of foliar applications of boron and zinc on the quality of tomato cv. Thilina. The experiment was designed as a completely randomized design with eight replications, comprising of ten treatments: T_1-H_3BO_3 (150 ppm), T_2- H_3BO_3 (250 ppm), T_3-H_3BO_3 (350 ppm), T_4-$ZnSO_4$ (150 ppm), T_5-$ZnSO_4$ (250 ppm), T_6-$ZnSO_4$ (350 ppm), T_7-H_3BO_3 (150 ppm) + $ZnSO_4$ (150 ppm), T_8- H_3BO_3 (250 ppm) + $ZnSO_4$ (250 ppm), T_9-

H_3BO_3 (350 ppm) + $ZnSO_4$ (350 ppm) and T_{10}- Control. Results indicated that $ZnSO_4$ @ 250 ppm increased yield by 2.5 times compared to control, while H_3BO_3 at 250 ppm significantly boosted pulp weight by 2.5 times. The combination of H_3BO_3 (350 ppm) and $ZnSO_4$ (350 ppm) enhanced acidity and ascorbic acid levels. Additionally, H_3BO_3 at 150 ppm increased total soluble solids and at 350 ppm, it raised the pH of tomato fruits.

El-Sayed et al. (2015) The study conducted at EL-Baramon experimental farm near EL-Mansoura, Dakahlia Governorate, Egypt by El-Sayed et al. (2015) during the summer seasons of 2012 and 2013, assessed 15 treatments on bell pepper (cv. California Wonder). The combination of humic acid (5 kg fed^{-1}) and the foliar spray of yeast + NAA + potassium citrate (Y+NAA+K) resulted in maximum quality values: total soluble solids (TSS) reached 8.14 %, total sugar content was 4.27 % and vitamin C content was 98.91 mg/100g.

A pot experiment was conducted by Manas et al. (2014) at Bidhan Chandra Krishi Viswavidyalaya, West Bengal, using a randomized block design with three replications to investigate the effect of foliar application of HA- humic acid (0.05 %), zinc (0.05 %) and boron (0.02 %) on biochemical changes and productivity in pungent pepper cv. Bullet. Results showed a significant increase in total chlorophyll content with HA + B treatment. The application of HA + Zn + B resulted in the highest levels of reducing sugars, total sugars and starch. Protein, fat, energy and phenol content were maximized with Zn + B treatment. Polyphenol oxidase activity was significantly higher in HA + Zn + B treatments. Component analysis indicated that HA + Zn, Zn + B and HA + Zn + B provide optimal value addition to both the quality and productivity of pungent pepper through improved physiological and biochemical traits.

Shadia (2014) conducted a two-season study at the Desert Research Centre, Cairo, Egypt, to evaluate the effects of iron and zinc on sweet pepper (cv. California Wonder) growth and quality. The experiment involved 18 treatments, including both soil addition and foliar sprays. Iron (25 and 30 kg fed^{-1}) and zinc (15 and 20 kg fed^{-1}) were applied to the soil, while Fe-EDTA and Zn-EDTA were sprayed at 50 and 100 ppm. Applied at 30, 45 and 60 days post-transplant, the highest foliar spray doses of both micronutrients significantly improved total chlorophyll, protein, vitamin C and nutrient content (N, P, K, Ca, Zn and Fe) in the fruit.

Shafeek et al. (2014) conducted two plastic house experiments in 2011 and 2012 at the Experimental Station of the National Research Centre, Nubaria, North Egypt. The study found that hot pepper plants sprayed with the minor nutrient liquid Greenzit (Fe, Mn, Zn, B, Mo, Cu) had higher nitrogen, potassium and protein content in fruit tissues compared to those treated with micronutrient Novatren (Fe, Mn, Zn, B, Mo, Cu) liquid at the same concentration. However, as the level of nutritional application increased, vitamin C content in the fruit tissues significantly decreased compared to the control, indicating a trade-off between nutrient enrichment and vitamin C levels in hot peppers.

El-Said (2009) conducted two field experiments at El-Baramon Experimental Station, Egypt, during the years 2007 and 2008 to examine the effects of boron foliar nutrition and different combinations of mineral and organic nitrogen fertilization on sweet pepper (cv. California Wonder). The study found that foliar application of boron at 100 ppm, combined with 75 % mineral nitrogen and 25 % organic nitrogen, significantly increased chlorophyll A, B, total chlorophyll, carotene and the nutrient content of N, P, K and Ca in the plant leaves. This treatment also resulted in the highest levels of total soluble solids (TSS) and vitamin C, demonstrating the effectiveness of boron foliar nutrition with mixed nitrogen fertilization.

Two field experiments were conducted by El-Mohsen et al. (2007) during the summer seasons of 2005 and 2006 at the National Research Centre, Cairo, Egypt to investigate the response of California Wonder pepper plants to foliar applications of microelements (Fe, Mn and Zn). The results showed that the treatment with Fe, Mn and Zn at 1 g/L each produced the highest concentrations of nitrogen, phosphorus, potassium and the micronutrients (Fe, Mn and Zn) in both fruits and leaves, while control plants had the lowest levels.

2.3 Economics of the different treatment

Coloured capsicum represents a lucrative segment of the horticultural market, with its high nutritional value driving consumer demand and price premiums. The economic viability of its cultivation is significantly influenced by the strategic application of micronutrients such as boron, zinc and calcium. These elements enhance growth, yield and fruit quality, ultimately translating into increased profitability for farmers. According to Singh et al. (2019), proper nutrient management can yield up to 30 % higher returns on investment. The initial costs associated with micronutrient applications are often outweighed by the resulting increases in marketable yield and quality, making them a critical factor in competitive agricultural practices.

Furthermore, as production costs rise, maximizing efficiency and profitability becomes paramount for growers. Understanding the economic implications of micronutrient application enables farmers to make informed decisions that align with market demands and sustainability goals, ensuring long-term financial success in the coloured capsicum sector.

A summary and review of existing literature on the economic aspects of micronutrient applications, especially on hybrids of coloured capsicum are presented below:

Chhaba et al. (2024) conducted an experiment on tomato cv. 'Abhilash' at Suresh Gyan Vihar University, Jaipur, during the *kharif* season. The study, using a Factorial Randomized Block Design with three replications, involved sixteen treatment combinations of Boron (0, 0.1, 0.2 and 0.3 %) and Zinc (0, 0.1, 0.2 and 0.3 %). The highest benefit-cost (B:C) ratio of 4.88 was recorded in Boron @ 0.2 % + Zinc @ 0.2 %, followed by 3.93 in Boron @ 0.2 % + Zinc @ 0.3 %. The lowest B:C ratio (1.30) was observed in the control with water spray.

Mahajan et al. (2024) conducted a randomized block design experiment to assess the effects of nano-minerals (nano iron, nano zinc and nano magnesium) and micronutrients (Cu, B and Mn), each at three levels, on the growth, flowering, fruiting and yield of capsicum. The treatments were statistically analyzed using a two-way analysis. The most effective treatments for improving plant growth and productivity were N_1M_2 (nano-Zn and borax at 1000 ppm), N_1M_1 (nano-Zn and $CuSO_4$ at 1000 ppm) and N_2M_2 (nano-Fe and borax at 1000 ppm). These combinations provided the highest economic returns, with N_1M_2 achieving the maximum gross return (₹14,47,500), net return (₹10,31,745) and benefit:cost (B:C) ratio (2.48), followed by N_1M_1 (₹13,12,500; ₹8,96,480; 2.15) and N_2M_2 (₹12,22,500; ₹8,04,585; 1.93).

Singh (2024) studied the impact of zinc and iron foliar application on the growth and fruit production of sweet pepper (cv. Sweet Banana) at Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni-Solan. The experiment was designed using a Factorial Randomized Block Design with 20 treatments and three replications, incorporating five levels of $ZnSO_4$ and four levels of $FeSO_4$. The highest gross income was recorded in treatment T_{11}, which included $ZnSO_4$ (0.50 %) and $FeSO_4$ (0.40 %), amounting to ₹12,65,670. This treatment also achieved the highest net income of ₹10,29,690, with a benefit-cost (B:C) ratio of 4.36, highlighting the economic advantages of using zinc and iron foliar applications in sweet pepper cultivation.

Sunil et al. (2024) conducted a field trial at the Agricultural & Horticultural Research Station, Shivmogga, to evaluate the effects of foliar applications of nano nitrogen (nano N) and zinc (nano Zn) alongside conventional urea and $ZnSO_4$ on the growth and yield of green chili. The experiment tested combinations of three recommended nitrogen doses (75 %, 100 % and 125 %) with nano (nano N and nano Zn @ 0.4 %) and conventional (urea @ 2 % and $ZnSO_4$ @ 0.2 %) sources. The highest yield was observed with the foliar application of nano N and nano Zn @ 0.4 % + 125 % RDN (T_3), producing 33.07 t ha^{-1} of green chili, a 39.0 % increase compared to conventional treatments (T_6- 30.9 t ha^{-1}) and RDF (T_1- 23.8 t ha^{-1}). T_3 also resulted in significant economic benefits, with net returns increasing by 57.2 % and 49.3 % over conventional nitrogen and zinc sources, respectively. Additionally, land productivity reached $ 13.5 per day and using nano-fertilizers saved 25-50 % of RDN, indicating economic viability and resource efficiency.

Dwivedi et al. (2023) evaluated the effectiveness of nano-minerals (Zn, Fe and Mg) combined with calcium (Ca), sulphur (S) and molybdenum (Mo) on the growth and yield of capsicum (cv. Rani) using a factorial randomized block design with three replications. The study revealed that applying nano-Zn with wettable $CaCl_2$ (N_1M_I) showed the highest gross return (₹ 13,64,247) and a benefit-cost ratio (B:C) of 3.29, followed by (N_3M_1) nano-Mg with wettable $CaCl_2$ (₹ 12,91,542; B:C 3.11) making these combinations highly effective for enhancing economic yield and profitability in capsicum cultivation.

A study was conducted by Yadav et al. (2023b) at the Department of Horticulture, Suresh Gyan Vihar University, Jaipur, Rajasthan. A Randomized Block Design with ten treatments was employed: Control (T_0), boric acid at 0.2 % (T_1), 0.4 % (T_2) and 0.6 % (T_3); copper sulphate at 0.2 % (T_4), 0.4 % (T_5) and 0.6 % (T_6) and zinc sulphate at 0.2 % (T_7), 0.4 % (T_8) and 0.6 % (T_9), replicated thrice. Foliar application of boric acid @ 0.4 % (T_2) significantly outperformed other treatments, achieving the highest green chilli yield per hectare (15.89 t ha^{-1}). Additionally, the highest benefit-cost ratio (2.90) was also recorded by foliar application of boric acid @ 0.4 % (T_2) followed by (2.41) and (2.15) in boric acid @ 0.6 % (T_3) and boric acid @ 0.2 % (T_1), respectively.

Anita (2022) evaluated the impact of crop management practices on Capsicum cv. Sweet Banana at the Vegetable Research Farm, Dr. YS Parmar University of Horticulture and Forestry, Nauni-Solan. The study, conducted in a Factorial Randomized Block Design with nine treatments replicated thrice, assessed three nutrient levels: no nutrient application, boric acid @ 0.1% and calcium chloride @ 0.5%. The treatment combination of two-stem training with boric acid @ 0.1 % resulted the highest gross returns (₹13,95,540), net returns (₹11,08,969) and a B:C ratio of 3.87, while no training with no nutrients resulted in the lowest returns and a B:C ratio of 1.58.

A field experiment was conducted by Kaur and Kaur (2021) at the Department of Horticulture, Khalsa College, Amritsar, during 2017-18 to evaluate the effect of foliar application of macro- and micro-nutrients on the economics of tomato cv. NS-524. The study, arranged in a Randomized Block Design with three replications, tested ten treatments, including potassium sulphate (0.50 %, 0.75 %, 1.00 %), zinc sulphate (200 ppm, 300 ppm, 400 ppm), boric acid (200 ppm, 300 ppm, 400 ppm) and a control (water). The highest net return of ₹10,83,552 and a Benefit-Cost ratio (B:C) of 5.94 were recorded in T_8 (0.75 % potassium sulphate). Additionally, higher concentrations of boric acid and zinc sulphate showed better returns compared to other treatments.

Kurubetta et al. (2020) conducted a field experiment at the Horticulture Research and Extension Station, Devihosur, Haveri, Karnataka, over three *kharif* seasons (2016-2018) on medium deep black clay soil. The treatment applying Ca + Mg + S (each @ 25 kg ha^{-1}) produced significantly higher dry chilli yields of 1056, 571 and 799 kg ha^{-1} in 2016, 2017 and 2018, respectively, compared to other treatments. This treatment also resulted in the highest gross returns of ₹1,09,215/ha, net returns of ₹73,165 per hectare and a benefit-cost ratio (B:C) of 3.03, making it the most economically viable option.

An experiment to study the effect of zinc and boron on growth, yield and quality of tomato Hybrid-Titano 1001 under protected cultivation was conducted by Rayudu et al. (2017) at the Bhagwant University, Ajmer, Rajasthan. The study focused on the effects of zinc and boron, employing a Randomized Block Design with three replications and nine treatments, including control and varying combinations of zinc and boron. Among the treatments, the foliar application of boron at 1.25 g/L and zinc at 1.5 g/L yielded the highest gross returns of ₹4 0,64,904 per hectare net returns of ₹ 33,38,460 per hectare and a benefit-cost ratio of 4.59.

Shukla (2017) conducted a field experiment at the Horticulture cum Instructional Farm, College of Agriculture, IGKV, Raipur, to evaluate the effect of foliar application of micronutrients on tomato cv. Arka Rakshak. The study was laid out in a randomized block design with eight treatments and four replications. The treatments included T_1- FeSO4 @ 0.2 %, T_2- Calcium nitrate @ 0.2 %, T_3- Boron @ 0.1 %, T_4- ZnSO4 @ 0.2%, T_5- a mixture of all sprays, T_6 – containing $T_2 + T_4$, T_7 - containing $T_2 + T_3$ and T8- control (water spray). Among these, T_5 (mixture of all sprays) recorded the maximum gross income (₹ 225,028/ha), net return (₹ 138,528/ha) and benefit-cost ratio (3.08)

A field experiment was conducted by Saravaiya et al. (2014) during the *rabi* season of 2012-2013 at Navsari Agriculture University, Navsari to study the effects of foliar application of micronutrients on tomato cv. Gujarat Tomato-2. The experiment involved eight treatments, with T_1 (NPK- 75:37.5:62.5 kg ha^{-1}) serving as the control. Other treatments (T_2-T_8) included the addition of 100 ppm of boron, zinc, copper, iron, manganese or a mixture of all micronutrients. The highest yield and economic returns were observed in treatment T_7, which used a combination of all micronutrients with RDF. This treatment produced the maximum net return of ₹1,66,757 per hectare and the highest benefit-cost (B:C) ratio of 2.72, significantly outperforming other treatments and the control.

Neelgar (2012) conducted a field experiment during the *kharif* season of 2010-11 at the University of Agricultural Sciences, Dharwad, to examine the effect of foliar feeding of water-soluble fertilizers with iron and boron on yield and quality of red chillies. The experiment followed a randomized block design with nine treatments and three replications. Treatment T_8, which involved two foliar sprays of 19:19:19 (1 %) + Fe-EDTA (0.5 %) + borax (0.5%) at 60 and 90 days after transplanting, produced the highest gross income (₹ 69,485), net income (₹ 47,435) and benefit-cost (B:C) ratio of 2.17.

Dalavi (2009) conducted a polyhouse experiment on at the Hi-Tech Vegetable and Floriculture Project, College of Agriculture, Pune, during 2003-04 and 2004-05. The study, using a split plot design with three replications, evaluated the economic impact of different nutrient levels on capsicum F_1 hybrid Orobelle (Yellow) in a naturally ventilated polyhouse. The highest gross and net monetary returns, along with the best benefit-cost (B:C) ratio, were observed with the application of macronutrients at 300:200:250 kg ha^{-1} ($N:P_2O_5:K_2O$) combined with 100:37.5:1.0 kg ha^{-1} of Ca:Mg:Fe and 40 g ha^{-1} of boron.

Patil et al. (2008) conducted a field experiment at the University of Agricultural Sciences, Dharwad, during 2006 and 2007 to evaluate the effect of foliar micronutrient applications on tomato (cv. Megha). The study revealed that boron application @ 100 ppm provided the highest benefit-cost ratio of 1.80, resulting in net returns of ₹ 97,850 per hectare. This was followed by the application of a micronutrient mixture (Boron, Zinc, Manganese, Iron and Molybdenum), which recorded a benefit-cost ratio of 1.74 with net returns of ₹ 88,900 per hectare. In contrast, the control treatment showed the lowest net returns of ₹ 53,250 per hectare with a benefit-cost ratio of 1.40, demonstrating the significant economic benefits of micronutrient foliar applications in enhancing tomato yield and profitability.

Chapter-3

MATERIALS AND METHODS

The present research investigation, titled **"Response of Micronutrient Applications on Hybrids of Coloured Capsicum"**, was undertaken at the Experimental Farm and Laboratory of the Department of Vegetable Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, during the cropping seasons of 2022-2023 and 2023-2024. This chapter provides a comprehensive account of the experimental materials utilized, the methodological framework adopted and the detailed observations recorded throughout the course of the study.

3.1 EXPERIMENTAL SITE

3.1.1 Location

The field experiments were conducted in a polyhouse situated at the Experimental Farm located in Nauni, approximately 13 km from Solan city, at an altitude of 1270 meters above mean sea level, positioned at a latitude of 30°51'N and longitude of 77°11'E. This site falls within the mid-hill zone of Himachal Pradesh. Concurrently, the laboratory experiments were carried out in the Experimental Laboratory of the Department of Vegetable Science and the Department of Soil Science and Water Management, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh.

3.1.2 Climate

The region is characterized by a predominantly sub-temperate, semi-humid climate, with cold winters and peak temperatures occurring in May and June, while December and January are the coldest months. The Experimental Farm, situated in the mid-hill zone of Himachal Pradesh, experiences a sub-temperate to sub-tropical climate, with an annual precipitation ranging between 1000 and 1300 mm. The meteorological data, outside polyhouse, including maximum and minimum temperature, were recorded at the Meteorological Observatory, Department of Environmental Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh. The meteorological data inside the polyhouse was also recorded by using digital thermometer during the cropping periods from February to October in both 2022 and 2023 and are illustrated in Figures 3.1 and 3.2.

Figure 3.1: **Graphical representation of mean monthly temperature (maximum and minimum) outside and inside the naturally ventilated polyhouse recorded during 2022**

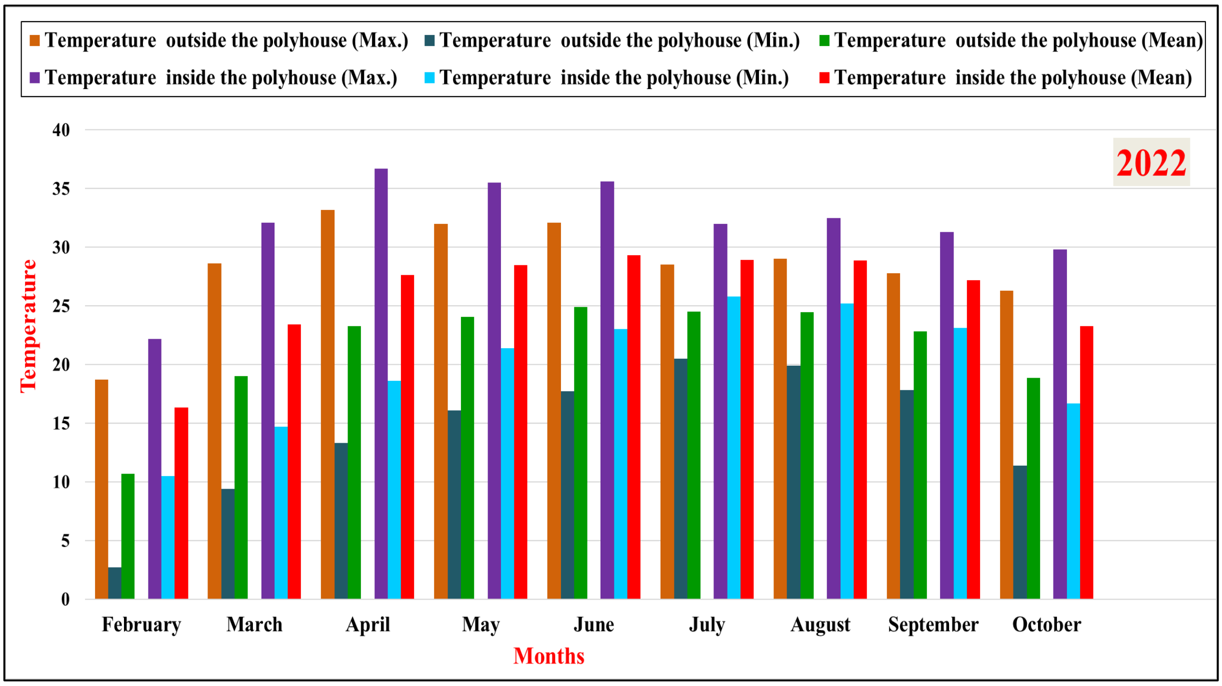
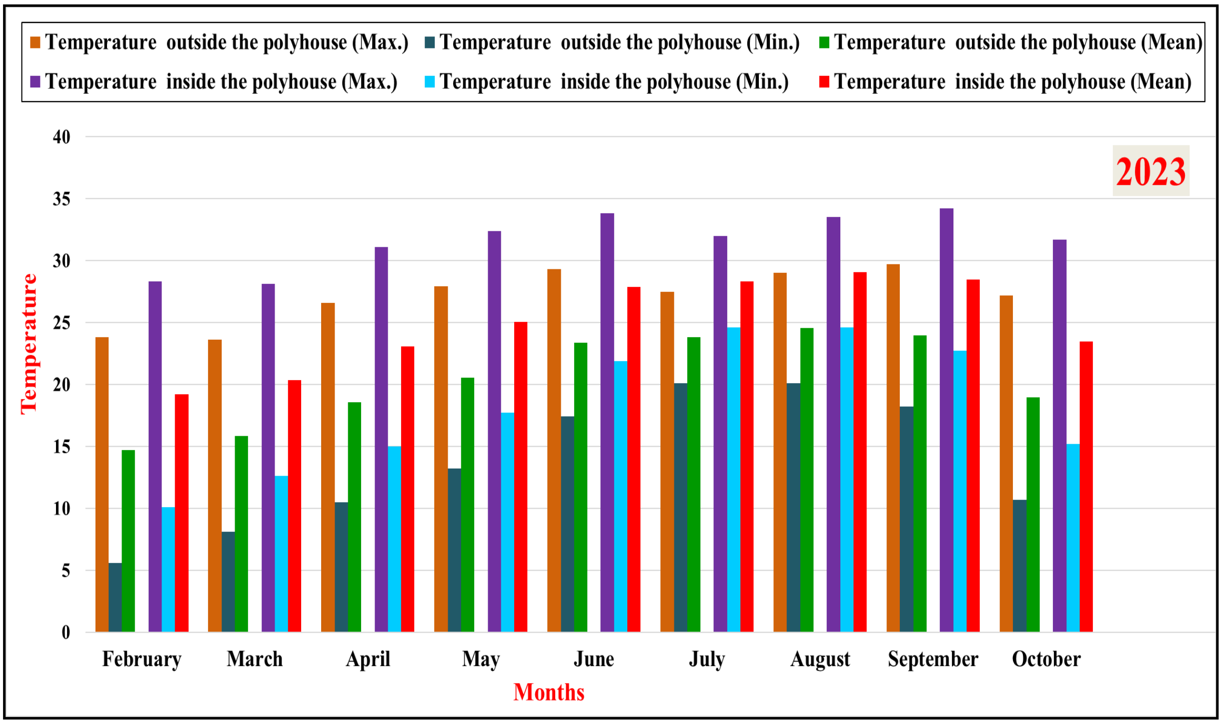


Figure 3.2: **Graphical representation of mean monthly temperature (maximum and minimum), outside and inside the naturally ventilated polyhouse recorded during 2023**



Source 1: **Temperature outside the polyhouse -** Meteorological Observatory, Department of Environmental Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, HP- 173 230

2. **Temperature inside the polyhouse -** Recorded by using digital thermometer

3.1.3 Soil characteristics

Before the experimental layout was established, soil samples were collected from five randomly selected locations inside the polyhouse at a depth of 0-15 cm within the experimental area. These samples were subsequently combined to form a composite sample, which was analyzed for key physical and chemical properties. The results of the analysis are presented in Table 3.1. After the termination of the experiment, soil samples from each plot were collected and analyzed for available nutrient content using standard analytical methods.

Table 3.1 Physico-chemical properties of the soil before planting

Parameters	**Values obtained (Year 2022-2023)**	**Values obtained (Year 2023-2024)**	**Methods used**
Soil pH	7.32	7.46	Digital pH meter (Jackson 1973)
Soil EC (dS m^{-1})	0.20	0.21	Electrical conductivity meter (Jackson 1973)
Organic carbon (%)	1.27	1.28	Rapid titration method (Walkley and Black 1934)
Available N (kg ha^{-1})	281.30	296.12	Alkaline potassium permanganate method (Subbiah and Asija 1956)
Available P (kg ha^{-1})	32.64	35.95	Olsen's method (Olsen et al. 1954)
Available K (kg ha^{-1})	320.65	331.27	Neutral normal ammonium acetate method (Merwin and Peech 1951)
Available B (mg kg^{-1})	0.21	0.23	Hot water-soluble extraction method and colorimetry using Azomethine-H reagent (Wolf 1971)
Available Zn (mg kg^{-1})	2.11	2.37	DTPA extraction, atomic adsorption spectrophotometric method (Lindsay and Norwell 1978)
Available Ca (mg kg^{-1})	120.52	125.64	Neutral normal ammonium acetate method (Merwin and Peech 1951)

3.1.4 Polyhouse details

A naturally ventilated polyhouse, with an area of 200 m² (20 m × 10 m), already established at the Experimental Farm of the Department of Vegetable Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, was utilized for conducting the present experiment during both study years. The polyhouse was equipped with a well-functioning drip fertigation system.

3.2 EXPERIMENTAL MATERIALS

3.2.1 Description of hybrids

Two hybrids of coloured capsicum were utilized for the investigation. The first hybrid selected for the investigation was "Indam Mamatha", from Indo American Hybrid Seeds

(India) Pvt. Ltd. “Indam Mamtha” produces blocky, shiny red fruits with an average weight of 125 to 250 g. The first harvest occurs 100-110 days after transplanting, with plants being tall and prolific bearers. The yield ranges from 100 to 150 t ha^{-1}. “Orobelle”, a hybrid from Syngenta (India) Pvt. Ltd., recommended for cultivation in Himachal Pradesh, was the second hybrid selected for the experiment. The first harvest is typically obtained 70 to 75 days after transplanting. The fruits are smooth, yellow, predominantly four-lobed and blocky in shape, with an average weight of 100 to 250 g. The plants are tall and highly productive, yielding 80 to 150 t ha^{-1}. The fruits of these hybrid varieties fetch a lucrative price in the market.

3.2.2 Source of seed

The seeds for the hybrid “Indam Mamatha” were procured from Indo American Hybrid Seeds (India) Pvt. Ltd. whereas, the seeds for the hybrid “Orobelle” were obtained from Syngenta (India) Pvt. Ltd.

3.2.3 Cultural practices

The standard cultural practices recommended for cultivating a healthy capsicum crop, as outlined in the Package of Practices for Vegetable Crops published by the Directorate of Extension Education, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, were adhered to during the study (Anonymous 2020).

3.2.3.1 Nursery sowing and raising of seedlings

The 98-cell plastic pro trays (1 inch size) were first disinfected with a 0.1% Bavistin solution to prevent seed-borne diseases. The seeds of the hybrids “Indam Mamtha” and “Orobelle” were sown in disinfected pro trays filled with cocopeat, vermiculite and perlite (3:1:1) medium to raise healthy and disease-free seedlings. The pro trays were placed inside the polyhouse under optimal growth conditions, with all necessary precautions taken to ensure the successful establishment of the nursery. The trays were irrigated daily or on alternate days with a gentle spray using a water can depending upon prevailing weather conditions. Water soluble fertilizer (WSF 19:19:19) @ 2 gm L^{-1} was also sprayed twice a week to enhance plant growth. Nursery sowing was carried out during the second fortnight of February in both the years 2022 and 2023.

3.2.3.2 Preparation of beds in the polyhouse

The experimental area of the polyhouse was thoroughly ploughed with a power tiller. Stones, pebbles and residues from previous crops were manually removed. The field was leveled, with adequate drainage provisions. Based on the experimental layout, the entire polyhouse area was divided into forty eight plots, each measuring 1.50 m^2. The plots were dug to a depth of 15 to 30 cm. A growing medium comprising of Soil: Cocopeat: Vermicompost: FYM (2: 1: 0.5: 0.5 v/v) was prepared inside the naturally ventilated polyhouse. The components were thoroughly filled and mixed into the plots and levelled again, according to the designated layout. A basal fertilizer dose of 2: 1.5: 1.1 NPK per 200 m^2 was applied to the beds uniformly before transplanting in the form of 4.35 kg urea, 9.38 kg single super phosphate and 1.83 kg murate of potash. The beds were watered before transplanting of seedlings to minimize shock, promote proper root establishment and ensure quicker seedling recovery.

3.2.3.3 Transplanting of seedlings in the polyhouse

The seedlings were ready for transplanting 55 to 60 days after sowing and were subsequently transplanted in the first fortnight of April in both the years. Vigorous, uniform-sized seedlings were transplanted in each plot at a spacing of 45 × 30 cm between and within rows, accommodating 10 seedlings per plot (1.50 m^2). To minimize root disturbance, the seedlings were carefully uprooted from the plastic pro trays, which had been irrigated one hour prior to ensure ease of removal without damaging the root system. Transplanting was carried out in the afternoon. Additionally, surplus seedlings were planted along the borders of the experimental plots to facilitate gap filling. Gap filling was also done a week after transplanting to ensure optimum plant population

3.2.3.4 Application of fertilizers and irrigation

Fertigation was administered through the pre-installed drip irrigation system at bi-weekly intervals, starting from the first fortnight of April and continued until the end of October in each experimental year. Water-soluble fertilizer (WSF 19:19:19 @ 31.6 kg per 200 m^2 area) was used for fertigation. The fertilizer dose in the form of Urea @ 1.79 kg and MOP @ 9.52 kg per 200 m^2 area) as mentioned in the Package of Practices for Vegetable Crops, Directorate of Extension Education, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, was also administered through fertigation system. After each fertigation, the drip system was thoroughly flushed for 5 minutes to ensure proper maintenance. The drip irrigation system in the polyhouse was also utilized for irrigation purposes. Initially, light irrigation for 10 to 15 minutes daily was provided to the seedlings. However, as the plants grew, the duration was increased to 50 to 60 minutes per day or on alternate days, depending on the water requirements.

3.2.3.5 Crop management

All the intercultural operations were done thoroughly as per the Package of Practices recommendation. Pesticides and fungicides were used as needed to keep the crop free from pests and diseases. The crop was kept weed-free through hand weeding throughout the growing period. Regular hoeing and earthing-up were done to raise a healthy crop of capsicum.

3.2.3.6 Training and pruning of crop and picking

Training and pruning of capsicum in greenhouse cultivation is essential for achieving optimal yield. Two main branches were retained per plant to maintain proper plant structure, as well as optimal fruit size and number of fruits per plant. Since a single capsicum plant typically produces up to 15 fruits, excess flowers and fruits were carefully removed to ensure balanced fruiting. Crown flowers from each plant was also removed for optimum growth of plant. Each plant was supported by ropes tied to an overhead trellis system to provide structural stability. Fruits were hand-picked based on their size and colour once they reached full maturity. The first harvest took place 70 to 75 days after transplanting.

3.2.4 Chemicals and glassware

The glassware used in the experiment, including bottles, beakers, measuring cylinders, test tubes and flasks, were sourced from Borosil. All chemicals were procured from Central Drug House (P) Ltd. and HiMedia and were of analytical grade. They were stored according to the manufacturer’s instructions, either at room temperature or 4°C. Sterilized double-distilled water was used for preparing buffers and stock solutions.

3.2.5 Foliar application of nutrients

The application of nutrients (boron, zinc and calcium) was carried out in accordance with the different treatment combinations. Foliar application of nutrients was utilized as it

Plate 3.1: General view of crop from years 2022-2023 and 2023-2024

2022-2023

2023-2024

allows the rapid absorption of nutrients directly through the leaves, leading to quicker nutrient uptake.

3.2.5.1 Nutrient solutions

Boron (B), zinc (Zn) and calcium (Ca) were used as nutrients in the form of boric acid - H_3BO_3 (17.5 % boron), zinc sulphate heptahydrate - $ZnSO_4.7H_2O$ (22 % zinc) and calcium chloride - $CaCl_2$ (36 % calcium), respectively. All nutrients were procured from laboratory of Department of Vegetable Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh.

3.2.5.2 Method adopted for foliar spray of nutrients

The nutrients were applied to the foliage in aqueous form using freshly prepared solutions for each spray application. The first foliar spray was applied at the flower bud initiation stage, followed by a second application 30 days after the initial nutrient treatment, both conducted in the morning during each of the experimental years. To enhance the absorption of the solution by capsicum leaves, a surfactant (sticker) was incorporated into the spray solution. All necessary safety precautions were strictly adhered to during the chemical application process.

3.3 METHODOLOGY

1. **Crop** : Capsicum
2. **Hybrids** : 1. Indam Mamatha
   2. Orobelle
3. **Design of Experiment** : Randomized Complete Block Design (Factorial)
4. **Year of experiment** : 2022-2023 and 2023-2024
5. **Number of Replications** : 03
6. **Number of Treatments** : 16
7. **Plot size** : 1.5 m × 1.0 m = 1.5 m^2
8. **Polyhouse area** : 200 m^2
9. **Plant spacing** : 45 cm × 30 cm
10. **Number of plants per plot** : 10
11. **Total number of plots** : 48
12. **Location** : Experimental Research Farm
    Department of Vegetable Science
    Dr. YSP UHF, Nauni, Solan (HP)
13. **Stages of application** : 1. Flower bud initiation
    2. 30 days after first application

3.3.1 Experimental details

The experiment was carried out with the following details:

3.3.2 Treatment details

The details of the treatments used for the study are as under:

Factor 1 - Hybrids (2 levels)

1. **H_1** - Indam Mamatha - Red colour, Indo American Hybrids Seeds (India) Pvt. Ltd.
2. **H_2** - Orobelle - Yellow colour, Syngenta (India) Pvt. Ltd.

Factor 2 - Nutrient concentrations (8 levels)

1. **M_1** - Boric acid 0.5 %
2. **M_2** - Zinc sulphate 0.5 %
3. **M_3** - Calcium chloride 0.5 %
4. **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5 %
5. **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %
6. **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %
7. **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %
8. **M_8** - Control (No spray)

3.3.3 Treatment combinations

The details of 16 treatment combinations used for the study are provided as under:

Table 3.2: Details of treatment combinations

Sr. No.	Treatment codes	Treatments combinations	Treatment details
1.	**T_1**	H_1M_1	Indam Mamatha + Boric acid 0.5 %
2.	**T_2**	H_1M_2	Indam Mamatha + Zinc sulphate 0.5 %
3.	**T_3**	H_1M_3	Indam Mamatha + Calcium chloride 0.5 %
4.	**T_4**	H_1M_4	Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 %
5.	**T_5**	H_1M_5	Indam Mamatha + Boric acid 0.5 % + Calcium chloride 0.5 %
6.	**T_6**	H_1M_6	Indam Mamatha + Zinc sulphate 0.5 % + Calcium chloride 0.5 %
7.	**T_7**	H_1M_7	Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %
8.	**T_8**	H_1M_8	Indam Mamatha + Control (no spray)
9.	**T_9**	H_2M_1	Orobelle + Boric acid 0.5 %
10.	**T_{10}**	H_2M_2	Orobelle + Zinc sulphate 0.5 %
11.	**T_{11}**	H_2M_3	Orobelle + Calcium chloride 0.5 %
12.	**T_{12}**	H_2M_4	Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 %
13.	**T_{13}**	H_2M_5	Orobelle + Boric acid 0.5 % + Calcium chloride 0.5 %
14.	**T_{14}**	H_2M_6	Orobelle + Zinc sulphate 0.5 % + Calcium chloride 0.5 %
15.	**T_{15}**	H_2M_7	Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %
16.	**T_{16}**	H_2M_8	Orobelle + Control (no spray)

Plate 3.2: Illustration of the cultural practices and crop management

Plate 3.3: Illustration of the foliar nutrient applications on coloured capsicum

3.4 OBSERVATIONS RECORDED

The observations were recorded for growth, yield and quality of two hybrids of coloured capsicum subjected to different treatment combinations of nutrients as under:

3.4.1 Growth and yield characters

3.4.1.1 Days to first picking

This was recorded as the number of days from the date of transplanting to the date when at least one marketable fruit was harvested from 50 % of the plants in a plot.

3.4.1.2 Internodal length (cm)

The internodal distance of five randomly selected plants in each plot was measured using a scale during plant height measurement and the mean values were calculated.

3.4.1.3 Plant height (cm)

The height of five randomly selected plants from each plot was measured from ground level to the highest tip of the plant at the end of the cropping season. The average height was calculated and expressed in centimetres.

3.4.1.4 Leaf area index

Leaf area index (LAI) was determined after the third fruit harvest. For this purpose, five plants were randomly selected from each plot. The leaf area of each plant was measured using the area measurement system MK-2 (Delta-T Device Ltd., Burwell, Cambridge, England). To facilitate presentation and interpretation, the recorded values were converted to represent the total leaf area per plot. LAI was then calculated using the formula provided by Radford (1967), as outlined below:

$$\text{Leaf area index (LAI)} \quad = \quad \frac{\text{Leaf area}}{\text{Ground area}}$$

3.4.1.5 Fruit length (cm)

During the third picking, the length of ten randomly selected fruits from each plot was measured in centimeters using a Digital Vernier Caliper and the average fruit length was calculated.

3.4.1.6 Fruit breadth (cm)

The fruits used for measuring length were also used to determine fruit breadth. Measurements were taken at the pedicel end, middle and near the apex using a Digital Vernier Caliper. The average of these three values was recorded as the fruit breadth.

3.4.1.7 Fruit weight (g)

The fresh weight of ten randomly selected fruits from randomly chosen plants in each plot during the second harvest was measured using an electronic weighing balance. The average weight was then calculated and expressed in grams.

3.4.1.8 Number of pickings

The total number of pickings of marketable fruits was recorded from the first to the last picking and the average was calculated.

3.4.1.9 Number of fruits per plant

The total number of marketable fruits from each picking, collected from five randomly selected plants per treatment, was summed and averaged to determine the number of fruits per plant.

3.4.1.10 Fruit yield per plant (kg)

The fruit yield per plant was recorded at each picking and summed across all pickings to determine the total fruit yield per plant, which was expressed in kilograms.

3.4.1.11 Fruit yield per m^2 (kg)

The fruit yield per m^2 was calculated by multiplying the fruit yield per plant by the number of plants accommodated per square meter and the result was expressed in kilograms.

3.4.1.12 Harvest duration

Harvest duration was determined by calculating the total number of days from the first picking to the final harvest of fruits from randomly selected plants in each treatment combination. The average value was then expressed in days.

3.4.2 Quality parameters

3.4.2.1 Total soluble solid (°Brix)

Five fruits from randomly selected plants were allowed to reach full colour maturity, then crushed and their juice was filtered through a double layer of fine muslin cloth. A drop of the juice was placed on the plate of a Hand Refractometer and the reading was recorded. An average of five readings from each replication in every treatment combination was used to record the observation.

3.4.2.2 Ascorbic acid content (mg 100 g^{-1})

Ascorbic acid was determined by method given by Ranganna (1999). An accurate weight of 100 mg of L-ascorbic acid was dissolved in 100 ml of 3 per cent metaphosphoric acid (HPO_3). Subsequently, 10 ml of this solution was further diluted to 100 ml with 3 per cent metaphosphoric acid.

Dye solution: 50 mg of the sodium salt of 2,6- Dichlorophenol-indophenol was dissolved in approximately 50 ml of hot distilled water containing 42 mg of sodium bicarbonate. Once cooled, the solution was diluted with distilled water to a final volume of 250 ml and stored in the refrigerator.

To standardize the dye, 5 ml of the standard ascorbic acid solution was combined with 5 ml of metaphosphoric acid and then titrated with the dye solution until a pink colour was achieved.

$$\text{Dye factor} = \frac{0.5}{\text{Titre value (Standardization of dye with standard ascorbic acid)}}$$

Dye factor was calculated by using the following formula:

Estimation: 5 g of the composite sample (collected from each treatment) was blended with 3 per cent metaphosphoric acid and brought to a final volume of 100 ml with the same acid. The resulting solution was then centrifuged and filtered. An aliquot of 10 ml was taken from the filtered solution and titrated with the standard dye to the pink end point. The ascorbic acid content was calculated using the following equation:

$$\text{Ascorbic acid (mg 100 g}^{-1}\text{)} = \frac{\text{Titre value} \times \text{Dye factor} \times \text{Volume made up}}{\text{Volume of Aliquot taken} \times \text{Weight of sample}} \times 100$$

3.4.2.3 Carotenoid content (mg 100 g^{-1})

Carotenoid content was determined according to the method outlined by Roy (1973). This method involved extracting the sample with acetone, which was then transferred to a separating funnel containing petroleum ether. The colour absorbance was measured at 452 nm against a 3 per cent acetone blank and total carotenoid content was expressed as mg 100 g^{-1}.

Estimation: A 5 g composite sample collected from each treatment was weighed using an electronic balance and then ground in acetone using a pestle and mortar until it became colourless. The extracted material was transferred into a separating funnel, to which 20 ml of petroleum ether was added, followed by 10 ml of sodium sulphate to remove turbidity. The aqueous portion was carefully drained from the separating funnel, leaving the upper layer that contained the carotenoids. This top layer was collected in a beaker and transferred into a volumetric flask, with the final volume adjusted to 50 ml using petroleum ether. The optical density (O.D.) was recorded at 452 nm, using petroleum ether as a blank. The total carotenoid content was calculated using the formula provided below:

$$\text{Carotenoids (mg 100 g}^{-1}\text{)} = \frac{3.87 \times \text{O.D.}_{452\text{ nm}} \times \text{Dye factor} \times \text{Volume made up}}{\text{Weight of sample} \times 1000} \times 100$$

3.4.3 Incidence and severity of economically important diseases of capsicum

3.4.3.1 Incidence of collar rot (%)

Collar rot is a significant disease affecting capsicum and its epidemiology is primarily influenced by soil moisture and associated factors. Data on disease incidence were collected by counting the number of wilting plants attributed to the disease. At the end of the growing season, all plants that were uprooted due to disease were documented and the percentage of disease incidence was calculated based on the total number of plants planted in each plot. The incidence of collar rot was determined using the standard formula provided below:

$$\text{Incidence of collar rot (\%)} = \frac{\text{Number of plants affected}}{\text{Total number of plants}} \times 100$$

3.4.3.2 Incidence of anthracnose (%)

The incidence of anthracnose or ripe fruit rot was assessed by recording the percentage of rotten fruits observed on five randomly selected plants during each harvest. This evaluation was carried out systematically for all treatments and the average fruit rot incidence was calculated to provide a comprehensive representation of the disease's impact across different treatments and conditions. Incidence of anthracnose was calculated using the standard formula given below:

$$\text{Incidence of anthracnose (\%)} = \frac{\text{Number of plants affected}}{\text{Total number of plants}} \times 100$$

3.4.3.3 Severity of powdery mildew (%)

Observations on the disease index of powdery mildew were conducted based on the leaf area affected, commencing at the peak vegetative stage and subsequently recorded at 15-day intervals, following the criteria proposed by Ullasa et al. (1981). The severity scale was as follows: 1 indicated no symptoms; 2 represented 10 % of the leaf area affected; 3 corresponded to 11-20 % of the leaf area affected; 4 denoted 21-50 % of the leaf area affected; and 5 indicated that 51 % or more of the leaf area was affected. Further the percent disease index (PDI) to measure the powdery mildew severity was calculated with the above scales by using the formula of Wheeler (1969):

$$\text{Percent disease index} = \frac{\text{Sum of numerical values of all grades}}{\text{Number of observed plants}} \times \frac{100}{\text{Maximum disease rating}}$$

3.4.4 Soil analysis

At the completion of the experiment, soil samples from each treatment plot were collected and analyzed for various soil properties. Soil samples were taken from each plot to a depth of 15 cm, both before sowing and after the crop harvest. The samples were air-dried, crushed and sieved through a 2 mm mesh before being stored in cloth bags for subsequent chemical analysis. The methodologies employed for assessing different physico-chemical properties are outlined under the following sections:

3.4.4.1 Soil pH

The pH was measured in a 1:2.5 soil-to-water suspension using a glass electrode digital pH meter, as described by Jackson (1973).

3.4.4.2 Soil EC (dSm^{-1})

The electrical conductivity of the soil was measured in a 1:2 soil-to-water suspension using a glass electrode digital EC meter, following the method described by Jackson (1973).

3.4.4.3 Organic carbon (%)

The amount of organic carbon in the sample was determined using the Walkley-Black chromic acid wet oxidation method (Walkley and Black 1934).

3.4.4.4 Available N, P and K content in soil before planting and after termination of experiment (kg ha^{-1})

Collection and preparation of soil sample and analysis: Representative soil samples were collected from a depth of 0-15 cm within the experimental plot. The collected soil samples were air-dried in the shade and ground using a pestle and mortar. After grinding, the samples were sieved through a 2 mm sieve and stored in polyethylene bags for further analysis to determine the available nitrogen (N), phosphorus (P) and potassium (K) content. To ensure complete drying, the samples were spread on filter paper and subsequently placed in paper bags, which were then kept in a hot air oven at 60 ± 5 °C for 48 hours. Once dried, the samples were crushed, ground again and stored in polyethylene bags for the estimation of N, P and K contents using standard methods.

Digestion of samples and analysis: The digestion of samples from various treatment plots involved the use of well-ground samples with a known weight, which were digested in a diacid mixture. This mixture was prepared by combining concentrated nitric acid (HNO_3) and perchloric acid ($HClO_4$) in a 4:1 ratio, in accordance with the safety and procedural precautions established by Piper (1966) for the analysis of phosphorus (P) and potassium (K) nutrients. For nitrogen estimation, a separate digestion process was conducted using concentrated sulfuric acid (H_2SO_4) along with a digestion mixture composed of 400 parts potassium sulfate, 20 parts copper sulfate, 3 parts mercuric oxide and 1 part selenium powder, as recommended by Jackson (1973).

3.4.4.4.1 Available N (kg ha^{-1})

The available nitrogen content in the soil was estimated using the alkaline potassium permanganate method as described by Subbiah and Asija (1956) and the results were expressed in kilograms per hectare (kg ha^{-1}).

3.4.4.4.2 Available P (kg ha^{-1})

The available phosphorus content in the soil was determined using the stannous chloride- reduced ammonium molybdate method with Olsen’s extractant, as outlined by

Olsen et al. (1954). The analysis was conducted using a Nukes UV-VIS Spectrophotometer at a wavelength of 660 nm. The estimated phosphorus content was expressed in kilograms per hectare (kg ha^{-1}).

3.4.4.4.3 Available K (kg ha^{-1})

The available potassium in the soil was extracted using neutral ammonium acetate, following the procedure established by Merwin and Peech (1951). The potassium concentration was then measured with a Flame Photometer (Model TMF-45) and expressed in kilograms per hectare (kg ha^{-1}).

3.4.4.5 Available B, Zn and Ca content in soil before planting and after termination of experiment (mg kg^{-1})

3.4.4.5.1 Available B (mg kg^{-1})

The available boron was extracted by boiling soil water suspension (1:2) for five minutes; filtered boron content was determined by Azomethine-H colorimetric method. (Wolf 1971). Five ml of the sample aliquot were mixed with 2 ml of ammonium acetate buffer (pH 5.5) and 2 ml of 0.02 M EDTA (ethylenediaminetetraacetic acid) in a 20 ml boron-free test tube and vortexed thoroughly. Following the addition of 1 ml of azomethine-H reagent (a solution of 0.9 % azomethine-H and 2 % ascorbic acid), the mixture was vortexed again and allowed to stand at approximately 25°C for one hour. After a final vortexing, absorbance readings were taken at 420 nm using a spectrophotometer and the results were expressed in milligrams per kilogram (mg kg^{-1})

3.4.4.5.2 Available Zn (mg kg^{-1})

The available zinc (Zn) content in the soil was determined by following the procedure outlined by Lindsay and Norwell (1978). In this method, 10 grams of soil sample was shaken with 20 mL of DTPA (di-ethylenetriaminepentaacetic acid) extractant, adjusted to a pH of 7.3, for two hours. The solution was then filtered to remove any particulates. The available zinc (Zn) in the extract were measured using an Analyst 400 Atomic Absorption Spectrophotometer and the results were expressed in milligrams per kilogram (mg kg^{-1}).

3.4.4.5.3 Available Ca (mg kg^{-1})

The exchangeable calcium in the soil was extracted using neutral ammonium acetate, following the procedure established by Merwin and Peech (1951). The calcium concentration was then measured with a Flame Photometer (Model TMF-45) and milligrams per kilogram (mg kg^{-1}).

3.4.5 Plant analysis

Collection and preparation of fruits and leaves samples: Fruits and leaf samples were collected from the plants during the first harvest in both years of the study. A composite sample of ten randomly selected plants from each plot, at full mature stage (Tandon 1989), was used. The samples were washed sequentially, first with tap water, followed by 0.1 N HCl and finally with distilled water. After washing, the samples were air-dried and then oven-dried at 60°C until a constant weight was achieved. The dried samples were ground using an electric grinder and stored in butter paper bags for the analysis of nutrients such as nitrogen (N), phosphorus (P), potassium (K), boron (B), zinc (Zn) and calcium (Ca).

Digestion of fruits and leaves samples: Well ground samples of known weight were digested in diacid mixture prepared by mixing concentrated HNO_3 and $HClO_4$ in the ratio of 4:1 observing all relevant precautions as laid down by Piper (1966) for the nutrients of P and K. Separate digestion was carried out for nitrogen estimation using concentrated H_2SO_4 and digestion mixture (Potassium sulphate 480 parts, Copper sulphate 20 parts, Mercuric oxide 3 parts, Selenium powder 1 part) as suggested by Jackson (1973).

3.4.5.1 N, P and K content in plants (%)

3.4.5.1.1 Nitrogen (%)

For total nitrogen estimation, one gram of the plant sample was digested in concentrated H_2SO_4 using a digestion mixture. After digestion, nitrogen content was determined using the micro-Kjeldahl method as described by Jackson (1973) and the results were reported as a percentage of nitrogen on a dry weight basis of the sample.

3.4.5.1.2 Phosphorous (%)

Total phosphorus content was quantified using the Vanado-Molybdate Phosphoric Yellow Colour Method as outlined by Jackson (1973). Five ml of the digested aliquot were pipetted into a 25 ml volumetric flask, to which 5 ml of Vanado-Molybdate reagent were added. The solution was diluted to 25 ml with distilled water and allowed to develop colour for 30 minutes. The phosphorus concentration was then measured using a Nukes UV-VIS Spectrophotometer at a wavelength of 470 nm, with a blank sample run simultaneously to calibrate the zero absorbance. The results were expressed as percentage of phosphorous on a dry weight basis of the sample.

3.4.5.1.3 Potassium (%)

Total potassium content in the di-acid extract was determined by flame photometer as suggested by Jackson (1967). Potassium was estimated on the flame photometer. The potassium concentration in leaves was reported as a percentage on a dry weight basis.

3.4.5.2 B, Zn and Ca content in plants

For the estimation of B, Zn and Ca, one gram of the plant sample was digested in 4:1 nitric acid and perchloric acid (HNO_3:$HClO_4$) mixture. In order to have complete transfer of digestion material, three washings of the digestion flask were given with distilled water and volume was made to 100 ml.

The boron content in the sample was quantified using the Azomethine-H method, as described by Wolf (1971) and the results were expressed in parts per million (ppm) on a dry weight basis. The zinc content was assessed according to the procedure outlined by Lindsay and Norwell (1978), employing an atomic absorption spectrophotometer and was also expressed in ppm on a dry weight basis. The calcium content was also determined using atomic absorption spectrophotometer following the method established by Berry and Johnson (1966), with results expressed percentage of calcium on a dry weight basis of the sample.

3.4.6 Periodic analysis of nutrients

Boron, zinc and calcium content in leaves and fruits were assessed one day prior to the first and second foliar sprays (in leaves) and 15 days following the second spray (in both fruits and leaves) using the aforementioned analytical methods.

3.4.7 Economics of the treatments

The economics of treatments is the most important consideration of making any recommendation to the farmer for its adoption. The cost of cultivation was worked out for calculating economics of different treatments in the experiment. The total cost of cultivation was determined by summing the fixed costs per hectare, risk factors, management factors and the costs associated with treatments per hectare. Net income was calculated by subtracting the total cost of cultivation from gross income. The benefit-cost ratio was derived by dividing net income by the total cost of cultivation, as outlined by Sharma et al. (2008).

3.5 STATISTICAL ANALYSIS

Analysis of variance for the experiment was done as per the model suggested by Panse and Sukhatme (1995). The data recorded was analysed using Microsoft Excel 2021, OPSTAT package and WASP 2.0 as per design of the experiment for working out the following values:

Analysis of Variance (ANOVA) Table for RBD Factorial:

Source of Variation	Degree of Freedom	Sum of Squares	Mean Sum of Squares (MSS)	F Value calculated
Replication (r)	r - 1	Sr	Mr = Sr / (r - 1)	-
Factor A	a - 1	Sa	Ma = Sa / (a - 1)	Ma / Me
Factor B	b - 1	Sb	Mb = Sb / (b - 1)	Mb / Me
Interaction (A × B)	(a - 1) (b - 1)	Sab	Mab = Sab / (a - 1)(b - 1)	Mab / Me
Error (e)	(r - 1) (ab - 1)	Se	Me = Se / (r - 1) (ab - 1)	-
Total	rab - 1	Sa + Sb + Sab + Sr + Se		-

Where,

r : Number of replications
a : Number of levels in Factor A
b : Number of levels in Factor B
Sr : Sum of squares due to replications
Sa : Sum of squares due to Factor A
Sb : Sum of squares due to Factor B
Sa : Sum of squares due to the interaction between Factor A and Factor B
Se : Sum of squares due to error
Mr : Mean sum of squares due to replications
Ma : Mean sum of squares due to Factor A
Mb : Mean sum of squares due to Factor B
Mab : Mean sum of squares due to the interaction between Factor A and Factor B
Me : Mean sum of squares due to error

Each factor's mean sum of squares is tested against the error mean sum of squares using:

F_A = Ma / Me,   F_B = Mb / Me,   F{A × B} = Mab / Me

The calculated F-values are compared with the tabulated F-values at $P = 0.05$.

Where F-test was found significant, critical difference was calculated to find out the superiority of one treatment over the other.

The standard errors and critical differences were calculated as follows:

SE (m) ± = $\sqrt{Me/r}$

SE (d) ± = $\sqrt{2Me/r}$

$CD_{(0.05)}$ = S.E. (d) × $t_{(0.05)}$ (r-1) (ab-1) df

SE (m) ± = Standard error of mean

SE (d) ± = Standard error of difference

$CD_{(0.05)}$ = Critical difference at 5 per cent level of significance

The graphs were created using Microsoft Excel 2021 (graph tool).

Plate 3.4: Illustration of the harvesting of coloured capsicum

Plate 3.5a: Illustration of the recording of observations

Plate 3.5b: Illustration of the recording of observations

Chapter-4

RESULTS AND DISCUSSION

The application of nutrients in the cultivation of coloured capsicum is a vital agronomic practice that profoundly impacts plant growth, fruit yield and quality. Micronutrients, though required in trace amounts, play an essential role in various physiological and biochemical processes, including enzyme activation, chlorophyll synthesis and nutrient mobilization, thereby impacting the overall health and productivity of the crop. Hybrid coloured capsicum, being a high-value horticultural crop, requires precise nutrient management to meet its intensive growth demands. However, the specific responses of hybrids to different macro and micro nutrient treatments remain inadequately studied, necessitating further research to optimize productivity and profitability.

The present study, titled **"Response of Micronutrient Applications on Hybrids of Coloured Capsicum",** explores the effects of nutrient applications on various aspects of coloured capsicum cultivation, with a focus on growth dynamics, yield attributes, quality parameters, disease incidence and severity, soil properties, plant nutrient status, periodic analysis of plants and the economic viability of treatments. By examining these factors systematically, the study aims to provide comprehensive insights into the role of nutrients in improving the performance of coloured capsicum hybrids under protected cultivation systems.

The data obtained during the study were subjected to rigorous statistical analysis to evaluate the significance of the results. This chapter presents a detailed discussion of the findings, categorized under various sub-headings. The interpretation of results is supported by relevant evidence and contextualized with existing literature to provide a broader understanding of the implications for capsicum cultivation practice. The results have been systematically categorized and discussed under the following sub-headings:

4.1 Growth and yield characters
4.2 Quality parameters
4.3 Incidence and severity of economically important diseases of capsicum
4.4 Soil analysis
4.5 Plant analysis

4.6 Periodic analysis of nutrients

4.7 Economics of the treatments

4.1 Growth and yield characters

4.1.1 Days to first picking

Days to first picking is a vital trait that indicates the relative earliness or lateness of a hybrid in reaching marketable maturity. This parameter holds significant agronomic and economic importance, as earlier picking enables the timely supply of fresh produce to the market, capitalizing on higher market prices and consumer demand during initial harvest periods. Additionally, a reduced duration to first picking allows for an extended harvest window, providing the plant with an opportunity to produce a greater cumulative yield over its productive lifespan.

The data on the effect of coloured capsicum hybrids and foliar nutrient applications on days to first picking during the two consecutive years 2022-2023 and 2023-2024 and the pooled data (Table 4.1.1) showed significant differences among the treatments.

During the first year 2022-2023, the effects of coloured capsicum hybrids and foliar nutrient applications on days to first picking were significant, whereas their interaction effect was non-significant. Regarding the effect of coloured capsicum hybrids, the Indam Mamatha (H_1) recorded a statistically lower number of days to first picking (72.33), while the hybrid Orobelle (H_2) recorded a statistically higher number of days to first picking (73.21). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum days to first picking (71.50). This was statistically at par with treatments M_4 : Boric acid 0.5 % + Zinc sulphate 0.5 % (72.33), M_6 : Zinc sulphate 0.5 % + Calcium chloride 0.5 % (72.67), M_5 : Boric acid 0.5 % + Calcium chloride 0.5 % (72.68) and M_1 : Boric acid 0.5 % (72.83). The control treatment (M_8), with no foliar nutrient application, recorded the maximum days to first picking (74.17). The interaction between coloured capsicum hybrids and foliar nutrient applications showed a non-significant effect, with values ranging from 71.00 to 74.33 days.

During the second year 2023-2024, the effects of coloured capsicum hybrids, foliar nutrient applications and their interaction were non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded an average of 72.67

days to first picking, while the hybrid Orobelle (H_2) recorded 72.92 days, with no significant difference between them. The effect of foliar nutrient applications was also non-significant, with values ranging from 72.00 to 74.33 days. The interaction between coloured capsicum hybrids and foliar nutrient applications also showed a non-significant effect, with values ranging from 71.00 to 74.67 days.

The pooled data for both the years revealed that the effect of coloured capsicum hybrids and foliar nutrient applications on days to first picking were significant, whereas their interaction effect was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower number of days to first picking (72.50), while the hybrid Orobelle (H_2) recorded a statistically higher number of days to first picking (73.06). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum days to first picking (71.75). This was statistically at par with treatments M_4 : Boric acid 0.5 % + Zinc sulphate 0.5 % (72.33), M_5 : Boric acid 0.5 % + Calcium chloride 0.5 % (72.50), M_6 : Zinc sulphate 0.5 % + Calcium chloride 0.5 % (72.58) and M_1 : Boric acid 0.5 % (72.75). The control treatment (M_8), with no foliar nutrient application, recorded the maximum days to first picking (74.25). The interaction between coloured capsicum hybrids and foliar nutrient applications showed a non-significant effect, with values ranging from 71.50 to 74.33 days.

The results from both the years 2022-2023 and 2023-2024, along with the pooled analysis, indicate that the effect of coloured capsicum hybrids and foliar nutrient applications on days to first picking was significant.

The observed lesser number of days to first picking in hybrid "Indam Mamatha" aligns with findings from Singh (2024), Yadav et al. (2023b) and Anita (2022), who reported similar results for early fruiting in certain varieties. These studies suggest that specific hybrid can be more responsive to nutrient applications, leading to quicker fruit development and earlier harvest. In this study, the hybrid "Indam Mamatha" matured earlier than hybrid "Orobelle", which can be attributed to its enhanced ability to regulate physiological processes such as flowering and fruit set, resulting in faster maturity.

In terms of foliar nutrient applications, the combination of boric acid, zinc sulphate and calcium chloride had a significant effect on reducing days to first picking.

Table 4.1.1: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on days to first picking

Treatments	**Days to first picking**		
	2022-2023	**2023-2024**	**Pooled**
H_1	72.33	72.67	72.50
H_2	73.21	72.92	73.06
Mean	**72.77**	**72.79**	**72.78**
SE (m)±	**0.22**	**0.27**	**0.17**
$CD_{0.05}$	**0.66**	**NS**	**0.50**
M_1	72.83	72.50	72.75
M_2	73.00	73.00	73.00
M_3	73.00	73.17	73.08
M_4	72.33	72.33	72.33
M_5	72.68	72.17	72.50
M_6	72.67	72.83	72.58
M_7	71.50	72.00	71.75
M_8	74.17	74.33	74.25
Mean	**72.77**	**72.79**	**72.78**
SE (m)±	**0.45**	**0.54**	**0.35**
$CD_{0.05}$	**1.33**	**NS**	**1.00**
Interaction:			
H_1M_1	72.33	71.33	71.83
H_1M_2	73.00	73.33	73.17
H_1M_3	72.67	73.33	73.00
H_1M_4	71.33	72.67	72.00
H_1M_5	72.00	71.00	71.50
H_1M_6	72.33	73.00	72.67
H_1M_7	71.00	72.00	71.50
H_1M_8	74.00	74.67	74.33
H_2M_1	73.00	73.67	73.33
H_2M_2	73.00	72.67	72.83
H_2M_3	73.33	73.00	73.17
H_2M_4	73.33	72.00	72.67
H_2M_5	73.67	73.33	73.50
H_2M_6	73.00	72.67	72.83
H_2M_7	72.00	72.00	72.00
H_2M_8	74.33	74.00	74.17
Mean	**72.77**	**72.79**	**72.78**
SE (m)±	**0.64**	**0.77**	**0.50**
$CD_{0.05}$	**NS**	**NS**	**NS**

H_1 - Indam Mamatha; **H_2** - Orobelle

***M_1* -** Boric acid 0.5 %; **M_2 -** Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8 -** Control (No spray)

This finding is in agreement with previous research, including Yadav et al. (2023b), which demonstrated that nutrients like boron, zinc and calcium play a crucial role in promoting faster fruiting by enhancing key metabolic pathways involved in plant development. Similar studies by Singh (2024) and Anita (2022) have shown that the application of these nutrients can accelerate the fruiting process, ensuring earlier harvests and thus facilitating early market supply.

The non-significant interaction between coloured capsicum hybrids and foliar nutrient applications suggests that while both factors independently influenced the days to first picking, their combined effect did not significantly alter the results. This supports the findings of Yadav et al. (2023b), who observed that nutrient applications consistently affected fruit development across various cultivars.

Overall, these results emphasize the importance of selecting appropriate hybrids and nutrient management practices for accelerating maturity in capsicum cultivation. The consistency of the effects observed across years highlights the potential of foliar nutrient applications, particularly those involving boron, zinc and calcium, in ensuring early fruiting and improving crop productivity.

4.1.2 Internodal length (cm)

Internodal length (cm) is a morphological trait that determines the spacing between successive nodes on the stem. This parameter significantly influences the overall plant architecture, light interception and canopy structure, which are vital for optimizing photosynthetic efficiency. Shorter internodal lengths contribute to compact plant growth, which is often desirable in high-density planting systems or protected cultivation. Conversely, longer internodes may enhance ventilation and reduce the risk of disease by allowing better air circulation. The balance of internodal length also impacts agronomic practices such as training, pruning and harvesting, ultimately affecting yield potential and resource use efficiency.

The data on the effect of coloured capsicum hybrids and foliar nutrient applications on internodal length (cm) during the two consecutive years 2022-2023 and 2023-2024 and the pooled data (Table 4.1.2) showed significant differences among the treatments.

During the first year 2022-2023, the effects of coloured capsicum hybrids, foliar nutrient applications and their interactions were significant for internodal length (cm).

Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower internodal length (8.07 cm), while the hybrid Orobelle (H_2) recorded a statistically higher internodal length (8.23 cm). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum internodal length (7.60 cm). The control treatment (M_8), with no foliar nutrient application, recorded the maximum internodal length (8.88 cm). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the minimum internodal length (7.60 cm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % . This was statistically at par (7.61 cm) with treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % . The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum internodal length (8.90 cm).

During the second year 2023-2024, the effects of coloured capsicum hybrids, foliar nutrient applications and their interactions were significant for internodal length (cm). Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower internodal length (7.61 cm), while the hybrid Orobelle (H_2) recorded a statically higher internodal length (7.75 cm). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum internodal length (7.20 cm). The control treatment (M_8), with no foliar nutrient application, recorded the maximum internodal length (8.38 cm). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the minimum internodal length (7.20 cm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % . This was statistically at par (7.21 cm) with treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % . The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum internodal length (8.40 cm).

The pooled data for both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions were significant for internodal length (cm). Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower internodal length (7.84 cm), while the hybrid Orobelle (H_2) recorded a statistically higher internodal length (7.99 cm).

Table 4.1.2: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on internodal length

Treatments	Internodal length (cm)		
	2022-2023	2023-2024	Pooled
H_1	8.07	7.61	7.84
H_2	8.23	7.75	7.99
Mean	**8.15**	**7.68**	**7.92**
SE (m)±	**0.01**	**0.03**	**0.05**
$CD_{0.05}$	**0.02**	**0.08**	**0.14**
M_1	8.03	7.60	7.82
M_2	7.92	7.45	7.68
M_3	8.02	7.55	7.78
M_4	8.12	7.65	7.88
M_5	8.27	7.75	8.01
M_6	8.37	7.85	8.11
M_7	7.60	7.20	7.40
M_8	8.88	8.38	8.63
Mean	**8.15**	**7.68**	**7.91**
SE (m)±	**0.01**	**0.01**	**0.01**
$CD_{0.05}$	**0.04**	**0.02**	**0.02**
Interaction			
H_1M_1	7.77	7.30	7.53
H_1M_2	7.87	7.40	7.63
H_1M_3	7.97	7.50	7.73
H_1M_4	8.07	7.60	7.83
H_1M_5	8.17	7.70	7.93
H_1M_6	8.27	7.80	8.03
H_1M_7	7.60	7.20	7.40
H_1M_8	8.87	8.37	8.62
H_2M_1	8.30	7.90	8.10
H_2M_2	7.97	7.50	7.73
H_2M_3	8.07	7.60	7.83
H_2M_4	8.17	7.70	7.93
H_2M_5	8.37	7.80	8.08
H_2M_6	8.47	7.90	8.18
H_2M_7	7.61	7.21	7.41
H_2M_8	8.90	8.40	8.65
Mean	**8.15**	**7.68**	**7.91**
SE (m)±	**0.02**	**0.01**	**0.01**
$CD_{0.05}$	**0.06**	**0.02**	**0.04**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1** - Boric acid 0.5 %; **M_2** - Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8** - Control (No spray)

In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum internodal length (7.40 cm). The control treatment (M_8), with no foliar nutrient application, recorded the maximum internodal length (8.63 cm). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the minimum internodal length (7.40 cm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % . This was statistically at par (7.41 cm) with treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum internodal length (8.65 cm).

The results from both the years 2022-2023 and 2023-2024, along with the pooled analysis, indicate that the effect of coloured capsicum hybrids and foliar nutrient applications on internodal length (cm) was significant.

The variations in internodal length observed in the study can be attributed to the physiological roles of boron, zinc and calcium in regulating plant growth and development. The hybrid “Indam Mamatha” exhibited shorter internodal length compared to “Orobelle” which can be due to the fact that certain hybrids respond differently to nutrient applications due to their inherent genetic traits. The reduced internodal length in “Indam Mamatha” suggests that it may have a better regulatory mechanism for stem elongation, influenced by nutrient availability and uptake efficiency.

The significant effect of foliar nutrient applications, particularly the combination of boric acid, zinc sulphate and calcium chloride, supports the findings of Mayorga-Gómez et al. (2020), who emphasized the role of these nutrients in cell division, structural integrity and hormone balance. Boron is essential for cell wall formation, ensuring structural rigidity and preventing excessive elongation, while zinc plays a key role in auxin biosynthesis, regulating internode length by modulating cell expansion (Yadav et al. 2023a). Calcium further stabilizes cell membranes and supports intercellular communication, which contributes to controlled plant architecture (Mayorga-Gómez et al. 2020). The synergistic action of these nutrients likely harmonized hormonal activities and structural development, leading to compact plant growth.

The interaction effect between hybrids and nutrient applications being significant indicates that different hybrids respond uniquely to nutrient availability. This aligns with

Kishor et al. (2023), who observed that foliar application of specialized nutrient formulations resulted in reduced internodal length, particularly in hybrids with higher growth potential. The longer internodal length observed in control treatments, where no nutrients were applied, highlights the importance of these nutrients in restricting unregulated stem elongation.

Additionally, environmental factors such as light intensity, temperature and humidity could have influenced internodal length by affecting nutrient uptake and metabolism. However, the consistency in response across both years suggests that foliar nutrient applications provided stability in internode regulation, mitigating environmental variations. These findings emphasize the role of targeted nutrient management in optimizing plant growth and ensuring uniform canopy structure, which is crucial for better yield and resource use efficiency in capsicum cultivation.

4.1.3 Plant height (cm)

Plant height is a fundamental morphological trait in capsicum cultivation, significantly impacting photosynthetic efficiency and overall productivity. Greater plant height is often correlated with an increased leaf area index and improved light interception, which enhance the plant's photosynthetic activity and biomass accumulation. This, in turn, supports higher fruit yield and quality. Moreover, optimal plant height promotes better canopy architecture, facilitating improved air circulation and reducing the incidence of foliar diseases.

The data on the effect of coloured capsicum hybrids and foliar nutrient applications on plant height (cm) during the two consecutive years 2022-2023 and 2023-2024 and the pooled data (Table 4.1.3) showed significant differences among the treatments.

During the first year 2022–2023, the effects of coloured capsicum hybrids on plant height (cm) were non-significant, while the effects of foliar nutrient applications and their interactions with coloured capsicum hybrids were significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a plant height of 143.08 cm, while the hybrid Indam Mamatha (H_1) recorded 141.00 cm, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum plant height (154.00 cm). This was statistically at par with treatments M_5 : Boric acid 0.5 % + Calcium chloride 0.5 %, M_6 : Zinc sulphate 0.5 % + Calcium chloride 0.5 % and M_4 : Boric acid 0.5 % + Zinc sulphate 0.5 % with values of 149.83, 149.50 and 147.17 cm respectively. The control treatment (M_8), with no foliar nutrient application, recorded the minimum plant height (126.33 cm).

The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum plant height (155.67 cm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % . This was statistically at par with treatment combination H_2M_7 (152.33 cm), H_1M_5 (151.67 cm), H_1M_4 (150.67 cm), H_2M_6 (149.67 cm), H_1M_6 (149.33 cm), H_2M_3 (148.33 cm) and H_2M_5 (148.00 cm). The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum plant height (125.00 cm).

During the second year 2023–2024, the effects of coloured capsicum hybrids on plant height (cm) were non-significant, while the effects of foliar nutrient applications and their interactions with coloured capsicum hybrids were significant. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a plant height of 151.38 cm, while the hybrid Orobelle (H_2) recorded 150.29 cm, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum plant height (170.17 cm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum plant height (138.17 cm).

The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum plant height (173.67 cm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % . This was statistically at par with treatment combination H_2M_7 (166.67 cm), H_1M_4 (162.33 cm) and H_1M_5 (161.67 cm). The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum plant height (128.33 cm).

The pooled data for both the years revealed that the effects of coloured capsicum hybrids on plant height (cm) were non-significant, while the effects of foliar nutrient applications and their interactions with coloured capsicum hybrids were significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a plant height of 146.68 cm, while the hybrid Indam Mamatha (H_1) recorded 146.18 cm, with no significant difference between them. In terms of foliar nutrient applications, the combined

Table 4.1.3: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on plant height

Treatments	Plant height (cm)		
	2022-2023	2023-2024	Pooled
H_1	141.00	151.38	146.18
H_2	143.08	150.29	146.68
Mean	**142.04**	**150.83**	**146.44**
SE (m)±	**1.40**	**1.50**	**1.02**
$CD_{0.05}$	**NS**	**NS**	**NS**
M_1	135.67	143.50	139.58
M_2	136.33	144.33	140.33
M_3	137.50	141.17	139.33
M_4	147.17	157.00	152.08
M_5	149.83	158.67	154.25
M_6	149.50	153.67	151.58
M_7	154.00	170.17	162.08
M_8	126.33	138.17	132.25
Mean	**142.04**	**150.83**	**146.44**
SE (m)±	**2.81**	**3.00**	**2.04**
$CD_{0.05}$	**8.16**	**8.71**	**5.78**
Interaction			
H_1M_1	139.00	152.00	145.50
H_1M_2	130.00	135.00	132.50
H_1M_3	127.67	136.67	132.17
H_1M_4	150.67	162.33	156.50
H_1M_5	151.67	161.67	156.67
H_1M_6	149.33	158.33	153.83
H_1M_7	155.67	173.67	164.67
H_1M_8	125.00	139.67	132.33
H_2M_1	132.33	135.00	133.67
H_2M_2	142.67	153.67	148.17
H_2M_3	148.33	154.00	151.17
H_2M_4	143.67	151.67	147.67
H_2M_5	148.00	155.67	151.83
H_2M_6	149.67	149.00	149.33
H_2M_7	152.33	166.67	159.50
H_2M_8	126.67	128.33	127.50
Mean	**142.04**	**150.83**	**146.44**
SE (m)±	**3.97**	**4.24**	**2.89**
$CD_{0.05}$	**11.54**	**12.32**	**8.17**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1** - Boric acid 0.5 %; **M_2** - Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8** - Control (No spray)

foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum plant height (162.08 cm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum plant height (132.25 cm).

The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum plant height (164.67 cm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % . This was statistically at par with treatment combination H_2M_7 (159.50 cm), H_1M_5 (156.67 cm) and H_1M_4 (156.50 cm).The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum plant height (127.50 cm).

The variations in plant height observed in the study can be attributed to the physiological roles of boron, zinc and calcium in regulating plant growth and development. The non-significant effect of coloured capsicum hybrids on plant height across both years suggests that genetic differences among hybrids did not strongly influence this trait under the given environmental conditions. However, the significant effects of foliar nutrient applications and their interactions with hybrids indicate that external nutrient supplementation played a crucial role in promoting plant growth.

The significant increase in plant height with the combined foliar application of boric acid, zinc sulphate and calcium chloride align with findings from Haleema et al. (2018), who reported enhanced vegetative growth in tomato with similar foliar applications. Boron is essential for cell wall synthesis and integrity, influencing cell division and elongation, which directly impacts plant height. Zinc plays a vital role in enzyme activation and protein synthesis, contributing to overall plant development, while calcium stabilizes cell walls and maintains membrane integrity, supporting structural growth (Chhaba et al. 2024; Yadav et al. 2023b). The synergistic effects of these nutrients likely enhanced vegetative growth, leading to increased plant height in capsicum hybrids.

The observation that “Indam Mamatha” attained a maximum plant height with the combined foliar application of boric acid, zinc sulphate and calcium chloride suggests that this hybrid responded more efficiently to nutrient supplementation. This response may be attributed to its genetic predisposition for higher nutrient uptake and assimilation efficiency. The control treatment, which received no foliar nutrient application, consistently recorded the lowest plant height, emphasizing the importance of these micronutrients in promoting stem elongation and overall plant growth.

In the polyhouse experiment, plant height was greater in the second year than in the first, likely due to variations in environmental factors such as temperature, light intensity and soil moisture. These factors influence nutrient uptake and assimilation, ultimately affecting plant growth. Previous studies have reported that environmental variations significantly impact plant growth parameters by altering metabolic activities and nutrient utilization efficiency (Yadav et al. 2023b). The pooled data further confirmed the stability of the nutrient-induced effects, as significant improvements in plant height were recorded across both years.

The interaction effects between hybrids and nutrient applications suggest that different hybrids exhibit varying degrees of responsiveness to foliar nutrition. The statistical parity of various treatments with the most effective treatment indicates that boron, zinc and calcium function complementarily in promoting capsicum growth. This finding is in agreement with earlier studies where foliar applications of boric acid and zinc sulphate significantly increased vegetative growth parameters (Chhaba et al. 2024; Singh et al. 2019).

These results highlight the significance of targeted foliar nutrient management in optimizing plant growth and development in coloured capsicum hybrids. The positive response of plant height to combined nutrient applications indicate that boron, zinc and calcium play essential roles in cellular functions that contribute to overall plant vigour.

4.1.4 Leaf area index

Leaf Area Index (LAI) is a critical physiological parameter that measures the total leaf area per unit ground area and serves as an indicator of the plant canopy’s photosynthetic capacity. It plays a pivotal role in determining the efficiency of light interception, carbon assimilation and overall biomass production in crops (Monteith 1977). A higher LAI generally correlates with enhanced photosynthetic efficiency and resource utilization, directly influencing crop yield and quality.

The data from the two consecutive years 2022-2023 and 2023-2024, along with pooled analysis, indicate substantial differences in leaf area index across the various treatments as presented in Table 4.1.4.

During the first year 2022-2023, the effects of coloured capsicum hybrids, foliar nutrient applications and their interaction was significant for leaf area index. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher leaf area index (3.16), while the hybrid Indam Mamatha (H_1) recorded a statistically lower leaf area index (3.05). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum leaf area index (4.13). The control treatment (M_8), with no foliar nutrient application, recorded the minimum leaf area index (2.51). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum leaf area index (4.17) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % . This was statistically at par (4.10) with treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum leaf area index (2.47).

During the second year 2023-2024, the effects of coloured capsicum hybrids, foliar nutrient applications and their interaction was significant for leaf area index. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher leaf area index (3.56), while the hybrid Indam Mamatha (H_1) recorded a statistically lower leaf area index (3.48). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum leaf area index (4.40). The control treatment (M_8), with no foliar nutrient application, recorded the minimum leaf area index (3.03). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum leaf area index (4.41) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % . This was statistically at par (4.40) with treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum leaf area index (3.00).

The pooled data for both the years revealed that the effects of coloured capsicum hybrids, foliar nutrient applications and their interaction was significant for leaf area index. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher leaf area index (3.36), while the hybrid Indam Mamatha (H_1) recorded a statistically lower leaf area index (3.26). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum leaf area index (4.27). The control treatment (M_8), with no foliar nutrient application, recorded the minimum leaf area index (2.77). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum leaf area index (4.28) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % . This was statistically at par (4.25) with treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum leaf area index (2.73).

The variations in leaf area index (LAI) observed across treatments highlight the significant role of nutrient supplementation in promoting canopy growth and overall vegetative development in capsicum. The results indicate that the application of boric acid, zinc sulphate and calcium chloride contributed notably to improved LAI by supporting key physiological processes involved in leaf expansion and structural integrity. The hybrid “Orobelle” consistently exhibited a higher LAI than “Indam Mamatha,” suggesting genetic differences in leaf development and nutrient utilization efficiency.

The increased LAI recorded in response to foliar application of boric acid, zinc sulphate and calcium chloride can be attributed to the synergistic effects of these nutrients in promoting vegetative growth. Boron plays a crucial role in cell wall formation and stability, facilitating enhanced leaf expansion (Mayorga-Gómez et al. 2020). Zinc is essential for auxin biosynthesis and enzymatic activity, which stimulate cell division and tissue growth, ultimately contributing to a higher LAI (Yadav et al. 2023a). Calcium further reinforces cell membrane integrity and facilitates nutrient translocation, ensuring sustained leaf development and enhanced photosynthetic efficiency (Ghosh et al. 2020). These combined effects led to an improved canopy structure, optimizing light interception and enhancing overall plant vigour.

The significant effect of foliar nutrient applications on LAI supports previous findings in other vegetable crops, such as tomato, where boric acid, zinc sulphate and calcium chloride applications positively influenced leaf expansion and canopy development (Haleema et al. 2018). Similar trends were observed in capsicum by Nawrin et al. (2020), who reported increased LAI with targeted foliar nutrient supplementation.

Table 4.1.4: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on leaf area index

Treatments	Leaf area index		
	2022-2023	**2023-2024**	**Pooled**
H_1	3.05	3.48	3.26
H_2	3.16	3.56	3.36
Mean	**3.10**	**3.52**	**3.31**
SE (m)±	**0.03**	**0.01**	**0.01**
$CD_{0.05}$	**0.08**	**0.03**	**0.04**
M_1	2.98	3.38	3.18
M_2	2.59	3.23	2.91
M_3	2.79	3.33	3.06
M_4	3.03	3.47	3.25
M_5	3.23	3.57	3.40
M_6	3.54	3.72	3.63
M_7	4.13	4.40	4.27
M_8	2.51	3.03	2.77
Mean	**3.10**	**3.52**	**3.31**
SE (m)±	**0.06**	**0.02**	**0.03**
$CD_{0.05}$	**0.17**	**0.07**	**0.05**
Interaction			
H_1M_1	2.47	3.07	2.77
H_1M_2	2.72	3.27	2.99
H_1M_3	2.90	3.37	3.13
H_1M_4	3.07	3.47	3.27
H_1M_5	3.25	3.57	3.41
H_1M_6	3.40	3.67	3.53
H_1M_7	4.10	4.40	4.25
H_1M_8	2.47	3.00	2.73
H_2M_1	3.50	3.70	3.60
H_2M_2	2.47	3.20	2.83
H_2M_3	2.68	3.30	2.99
H_2M_4	3.00	3.47	3.23
H_2M_5	3.20	3.57	3.38
H_2M_6	3.67	3.77	3.72
H_2M_7	4.17	4.41	4.28
H_2M_8	2.55	3.07	2.81
Mean	**3.10**	**3.52**	**3.31**
SE (m)±	**0.08**	**0.03**	**0.04**
$CD_{0.05}$	**0.25**	**0.09**	**0.13**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1** - Boric acid 0.5 %; **M_2** - Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8** - Control (No spray)

The second-year results demonstrated an overall increase in LAI compared to the first year, which may be attributed to variations in environmental conditions such as temperature, soil moisture and light intensity in the polyhouse. Favourable conditions in 2023–2024 likely enhanced nutrient absorption and metabolism, leading to greater canopy development and improved vegetative growth. These findings align with the reports of Ameta et al. (2017), who emphasized the importance of environmental factors in nutrient uptake efficiency and plant growth regulation. The significant interaction effect between hybrids and nutrient applications suggests that different hybrids respond uniquely to foliar fertilization, reinforcing the importance of genotype-specific nutrient management strategies (Kishor et al. 2023).

The lower LAI observed in control treatments across both years highlights the necessity of essential nutrient supplementation for optimal vegetative growth. The absence of boron, zinc and calcium likely restricted crucial physiological processes such as cell division, leaf expansion and nutrient translocation, thereby limiting canopy growth.

The study underscores the significant role of foliar-applied boric acid, zinc sulphate and calcium chloride in enhancing LAI in coloured capsicum hybrids. The findings emphasize the importance of hybrid-specific nutrient management strategies to maximize vegetative growth and canopy development.

4.1.5 Fruit length (cm)

Fruit length is a vital agronomic and quality trait in capsicum, significantly influencing its market value, consumer acceptance and processing suitability. Longer fruits are often preferred for their appealing appearance, uniformity and compatibility with culinary uses such as stuffing and slicing. From an agronomic perspective, fruit length reflects the plant's genetic potential and its physiological capacity to support cell division and elongation during fruit development.

The data from the two consecutive years 2022-2023 and 2023-2024, combined with the pooled analysis, revealed significant variations in fruit length (cm) among the different treatments, as illustrated in Table 4.1.5.

During the first year 2022-2023, the effects of coloured capsicum hybrids, foliar nutrient applications and their interaction was significant for fruit length (cm). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher fruit length (7.92 cm), while the hybrid Indam Mamatha (H_1) recorded a statistically lower fruit length (7.63 cm). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit length (8.52 cm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit length (7.30 cm). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum fruit length (8.97 cm) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum fruit length (7.27 cm).

During the second year 2023-2024, the effects of coloured capsicum hybrids, foliar nutrient applications and their interaction was significant for fruit length (cm). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher fruit length (8.34 cm), while the hybrid Indam Mamatha (H_1) recorded a statistically lower fruit length (8.04 cm). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit length (8.92 cm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit length (7.72 cm). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum fruit length (9.30 cm) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum fruit length (7.63 cm).

The pooled data for both the years revealed that the effects of coloured capsicum hybrids, foliar nutrient applications and their interaction was significant for fruit length (cm). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher fruit length (8.13 cm), while the hybrid Indam Mamatha (H_1) recorded a statistically lower fruit length (7.83 cm).

In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit length (8.72 cm).

Table 4.1.5: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on fruit length

Treatments	Fruit Length (cm)		
	2022-2023	2023-2024	Pooled
H_1	7.63	8.04	7.83
H_2	7.92	8.34	8.13
Mean	**7.77**	**8.19**	**7.98**
SE (m)±	**0.02**	**0.02**	**0.01**
$CD_{0.05}$	**0.07**	**0.05**	**0.04**
M_1	7.75	8.02	7.88
M_2	7.73	8.28	8.01
M_3	7.67	8.07	7.87
M_4	7.82	8.25	8.03
M_5	7.75	8.07	7.91
M_6	7.65	8.22	7.93
M_7	8.52	8.92	8.72
M_8	7.30	7.72	7.51
Mean	**7.77**	**8.19**	**7.98**
SE (m)±	**0.05**	**0.04**	**0.03**
$CD_{0.05}$	**0.15**	**0.11**	**0.09**
Interaction			
H_1M_1	7.63	7.90	7.77
H_1M_2	7.60	8.13	7.87
H_1M_3	7.57	7.97	7.77
H_1M_4	7.70	8.10	7.90
H_1M_5	7.63	7.97	7.80
H_1M_6	7.53	8.10	7.82
H_1M_7	8.07	8.53	8.30
H_1M_8	7.27	7.63	7.45
H_2M_1	7.87	8.13	8.00
H_2M_2	7.87	8.43	8.15
H_2M_3	7.77	8.17	7.97
H_2M_4	7.93	8.40	8.17
H_2M_5	7.87	8.17	8.02
H_2M_6	7.77	8.33	8.05
H_2M_7	8.97	9.30	9.13
H_2M_8	7.33	7.80	7.57
Mean	**7.77**	**8.19**	**7.98**
SE (m)±	**0.07**	**0.05**	**0.04**
$CD_{0.05}$	**0.22**	**0.16**	**0.13**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1 -** Boric acid 0.5 %; **M_2 -** Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8 -** Control (No spray)

The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit length (7.51 cm). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum fruit length (9.13 cm) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum fruit length (7.45 cm).

The variations in fruit length observed in the study highlight the critical role of foliar nutrient applications in enhancing fruit development in coloured capsicum. The significant differences in fruit length among hybrids and nutrient treatments suggest that genetic factors and external nutrient supplementation both play a vital role in determining fruit elongation.

The hybrid “Orobelle”' consistently exhibited higher fruit length compared to “Indam Mamatha,” which can be attributed to its genetic potential for better cell expansion and elongation. The enhanced fruit length in “Orobelle” may indicate its higher efficiency in utilizing nutrient applications, aligning with findings from Malik et al. (2020) and Manas et al. (2014), who reported that genotype-specific responses to nutrient availability significantly influence fruit development.

The significant effect of foliar nutrient applications, particularly the combination of boric acid, zinc sulphate and calcium chloride, reinforces the crucial role these nutrients play in promoting fruit growth. Boron is essential for cell wall formation, ensuring structural integrity and facilitating elongation, while zinc plays a key role in auxin biosynthesis and protein metabolism, which are necessary for cell division and fruit elongation (Yadav et al. 2023b; Saha et al. 2023). Calcium, being an essential component of cell membranes, contributes to cell stability and efficient nutrient translocation, supporting better fruit growth (Islam et al. 2021).

The highest fruit length recorded in treatment H_2M_7 suggests a synergistic effect of these nutrients in enhancing fruit elongation. These findings align with previous research by Anita (2022) and Islam et al. (2021), who demonstrated that foliar applications of boron, zinc and calcium significantly improved fruit size and quality in capsicum and other solanaceous crops. The increased availability of these nutrients likely optimized enzymatic activities and hormonal balance, leading to improved fruit development.

Pooled data over two years indicated a stable response to foliar nutrient applications, suggesting that external nutrient supplementation can mitigate environmental variations and enhance fruit growth consistently. The increase in fruit length during the second year compared to the first year may be attributed to improved environmental conditions such as temperature, soil moisture and light availability, which could have augmented nutrient uptake and utilization.

The significant interaction between hybrids and nutrient applications suggests that different genetic backgrounds respond uniquely to external nutrient supply. This observation is supported by the study of Yadav et al. (2023b), which highlighted the importance of genotype and nutrient interaction in optimizing fruit parameters in vegetable crops. The lowest fruit length recorded in control treatments emphasizes the necessity of balanced nutrient management, as the absence of essential nutrients likely restricted cell elongation and fruit growth. The positive response to boric acid, zinc sulphate and calcium chloride highlights their potential for improving fruit development, supporting the idea that precision nutrient management can optimize crop performance.

4.1.6 Fruit breadth (cm)

Fruit breadth is an important morphological characteristic in horticultural crops like capsicum, directly influencing consumer preferences and agronomic value. Fruits with higher breadth are often perceived as visually appealing and of superior quality, thereby enhancing their marketability. From an agronomic perspective, increased fruit breadth reflects better growth and development of the fruit.

The data from the two consecutive years 2022-2023 and 2023-2024, combined with the pooled analysis, revealed significant variations in fruit breadth (cm) among the different treatments, as illustrated in Table 4.1.6.

During the first year 2022-2023, the effects of coloured capsicum hybrids, foliar nutrient applications and their interaction was significant for fruit breadth (cm). Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically higher fruit breadth (7.06 cm), while the hybrid Orobelle (H_2) recorded a statistically lower fruit breadth (6.09 cm). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit breadth (7.80 cm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit breadth (6.10 cm). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum fruit breadth (8.20 cm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum fruit breadth (5.60 cm).

During the second year 2023-2024, the effects of coloured capsicum hybrids, foliar nutrient applications and their interaction was significant for fruit breadth (cm). Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically higher fruit breadth (7.20 cm), while the hybrid Orobelle (H_2) recorded a statistically lower fruit breadth (6.22 cm). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit breadth (7.77 cm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit breadth (6.07 cm). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum fruit breadth (8.13 cm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum fruit breadth (5.53 cm).

The pooled data for both the years revealed that the effects of coloured capsicum hybrids, foliar nutrient applications and their interaction was significant for fruit breadth (cm). Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically higher fruit breadth (7.13 cm), while the hybrid Orobelle (H_2) recorded a statistically lower fruit breadth (6.15 cm). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit breadth (7.78 cm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit breadth (6.08 cm). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum fruit breadth (8.17 cm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum fruit breadth (5.57 cm).

Table 4.1.6: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on fruit breadth

Treatments	Fruit breadth (cm)		
	2022-2023	2023-2024	Pooled
H_1	7.06	7.20	7.13
H_2	6.09	6.22	6.15
Mean	**6.58**	**6.71**	**6.64**
SE (m)±	**0.01**	**0.01**	**0.01**
$CD_{0.05}$	**0.02**	**0.02**	**0.02**
M_1	6.20	6.80	6.50
M_2	6.30	6.40	6.35
M_3	6.40	6.50	6.45
M_4	6.50	6.60	6.55
M_5	6.60	6.70	6.65
M_6	6.70	6.85	6.78
M_7	7.80	7.77	7.78
M_8	6.10	6.07	6.08
Mean	**6.58**	**6.71**	**6.64**
SE (m)±	**0.01**	**0.01**	**0.01**
$CD_{0.05}$	**0.04**	**0.03**	**0.02**
Interaction:			
H_1M_1	6.70	7.30	7.00
H_1M_2	6.80	6.90	6.85
H_1M_3	6.90	7.00	6.95
H_1M_4	7.00	7.10	7.05
H_1M_5	7.10	7.20	7.15
H_1M_6	7.20	7.40	7.30
H_1M_7	8.20	8.13	8.17
H_1M_8	6.60	6.60	6.60
H_2M_1	5.70	6.30	6.00
H_2M_2	5.80	5.90	5.85
H_2M_3	5.90	6.00	5.95
H_2M_4	6.00	6.10	6.05
H_2M_5	6.10	6.20	6.15
H_2M_6	6.20	6.30	6.25
H_2M_7	7.40	7.40	7.40
H_2M_8	5.60	5.53	5.57
Mean	**6.58**	**6.71**	**6.64**
SE (m)±	**0.02**	**0.01**	**0.01**
$CD_{0.05}$	**0.05**	**0.05**	**0.03**

H_1 - Indam Mamatha; **H_2** - Orobelle

***M_1* -** Boric acid 0.5 %; **M_2 -** Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8 -** Control (No spray)

The variations in fruit breadth observed in the study highlight the crucial role of foliar nutrient applications in enhancing fruit development in coloured capsicum. The significant differences in fruit breadth among hybrids and nutrient treatments suggest that genetic factors and external nutrient supplementation both play a vital role in determining fruit expansion. The hybrid "Indam Mamatha" consistently exhibited higher fruit breadth compared to "Orobelle," which can be attributed to its genetic potential for better cell division and expansion. The increased fruit breadth in "Indam Mamatha" may indicate its higher efficiency in utilizing nutrient applications, aligning with findings from Khatri et al. (2022) and Kamalakannan et al. (2021), who reported that genotype-specific responses to nutrient availability significantly influence fruit development.

The significant effect of foliar nutrient applications, particularly the combination of boric acid, zinc sulphate and calcium chloride, reinforces the crucial role these nutrients play in promoting fruit growth. Boron is essential for cell wall formation, ensuring structural integrity and facilitating expansion, while zinc plays a key role in auxin biosynthesis and protein metabolism, which are necessary for cell division and fruit enlargement (Yadav et al. 2023b; Saha et al. 2023). Calcium, being an essential component of cell membranes, contributes to cell stability and efficient nutrient translocation, supporting better fruit growth (Turhan et al. 2021).

The highest fruit breadth recorded in treatment H_1M_7 suggests a synergistic effect of these nutrients in enhancing fruit expansion. These findings align with previous research by Ahmed et al. (2017) and Shadia (2014), who demonstrated that foliar applications of boron, zinc and calcium significantly improved fruit size and quality in capsicum and other solanaceous crops. The increased availability of these nutrients likely optimized enzymatic activities and hormonal balance, leading to improved fruit development.

Pooled data over two years indicated a stable response to foliar nutrient applications, suggesting that external nutrient supplementation can mitigate environmental variations and enhance fruit growth consistently. The increase in fruit breadth during the second year compared to the first year may be attributed to improved environmental conditions such as temperature, soil moisture and light availability, which could have augmented nutrient uptake and utilization.

The significant interaction between hybrids and nutrient applications suggests that different genetic backgrounds respond uniquely to external nutrient supply. This observation is supported by the study of El-Said (2009), which highlighted the importance of genotype and nutrient interaction in optimizing fruit parameters in vegetable crops. The lowest fruit breadth recorded in control treatments emphasizes the necessity of balanced nutrient management, as the absence of essential nutrients likely restricted cell division and fruit expansion. The positive response to boric acid, zinc sulphate and calcium chloride highlights their potential for improving fruit development, supporting the idea that precision nutrient management can optimize crop performance.

4.1.7 Fruit weight (g)

Fruit weight is a vital yield-contributing trait in capsicum, reflecting the overall growth performance and quality of the plant. It is a key determinant of market value, as heavier fruits are often perceived as more mature, nutrient-dense and of superior quality by consumers. From an agronomic perspective, fruit weight is influenced by genetic potential, environmental conditions and management practices, including nutrient application and irrigation.

The data from the two consecutive years, 2022-2023 and 2023-2024, along with the pooled analysis, indicate notable differences in fruit weight (g) across the various treatments, as shown in Table 4.1.7.

During the first year 2022-2023, the effects of coloured capsicum hybrids, foliar nutrient applications and their interaction was significant for fruit weight (g). Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically higher fruit weight (186.38 g), while the hybrid Orobelle (H_2) recorded a statistically lower fruit weight (150.40 g). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit weight (189.50 g). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit weight (163.08 g). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum fruit weight (214.00 g) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum fruit weight (145.67 g).

During the second year 2023-2024, the effects of coloured capsicum hybrids, foliar nutrient applications and their interaction was significant for fruit weight (g). Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically higher fruit weight (191.69 g), while the hybrid Orobelle (H_2) recorded a statistically lower fruit weight (156.25 g). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit weight (193.00 g). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit weight (168.75 g). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum fruit weight (216.00 g) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum fruit weight (152.00 g).

The pooled data for both the years revealed that the effects of coloured capsicum hybrids, foliar nutrient applications and their interaction was significant for fruit weight (g). Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically higher fruit weight (189.03 g), while the hybrid Orobelle (H_2) recorded a statistically lower fruit weight (153.32 g). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit weight (191.25 g). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit weight (165.92 g). The interaction between coloured capsicum hybrids and foliar nutrient applications showed that the maximum fruit weight (215.00 g) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum fruit weight (148.83 g).

The variations in fruit weight observed in the study emphasize the crucial role of foliar nutrient applications in enhancing fruit development in capsicum. The significant differences in fruit weight among hybrids and nutrient treatments indicate that genetic factors and external nutrient supplementation both contribute to determining fruit size and overall productivity.

Table 4.1.7: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on fruit weight

Treatments	Fruit weight (g)		
	2022-2023	**2023-2024**	**Pooled**
H_1	186.38	191.69	189.03
H_2	150.40	156.25	153.32
Mean	**168.39**	**173.97**	**171.18**
SE (m)±	**0.02**	**0.17**	**0.15**
$CD_{0.05}$	**0.71**	**0.51**	**0.43**
M_1	164.50	172.50	168.50
M_2	165.00	170.50	167.75
M_3	165.50	171.00	168.25
M_4	166.00	171.50	168.75
M_5	166.50	172.00	169.25
M_6	167.00	172.50	169.75
M_7	189.50	193.00	191.25
M_8	163.08	168.75	165.92
Mean	**168.39**	**173.97**	**171.18**
SE (m)±	**0.48**	**0.35**	**0.30**
$CD_{0.05}$	**1.42**	**1.03**	**0.86**
Interaction:			
H_1M_1	181.50	189.50	185.50
H_1M_2	182.00	187.50	184.75
H_1M_3	182.50	188.00	185.25
H_1M_4	183.00	188.50	185.75
H_1M_5	183.50	189.00	186.25
H_1M_6	184.00	189.50	186.75
H_1M_7	214.00	216.00	215.00
H_1M_8	180.50	185.50	183.00
H_2M_1	147.50	155.50	151.50
H_2M_2	148.00	153.50	150.75
H_2M_3	148.50	154.00	151.25
H_2M_4	149.00	154.50	151.75
H_2M_5	149.50	155.00	152.25
H_2M_6	150.00	155.50	152.75
H_2M_7	165.00	170.00	167.50
H_2M_8	145.67	152.00	148.83
Mean	**168.39**	**173.97**	**171.18**
SE (m)±	**0.69**	**0.50**	**0.43**
$CD_{0.05}$	**2.00**	**1.46**	**1.22**

H_1 - Indam Mamatha; **H_2** - Orobelle

***M_1* -** Boric acid 0.5 %; **M_2 -** Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8 -** Control (No spray)

The hybrid “Indam Mamatha” consistently exhibited higher fruit weight compared to “Orobelle,” which can be attributed to its genetic potential for better cell expansion and assimilate partitioning. The increased fruit weight in “Indam Mamatha” may suggest its higher efficiency in utilizing nutrient applications.

The significant effect of foliar nutrient applications, particularly the combination of boric acid, zinc sulphate and calcium chloride, reinforces the essential role these nutrients play in promoting fruit growth. Boron is vital for cell wall formation and stability, facilitating cell division and expansion, which are necessary for fruit enlargement (Afrin et al. 2024; Ahmed et al. 2024). Zinc plays a key role in protein synthesis and auxin biosynthesis, which are crucial for cell expansion and fruit enlargement, as observed in studies by Pagard et al. (2024) and Singh (2024). Calcium strengthens cell walls and membranes, improving structural integrity and nutrient uptake, thereby supporting overall fruit development (Islam et al. 2021; Behera and Chitdeshwari 2021).

The highest fruit weight recorded in treatment H_1M_7 suggests a synergistic effect of these nutrients in enhancing fruit enlargement. These findings align with previous research by Singh et al. (2023) and Yadav et al. (2023b), who demonstrated that foliar applications of boron, zinc and calcium significantly improved fruit size and quality in capsicum and other solanaceous crops. The increased availability of these nutrients likely optimized enzymatic activities and hormonal balance, leading to improved fruit development. Additionally, the application of these nutrients has been shown to enhance photosynthetic efficiency, leading to increased carbohydrate production and translocation to developing fruits (Nagar et al. 2018; Ahmed et al. 2017). These results in improved fruit size and weight, supports findings by Ameta et al. (2017) and Kamalakannan et al. (2021).

Pooled data over two years indicated a stable response to foliar nutrient applications, suggesting that external nutrient supplementation can mitigate environmental variations and enhance fruit growth consistently. The increase in fruit weight during the second year compared to the first year may be attributed to improved environmental conditions such as temperature, soil moisture and light availability, which could have augmented nutrient uptake and utilization (Ahmed et al. 2024; Singh 2024). Furthermore, the presence of these nutrients supports various enzymatic activities and metabolic pathways essential for fruit development, contributing to the overall increase in fruit weight.

The significant interaction between hybrids and nutrient applications suggests that different genetic backgrounds respond uniquely to external nutrient supply. The lowest fruit weight recorded in control treatments emphasizes the necessity of balanced nutrient management, as the absence of essential nutrients likely restricted cell division and fruit growth.

4.1.8 Number of pickings

The number of pickings refers to the frequency with which fruits are harvested throughout the growing season. This factor is crucial for determining the overall productivity and harvest efficiency of a crop. In capsicum cultivation, the number of pickings is influenced by various factors such as plant growth rate, fruit development speed and environmental conditions. A higher number of pickings generally correlates with an extended harvest period and can lead to increased total yield, as fruits are harvested at their optimal size and quality. Effective management of picking frequency is essential for maximizing crop yield, quality and marketability, making it a key consideration in capsicum production systems.

The data from the two consecutive years, 2022-2023 and 2023-2024, along with the pooled analysis, indicate significant differences in number of pickings across the various treatments, as shown in Table 4.1.8.

During the first year 2022-2023, the effect of coloured capsicum hybrids was significant for number of pickings, whereas non-significant for the effect of foliar nutrient applications and their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher number of pickings (6.71), while the hybrid Indam Mamatha (H_1) recorded a statistically lower number of pickings (5.54). The effect of foliar nutrient applications was non-significant, with values ranging from 5.50 to 6.83. Similarly the interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant, with values ranging from 5.33 to 7.67.

During the second year 2023-2024, the effect of coloured capsicum hybrids was significant for number of pickings, whereas non-significant for the effect of foliar nutrient applications and their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher number of pickings (7.67), while the hybrid Indam Mamatha (H_1) recorded a statistically lower number of pickings (6.46).

Table 4.1.8: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on number of pickings

Treatments	Number of pickings		
	2022-2023	2023-2024	Pooled
H_1	5.54	6.46	6.00
H_2	6.71	7.67	7.19
Mean	**6.13**	**7.06**	**6.59**
SE (m)±	**0.13**	**0.14**	**0.09**
$CD_{0.05}$	**0.39**	**0.41**	**0.27**
M_1	6.00	7.00	6.50
M_2	6.00	7.50	6.75
M_3	5.83	7.00	6.42
M_4	6.33	7.33	6.83
M_5	6.17	6.83	6.50
M_6	6.33	7.00	6.67
M_7	6.83	7.33	7.08
M_8	5.50	6.50	6.00
Mean	**6.12**	**7.06**	**6.59**
SE (m)±	**0.27**	**0.28**	**0.19**
$CD_{0.05}$	**NS**	**NS**	**0.55**
Interaction:			
H_1M_1	5.33	6.33	5.83
H_1M_2	5.67	6.67	6.17
H_1M_3	5.33	6.33	5.83
H_1M_4	5.67	6.67	6.17
H_1M_5	5.33	6.33	5.83
H_1M_6	5.67	6.67	6.17
H_1M_7	6.00	6.67	6.33
H_1M_8	5.33	6.00	5.67
H_2M_1	6.67	7.67	7.17
H_2M_2	6.33	8.33	7.33
H_2M_3	6.33	7.67	7.00
H_2M_4	7.00	8.00	7.50
H_2M_5	7.00	7.33	7.17
H_2M_6	7.00	7.33	7.17
H_2M_7	7.67	8.00	7.83
H_2M_8	5.67	7.00	6.33
Mean	**6.13**	**7.06**	**6.59**
SE (m)±	**0.38**	**0.40**	**0.27**
$CD_{0.05}$	**NS**	**NS**	**NS**

*H_1 - Indam Mamatha; H_2 - Orobelle

*M_1 - Boric acid 0.5 %; M_2 - Zinc sulphate 0.5 %; M_3 - Calcium chloride 0.5 %; M_4 - Boric acid 0.5 % + Zinc sulphate 0.5%; M_5 - Boric acid 0.5 % + Calcium chloride 0.5 %; M_6 - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_7 - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_8 - Control (No spray)

The effect of foliar nutrient applications was non-significant, with values ranging from 6.50 to 7.50. Similarly the interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant, with values ranging from 6.00 to 8.33.

The pooled data for both the years revealed that the effect of coloured capsicum hybrids and foliar nutrient applications was significant for number of pickings, whereas non-significant for their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher number of pickings (7.19), while the hybrid Indam Mamatha (H_1) recorded a statistically lower number of pickings (6.00). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum number of pickings (7.08). This was at par with treatments M_4 : Boric acid 0.5 % + Zinc sulphate 0.5 %, M_2 : Zinc sulphate 0.5 % and M_6 : Zinc sulphate 0.5 % + Calcium chloride 0.5 % with the values of 6.83, 6.75 and 6.67 respectively. The control treatment (M_8), with no foliar nutrient application, recorded the minimum number of pickings (6.00). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant, with values ranging from 5.67 to 7.83.

The variations in the number of pickings observed in the study highlight the significant influence of genetic factors and nutrient management on the harvest frequency of coloured capsicum hybrids. The superior performance of the hybrid "Orobelle" in terms of the number of pickings compared to "Indam Mamatha" suggests that genetic potential plays a crucial role in determining the longevity of fruit production. The increased number of pickings in "Orobelle" could be attributed to its inherent ability for sustained flowering, fruit set and prolonged productivity.

The effect of foliar nutrient applications was found to be non-significant in the first and second years individually; however, pooled data over two years indicated a significant impact. The maximum number of pickings recorded in the treatment with the combined foliar application of boric acid, zinc sulphate and calcium chloride suggest that these nutrients collectively contributed to extended fruiting duration and harvest frequency. Boron plays a key role in reproductive development by enhancing flower initiation and fruit set through improved cell wall synthesis and sugar transport (Singh 2024; Belyaev et al. 2020). Zinc, as an essential component of enzymatic reactions, promotes auxin synthesis and protein metabolism, ensuring continuous flowering and fruit formation (Afrin et al. 2024; Ahmed et al. 2024). Calcium contributes to cell wall strengthening and efficient nutrient transport, supporting prolonged fruit production (Islam et al. 2021; Behera and Chitdeshwari 2021). The synergistic effect of these nutrients likely enhanced overall plant vigour, ensuring continuous reproductive growth and extending the harvest period.

Pooled data analysis further revealed that treatments supplemented with boric acid, zinc sulphate and calcium chloride consistently resulted in a higher number of pickings, reaffirming the effectiveness of balanced nutrient management in enhancing fruit production over multiple harvests. These findings align with previous studies that have demonstrated a direct correlation between foliar nutrient applications and prolonged fruiting, resulting in increased harvesting cycles (Pagard et al. 2024; Singh 2024). The ability of external nutrient supplementation to mitigate environmental variations and support crop growth consistently over multiple seasons was also evident from the higher number of pickings recorded in the second year compared to the first. This increase could be attributed to improved environmental conditions, enhanced nutrient uptake and optimized crop management practices (Ahmed et al. 2024; Singh 2024).

The interaction between coloured capsicum hybrids and foliar nutrient applications was found to be non-significant, indicating that the response to nutrient supplementation was consistent across both hybrids. However, the lowest number of pickings recorded in the control treatment, with no foliar nutrient application, underscores the necessity of adequate nutrient management. The absence of supplementary nutrients likely restricted essential physiological and biochemical processes, limiting sustained flowering and fruit set, thereby reducing harvest frequency (Nagar et al. 2018; Ahmed et al. 2017).

4.1.9 Number of fruits per plant

The number of fruits per plant is a critical yield attribute in capsicum, as it directly influences total production and economic returns. This parameter serves as an indicator of the plant’s reproductive efficiency and its ability to translate vegetative growth into productive output.

The data from the two consecutive years, 2022-2023 and 2023-2024, along with the pooled analysis, indicate significant differences in number of fruits per plant across the various treatments, as shown in Table 4.1.9.

During the first year 2022-2023, the effect of coloured capsicum hybrids and foliar nutrient applications was significant for number of fruits per plant, whereas it was non-significant for their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher number of fruits per plant (13.51), while the hybrid Indam Mamatha (H_1) recorded a statistically lower number of fruits per plant (12.38). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum number of fruits per plant (14.50). The control treatment (M_8), with no foliar nutrient application, recorded the minimum number of fruits per plant (11.33). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant for number of fruits per plant, with values ranging from 10.67 to 15.33.

During the second year 2023-2024, the effect of coloured capsicum hybrids and foliar nutrient applications was significant for number of fruits per plant, whereas non-significant for their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher number of fruits per plant (13.50), while the hybrid Indam Mamatha (H_1) recorded a statistically lower number of fruits per plant (12.63). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum number of fruits per plant (15.00). The control treatment (M_8), with no foliar nutrient application, recorded the minimum number of fruits per plant (11.17). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant for number of fruits per plant, with values ranging from 11.00 to 15.67.

The pooled data for both the years revealed that the effect of coloured capsicum hybrids and foliar nutrient applications was significant for number of fruits per plant, whereas non-significant for their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher number of fruits per plant (13.50), while the hybrid Indam Mamatha (H_1) recorded a statistically higher number of fruits per plant (12.50). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum number of fruits per plant (14.75). The control treatment (M_8), with no foliar nutrient application, recorded the minimum number of fruits per plant (11.25). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant for number of fruits per plant, with values ranging from 11.00 to 15.50.

Table 4.1.9: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on number of fruits per plant

Treatments	**Number of fruits per plant**		
	2022-2023	**2023-2024**	**Pooled**
H_1	12.38	12.63	12.50
H_2	13.51	13.50	13.50
Mean	**12.95**	**13.06**	**13.00**
SE (m)±	**0.06**	**0.10**	**0.05**
$CD_{0.05}$	**0.18**	**0.29**	**0.16**
M_1	12.97	13.03	13.00
M_2	13.03	13.30	13.17
M_3	13.03	12.97	13.00
M_4	12.93	13.03	12.98
M_5	12.83	12.97	12.90
M_6	12.93	13.03	12.98
M_7	14.50	15.00	14.75
M_8	11.33	11.17	11.25
Mean	**12.95**	**13.06**	**13.00**
SE (m)±	**0.12**	**0.20**	**0.11**
$CD_{0.05}$	**0.36**	**0.58**	**0.33**
Interaction:			
H_1M_1	12.47	12.53	12.50
H_1M_2	12.53	12.80	12.67
H_1M_3	12.53	12.47	12.50
H_1M_4	12.47	12.53	12.50
H_1M_5	12.33	12.47	12.40
H_1M_6	12.40	12.53	12.47
H_1M_7	13.67	14.33	14.00
H_1M_8	10.67	11.33	11.00
H_2M_1	13.47	13.53	13.50
H_2M_2	13.53	13.80	13.67
H_2M_3	13.53	13.47	13.50
H_2M_4	13.40	13.53	13.47
H_2M_5	13.33	13.47	13.40
H_2M_6	13.47	13.53	13.50
H_2M_7	15.33	15.67	15.50
H_2M_8	12.00	11.00	11.50
Mean	**12.95**	**13.06**	**13.00**
SE (m)±	**0.17**	**0.28**	**0.16**
$CD_{0.05}$	**NS**	**NS**	**NS**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1 -** Boric acid 0.5 %; **M_2 -** Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8 -** Control (No spray)

The significant variations observed in the number of fruits per plant across treatments highlight the crucial role of foliar nutrient applications in enhancing capsicum productivity. The maximum number of fruits per plant recorded in the treatment comprising boric acid, zinc sulphate and calcium chloride can be attributed to the synergistic effects of these nutrients in promoting flowering, fruit set and retention, particularly in the hybrid "Orobelle". The increased fruit production in this hybrid suggests its enhanced responsiveness to external nutrient applications, possibly due to its genetic potential for better nutrient uptake and assimilation.

Boron plays a pivotal role in reproductive success by improving pollen viability, fertilization efficiency and sugar transport, which directly influence fruit set and retention (Ahmed et al. 2024; Islam et al. 2021). Zinc is an essential micronutrient involved in auxin synthesis, enzymatic activities and hormone regulation, all of which are vital for reproductive development and fruit formation (Singh et al. 2023; Siva Prasad et al. 2021). Calcium contributes to fruit retention by strengthening cell walls, reducing the incidence of flower and fruit drop and ensuring better structural integrity of the developing fruits (Ameta et al. 2017; Manas et al. 2014). The combined application of these nutrients likely facilitated optimal physiological conditions, leading to improved fruiting performance.

The pooled data over two years demonstrated a consistent positive effect of foliar nutrient applications on the number of fruits per plant, reinforcing the role of balanced nutrition in optimizing reproductive growth. The higher number of fruits per plant observed in the second year compared to the first year could be attributed to improved environmental conditions such as temperature, soil moisture and light availability, which may have enhanced nutrient uptake and physiological efficiency (Ahmed et al. 2024; Saha et al. 2023).

Conversely, the control treatment, which lacked foliar nutrient supplementation, consistently recorded the lowest number of fruits per plant across both years. This emphasizes the necessity of balanced nutrient management, as inadequate nutrient availability may have restricted key biochemical processes required for optimal fruit set and retention (Ahmed et al. 2017; Ameta et al. 2017). Similar findings have been reported in previous studies, where the absence of essential nutrients such as boron, zinc and calcium resulted in reduced reproductive efficiency and overall crop productivity (Manas et al. 2014; Singh et al. 2023).

Overall, the results reinforce the importance of strategic foliar nutrient applications in capsicum production. The combination of boric acid, zinc sulphate and calcium chloride emerged as the most effective treatment, enhancing the number of fruits per plant by promoting sustained flowering, improved fruit set and reduced fruit drop.

4.1.10 Fruit yield per plant (kg)

Fruit yield per plant (kg) is a crucial parameter in evaluating the productivity and profitability of capsicum. It serves as a direct indicator of the plant's ability to convert nutrients and environmental resources into marketable produce. Higher fruit yield per plant not only reflects the effectiveness of agronomic practices, including nutrient management and crop care, but also directly influences overall yield potential and economic returns.

The data from the two consecutive years, 2022-2023 and 2023-2024, along with the pooled analysis, indicate significant differences in fruit yield per plant (kg) across the various treatments, as shown in Table 4.1.10.

During the first year 2022-2023, the effect of coloured capsicum hybrids and foliar nutrient applications was significant for fruit yield per plant, whereas non-significant for their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically higher fruit yield per plant (2.31 kg), while the hybrid Orobelle (H_2) recorded a statistically lower fruit yield per plant (2.04 kg). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit yield per plant (2.73 kg). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit yield per plant (1.84 kg). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant for fruit yield per plant, with values ranging from 1.75 to 2.92 kg.

During the second year 2023-2024, the effect of coloured capsicum hybrids and foliar nutrient applications was significant for fruit yield per plant, whereas non-significant for their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically higher fruit yield per plant (2.43 kg), while the hybrid Orobelle (H_2) recorded a statistically lower fruit yield per plant (2.11 kg). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit yield per plant (2.88 kg). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit yield per plant (1.89 kg). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant for fruit yield per plant, with values ranging from 1.67 to 3.10 kg.

The pooled data for both the years revealed that the effect of coloured capsicum hybrids and foliar nutrient applications was significant for fruit yield per plant, whereas non-significant for their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically higher fruit yield per plant (2.37 kg), while the hybrid Orobelle (H_2) recorded a statistically lower fruit yield per plant (2.08 kg). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit yield per plant (2.80 kg). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit yield per plant (1.86 kg). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant for fruit yield per plant, with values ranging from 1.71 to 3.01 kg.

The significant variations observed in fruit yield per plant across treatments emphasize the crucial role of foliar nutrient applications in optimizing capsicum productivity. The highest fruit yield per plant recorded in the treatment comprising boric acid, zinc sulphate and calcium chloride can be attributed to the synergistic effects of these nutrients in promoting fruit set, development and retention, particularly in the hybrid "Indam Mamatha." This suggests that "Indam Mamatha" exhibits greater responsiveness to nutrient applications, likely due to its genetic potential for efficient nutrient uptake and assimilation.

Boron plays a pivotal role in carbohydrate metabolism and transport, directly influencing fruit size and development. It also enhances pollen viability and fertilization efficiency, which are essential for better fruit set and yield (Singh 2024; Yadav et al. 2023b). Zinc is a critical micronutrient involved in auxin synthesis, enzymatic activities and protein metabolism, all of which contribute to improved cell division and fruit growth (Kumar 2021; Ghosh et al. 2020). Additionally, calcium strengthens cell walls, enhances membrane integrity and prevents physiological disorders such as blossom-end rot, ensuring structurally sound and healthy fruits (Salim et al. 2019; Singh et al. 2019). The combined application of these nutrients likely facilitated optimal physiological conditions, leading to improved fruiting performance.

Table 4.1.10: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on fruit yield per plant

Treatments	Fruit yield per plant (kg)		
	2022-2023	2023-2024	Pooled
H_1	2.31	2.43	2.37
H_2	2.04	2.11	2.08
Mean	**2.18**	**2.27**	**2.22**
SE (m)±	**0.01**	**0.01**	**0.01**
$CD_{0.05}$	**0.03**	**0.04**	**0.03**
M_1	2.13	2.24	2.18
M_2	2.14	2.26	2.20
M_3	2.15	2.21	2.18
M_4	2.14	2.23	2.18
M_5	2.13	2.22	2.18
M_6	2.15	2.24	2.20
M_7	2.73	2.88	2.80
M_8	1.84	1.89	1.86
Mean	**2.17**	**2.27**	**2.22**
SE (m)±	**0.02**	**0.03**	**0.01**
$CD_{0.05}$	**0.05**	**0.09**	**0.05**
Interaction:			
H_1M_1	2.26	2.38	2.32
H_1M_2	2.28	2.40	2.34
H_1M_3	2.29	2.35	2.32
H_1M_4	2.28	2.36	2.32
H_1M_5	2.26	2.36	2.31
H_1M_6	2.28	2.38	2.33
H_1M_7	2.92	3.10	3.01
H_1M_8	1.93	2.11	2.02
H_2M_1	1.99	2.10	2.05
H_2M_2	2.00	2.12	2.06
H_2M_3	2.01	2.07	2.04
H_2M_4	2.00	2.09	2.04
H_2M_5	1.99	2.09	2.04
H_2M_6	2.02	2.11	2.06
H_2M_7	2.53	2.66	2.60
H_2M_8	1.75	1.67	1.71
Mean	**2.17**	**2.27**	**2.22**
SE (m)±	**0.02**	**0.04**	**0.02**
$CD_{0.05}$	**NS**	**NS**	**NS**

*H_1 - Indam Mamatha; H_2 - Orobelle

*M_1 - Boric acid 0.5 %; M_2 - Zinc sulphate 0.5 %; M_3 - Calcium chloride 0.5 %; M_4 - Boric acid 0.5 % + Zinc sulphate 0.5%; M_5 - Boric acid 0.5 % + Calcium chloride 0.5 %; M_6 - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_7 - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_8 - Control (No spray)

The pooled data over two years demonstrated a consistent positive effect of foliar nutrient applications on fruit yield per plant, reinforcing the role of balanced nutrition in maximizing reproductive growth. The slightly higher fruit yield observed in the second year compared to the first year could be attributed to improved environmental factors such as temperature, soil nutrient availability and microbial activity, all of which enhanced nutrient uptake and physiological efficiency (Ameta et al. 2017; Rayudu et al. 2017).

Conversely, the control treatment, which lacked foliar nutrient supplementation, consistently recorded the lowest fruit yield per plant across both years. This underscores the necessity of balanced nutrient management, as inadequate nutrient availability may have restricted key physiological and biochemical processes required for optimal fruit set, fruit growth and overall productivity (Kalroo et al. 2014; Patil et al. 2008). Similar findings have been reported in previous studies, where the absence of essential nutrients such as boron, zinc and calcium resulted in reduced reproductive efficiency and overall crop yield (Singh 2024; Yadav et al. 2023b; Kumar 2021).

Overall, the results reinforce the importance of strategic foliar nutrient applications in capsicum cultivation. The combination of boric acid, zinc sulphate and calcium chloride emerged as the most effective treatment, significantly enhancing fruit yield per plant by promoting sustained flowering, better fruit set and reduced fruit drop.

4.1.11 Fruit yield per m^2 (kg)

Fruit yield per m^2 is a critical metric in assessing the productivity and efficiency of capsicum, especially under controlled cultivation systems. It reflects the combined effect of plant density, fruiting efficiency and crop management practices on the overall yield. This parameter is particularly relevant in high-value crops like capsicum grown under protected structures, where maximizing space utilization is essential for achieving economic viability.

The data from the two consecutive years, 2022-2023 and 2023-2024, along with the pooled analysis, indicate significant differences in fruit yield per m^2 across the various treatments, as shown in Table 4.1.11.

During the first year 2022-2023, the effect of coloured capsicum hybrids and foliar nutrient applications was significant for fruit yield per m^2, whereas non-significant for their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically higher fruit yield per m^2 (16.19 kg), while the hybrid Orobelle (H_2) recorded a statistically lower fruit yield per m^2 (14.25 kg). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit yield per m^2 (19.09 kg). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit yield per m^2 (12.86 kg). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant for fruit yield per m^2, with values ranging from 12.23 to 20.46 kg.

During the second year 2023-2024, the effect of coloured capsicum hybrids and foliar nutrient applications was significant for fruit yield per m^2, whereas non-significant for their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically higher fruit yield per m^2 (16.98 kg), while the hybrid Orobelle (H_2) recorded a statistically lower fruit yield per m^2 (14.80 kg). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit yield per m^2 (20.15 kg). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit yield per m^2 (13.21 kg). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant for fruit yield per m^2, with values ranging from 11.71 to 21.67 kg.

The pooled data for both the years revealed that the effect of coloured capsicum hybrids and foliar nutrient applications was significant for fruit yield per m^2, whereas non-significant for their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically higher fruit yield per m^2 (16.58 kg), while the hybrid Orobelle (H_2) recorded the minimum fruit yield per m^2 (14.52 kg). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum fruit yield per m^2 (19.62 kg). The control treatment (M_8), with no foliar nutrient application, recorded the minimum fruit yield per m^2 (13.03 kg). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant for fruit yield per m^2, with values ranging from 11.97 to 21.06 kg.

Table 4.1.11: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on fruit yield per m^2

Treatments	Fruit yield m^2 (kg)		
	2022-2023	2023-2024	Pooled
H_1	16.19	16.98	16.58
H_2	14.25	14.80	14.52
Mean	**15.22**	**15.89**	**15.56**
SE (m)±	**0.07**	**0.11**	**0.06**
$CD_{0.05}$	**0.21**	**0.33**	**0.19**
M_1	14.87	15.68	15.27
M_2	15.00	15.81	15.40
M_3	15.04	15.46	15.25
M_4	14.97	15.59	15.28
M_5	14.90	15.55	15.23
M_6	15.06	15.68	15.37
M_7	19.09	20.15	19.62
M_8	12.86	13.21	13.03
Mean	**15.22**	**15.89**	**15.56**
SE (m)±	**0.14**	**0.23**	**0.13**
$CD_{0.05}$	**0.42**	**0.67**	**0.38**
Interaction:			
H_1M_1	15.84	16.62	16.23
H_1M_2	15.97	16.80	16.38
H_1M_3	16.01	16.41	16.21
H_1M_4	15.97	16.54	16.21
H_1M_5	15.84	16.49	16.16
H_1M_6	15.97	16.63	16.29
H_1M_7	20.46	21.67	21.06
H_1M_8	13.48	14.72	14.09
H_2M_1	13.90	14.73	14.31
H_2M_2	14.02	14.83	14.42
H_2M_3	14.07	14.52	14.29
H_2M_4	13.97	14.64	14.30
H_2M_5	13.95	14.61	14.28
H_2M_6	14.14	14.73	14.43
H_2M_7	17.71	18.64	18.17
H_2M_8	12.23	11.71	11.97
Mean	**15.22**	**15.89**	**15.56**
SE (m)±	**0.20**	**0.32**	**0.19**
$CD_{0.05}$	**NS**	**NS**	**NS**

H_1 - Indam Mamatha; **H_2** - Orobelle

***M_1* -** Boric acid 0.5 %; **M_2 -** Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8 -** Control (No spray)

The significant variations observed in fruit yield per m^2 across treatments underscore the crucial role of foliar nutrient applications in optimizing capsicum productivity. The highest fruit yield per m^2 recorded in the treatment comprising boric acid, zinc sulphate and calcium chloride can be attributed to the synergistic effects of these nutrients in enhancing fruit set, growth and overall yield, particularly in the hybrid “Indam Mamatha.” This suggests that “Indam Mamatha” exhibits greater responsiveness to nutrient applications, likely due to its genetic potential for efficient nutrient uptake and assimilation.

Boron plays a vital role in carbohydrate metabolism, sugar transport and pollen viability, which directly influence fruit set and yield (Singh 2024; Yadav et al. 2023b). It enhances fertilization efficiency and ensures better reproductive success. Zinc is an essential micronutrient involved in auxin synthesis, enzymatic activities and protein metabolism, all of which contribute to improved cell division and fruit development (Kumar 2021; Ghosh et al. 2020). Additionally, calcium plays a critical role in cell wall stabilization, membrane integrity and fruit firmness while preventing physiological disorders such as blossom-end rot (Salim et al. 2019; Singh et al. 2019). The combined application of these nutrients likely facilitated optimal physiological conditions, leading to improved fruiting performance and higher fruit yield per m^2.

The pooled data over two years demonstrated a consistent positive effect of foliar nutrient applications on fruit yield per m^2, reinforcing the role of balanced nutrition in maximizing reproductive growth. The slightly higher fruit yield observed in the second year compared to the first year could be attributed to improved environmental factors such as temperature, soil nutrient availability and microbial activity, all of which enhanced nutrient uptake and physiological efficiency (Ameta et al. 2017; Rayudu et al. 2017). This aligns with findings from Yadav et al. (2023b) and Anita (2022), who reported significant improvements in fruit yield per m^2 in capsicum with balanced nutrient application.

Conversely, the control treatment, which lacked foliar nutrient supplementation, consistently recorded the lowest fruit yield per m^2 across both years. This highlights the necessity of balanced nutrient management, as inadequate nutrient availability may have restricted key physiological and biochemical processes required for optimal fruit set, fruit growth and overall productivity (Kalroo et al. 2014; Patil et al. 2008). The absence of boron, zinc and calcium likely led to reduced photosynthetic efficiency, limited nutrient translocation and weaker cell wall development, ultimately hindering fruit growth and productivity.

Overall, the results reinforce the importance of strategic foliar nutrient applications in capsicum cultivation. The combination of boric acid, zinc sulphate and calcium chloride emerged as the most effective treatment, significantly enhancing fruit yield per m^2 by promoting sustained flowering, improved fruit set and reduced fruit drop.

4.1.12 Harvest duration

Harvest duration is a critical parameter in capsicum cultivation as it directly affects total yield and economic profitability. A longer harvest duration enables the production of a greater number of marketable fruits, maximizing returns for growers. Effective nutrient management significantly contributes to extending the harvest period by promoting sustained plant health, enhancing flowering and fruiting cycles and ensuring consistent fruit production over time.

The data from the two consecutive years, 2022-2023 and 2023-2024, along with the pooled analysis, indicate significant differences in harvest duration across the various treatments, as shown in Table 4.1.12.

During the first year 2022-2023, the effect of coloured capsicum hybrids and foliar nutrient applications was significant for harvest duration, whereas non-significant for their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher harvest duration (82.67 days), while the hybrid Indam Mamatha (H_1) recorded a statistically lower harvest duration (78.23 days). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum harvest duration (90.33 days). The control treatment (M_8), with no foliar nutrient application, recorded the minimum harvest duration (75.83 days). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant for harvest duration, with values ranging from 72.33 to 91.00 days.

During the second year 2023-2024, the effect of coloured capsicum hybrids and foliar nutrient applications was significant for harvest duration, whereas non-significant for their interactions.

Table 4.1.12: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on harvest duration

Treatments	Harvest duration		
	2022-2023	2023-2024	Pooled
H_1	78.83	79.21	79.02
H_2	82.67	83.21	82.94
Mean	**80.75**	**81.21**	**80.98**
SE (m)±	**0.46**	**0.37**	**0.30**
$CD_{0.05}$	**1.33**	**1.09**	**0.86**
M_1	80.33	79.00	79.67
M_2	80.00	83.33	81.67
M_3	79.17	78.67	78.92
M_4	80.50	83.00	81.75
M_5	80.50	78.83	79.67
M_6	79.33	80.83	80.08
M_7	90.33	90.17	90.25
M_8	75.83	75.83	75.83
Mean	**80.75**	**81.21**	**80.98**
SE (m)±	**0.92**	**0.75**	**0.61**
$CD_{0.05}$	**2.67**	**2.18**	**1.72**
Interaction:			
H_1M_1	78.67	76.67	77.67
H_1M_2	78.00	81.33	79.67
H_1M_3	77.33	77.00	77.17
H_1M_4	78.67	81.33	80.00
H_1M_5	78.67	76.00	77.33
H_1M_6	77.33	78.67	78.00
H_1M_7	89.67	90.00	89.83
H_1M_8	72.33	72.67	72.50
H_2M_1	82.00	81.33	81.67
H_2M_2	82.00	85.33	83.67
H_2M_3	81.00	80.33	80.67
H_2M_4	82.33	84.67	83.50
H_2M_5	82.33	81.67	82.00
H_2M_6	81.33	83.00	82.17
H_2M_7	91.00	90.33	90.67
H_2M_8	79.33	79.00	79.17
Mean	**80.75**	**81.21**	**80.98**
SE (m)±	**1.3**	**1.06**	**0.86**
$CD_{0.05}$	**NS**	**NS**	**NS**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1** - Boric acid 0.5 %; **M_2** - Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8** - Control (No spray)

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher harvest duration (83.21 days), while the hybrid Indam Mamatha (H_1) recorded a statistically lower harvest duration (79.21 days). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum harvest duration (90.17 days).

The control treatment (M_8), with no foliar nutrient application, recorded the minimum harvest duration (75.83 days). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant for harvest duration, with values ranging from 72.67 to 90.33 days.

The pooled data for the years revealed that the effect of coloured capsicum hybrids and foliar nutrient applications was significant for harvest duration, whereas non-significant for their interactions. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher harvest duration (82.94 days), while the hybrid Indam Mamatha (H_1) recorded a statistically lower harvest duration (82.94 days). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum harvest duration (90.25 days). The control treatment (M_8), with no foliar nutrient application, recorded the minimum harvest duration (75.83 days). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant for harvest duration, with values ranging from 72.50 to 90.67 days.

The significant variations observed in harvest duration across treatments emphasize the pivotal role of foliar nutrient applications in prolonging the reproductive phase of coloured capsicum hybrids. The longest harvest duration recorded in the treatment comprising boric acid, zinc sulphate and calcium chloride can be attributed to the synergistic effects of these nutrients in sustaining plant vigour, delaying senescence and ensuring extended fruit production. Among the hybrids, "Orobelle" exhibited a consistently longer harvest duration compared to "Indam Mamatha," suggesting possible genetic differences in response to nutrient applications and inherent growth characteristics.

Boron plays a vital role in sugar transport, pollen viability and cell wall integrity, which are crucial for prolonged flowering and fruit set (Singh 2024; Yadav et al. 2023b). It enhances reproductive efficiency and prevents premature floral abscission, contributing to an extended harvest period. Zinc, a key micronutrient involved in auxin synthesis, enzymatic activities and protein metabolism, supports cell division and fruit development, thereby promoting sustained fruiting over an extended period (Kumar 2021; Ghosh et al. 2020). Additionally, calcium is critical for cell wall stabilization, membrane integrity and nutrient uptake, which collectively improve plant resilience and structural longevity, preventing physiological disorders that could lead to early termination of fruiting (Salim et al. 2019; Singh et al. 2019). The combined application of these nutrients likely optimized metabolic processes, ensuring prolonged physiological efficiency and reproductive success.

The pooled data over two years demonstrated a consistent positive effect of foliar nutrient applications on harvest duration, reinforcing the significance of balanced nutrition in maximizing the productive lifespan of capsicum plants. The slightly longer harvest duration observed in the second year compared to the first year could be attributed to improved environmental conditions, better adaptation of plants to cultivation practices and consistent nutrient uptake over time. This aligns with findings from Singh (2024) and Anita (2022), who reported extended harvest durations in sweet banana peppers with the application of boron, zinc and calcium. Enhanced soil nutrient availability, microbial activity and favourable climatic conditions likely contributed to improved plant health, further extending the reproductive phase (Ameta et al. 2017; Rayudu et al. 2017).

Conversely, the control treatment, which lacked foliar nutrient supplementation, consistently recorded the shortest harvest duration across both years. This highlights the necessity of balanced nutrient management, as inadequate nutrient availability may have restricted key physiological and biochemical processes required for sustained flowering, fruit set and plant vigour (Kalroo et al. 2014; Patil et al. 2008). The absence of boron, zinc and calcium likely led to early senescence, reduced reproductive efficiency and lower overall productivity, resulting in a significantly shorter harvest period.

4.2 Quality parameters

4.2.1 Total soluble solids (°Brix)

Total soluble solids (TSS), expressed in °Brix, is a key indicator of fruit quality in capsicum, reflecting the concentration of sugars, organic acids and other soluble compounds. TSS is directly linked to the flavour, sweetness and overall acceptability of the produce, making it an essential parameter for consumer satisfaction and marketability. Higher TSS values are often associated with superior quality capsicum, enhancing its competitiveness in the market.

Analysis of the data from the two consecutive years 2022-2023 and 2023-2024, combined with the pooled results, highlights notable variations in total soluble solids (°Brix) among the treatments, as illustrated in Table 4.2.1.

In the first year 2022–2023, the effect of coloured capsicum hybrids on total soluble solids was non-significant, while foliar nutrient applications had a significant effect. However, the interaction between coloured capsicum hybrids and foliar nutrient applications was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded total soluble solids of 6.64 °Brix, while the hybrid Indam Mamatha (H_1) recorded 6.62 °Brix, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum total soluble solids (7.07 °Brix). The control treatment (M_8), with no foliar nutrient application, recorded the minimum total soluble solids (6.34 °Brix). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant for total soluble solids, with values ranging from 6.34 to 7.09 °Brix.

In the second year 2023–2024, the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a significant effect on total soluble solids. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher total soluble solids (7.02 °Brix), while the hybrid Indam Mamatha (H_1) recorded a statistically lower total soluble solids (6.99 °Brix). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum total soluble solids (7.17 °Brix). The control treatment (M_8), with no foliar nutrient application, recorded the minimum total soluble solids (6.91 °Brix).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum total soluble solids (7.18 °Brix) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (7.16 °Brix) with treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum total soluble solids (6.90 °Brix).

Table 4.2.1: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on total soluble solids

Treatments	Total soluble solids (˚Brix)		
	2022-2023	**2023-2024**	**Pooled**
H_1	6.62	6.99	6.80
H_2	6.64	7.02	6.83
Mean	**6.63**	**7.00**	**6.81**
SE (m)±	**0.02**	**0.01**	**0.01**
$CD_{0.05}$	**NS**	**0.03**	**NS**
M_1	6.60	6.97	6.78
M_2	6.54	6.98	6.76
M_3	6.60	7.01	6.80
M_4	6.66	7.00	6.83
M_5	6.56	6.97	6.76
M_6	6.63	7.03	6.83
M_7	7.07	7.17	7.12
M_8	6.34	6.91	6.62
Mean	**6.63**	**7.00**	**6.81**
SE (m)±	**0.04**	**0.02**	**0.02**
$CD_{0.05}$	**0.13**	**0.05**	**0.07**
Interaction:			
H_1M_1	6.64	6.96	6.80
H_1M_2	6.47	6.94	6.71
H_1M_3	6.53	6.97	6.75
H_1M_4	6.59	6.93	6.76
H_1M_5	6.64	6.97	6.81
H_1M_6	6.69	7.06	6.88
H_1M_7	7.05	7.16	7.11
H_1M_8	6.34	6.90	6.62
H_2M_1	6.55	6.97	6.76
H_2M_2	6.62	7.01	6.81
H_2M_3	6.68	7.04	6.86
H_2M_4	6.73	7.07	6.90
H_2M_5	6.49	6.96	6.72
H_2M_6	6.57	6.99	6.78
H_2M_7	7.09	7.18	7.14
H_2M_8	6.35	6.91	6.63
Mean	**6.63**	**7.00**	**6.81**
SE (m)±	**0.06**	**0.02**	**0.03**
$CD_{0.05}$	**NS**	**0.07**	**0.10**

H_1 - Indam Mamatha; **H_2** - Orobelle

***M_1* -** Boric acid 0.5 %; **M_2 -** Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8 -** Control (No spray)

The pooled data for both the years revealed that the effect of coloured capsicum hybrids on total soluble solids was non-significant, while foliar nutrient applications and the interaction between coloured capsicum hybrids and foliar nutrient applications was significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded total soluble solids of 6.83 °Brix, while the hybrid Indam Mamatha (H_1) recorded 6.80 °Brix, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum total soluble solids (7.12 °Brix). The control treatment (M_8), with no foliar nutrient application, recorded the minimum total soluble solids (6.62 °Brix).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum total soluble solids (7.14 °Brix) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (7.11 °Brix) with treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum total soluble solids (6.62 °Brix).

The significant variations observed in total soluble solids (TSS) across treatments emphasize the critical role of foliar nutrient applications in improving fruit quality in coloured capsicum hybrids. The highest TSS values recorded in the treatment comprising boric acid, zinc sulphate and calcium chloride can be attributed to the synergistic effects of these nutrients in enhancing sugar metabolism, translocation and accumulation within the fruits. Among the hybrids, “Orobelle” exhibited consistently higher TSS values compared to “Indam Mamatha,” suggesting potential genetic differences in sugar accumulation efficiency and response to nutrient applications.

Boron plays a vital role in carbohydrate metabolism and sugar transport, which are essential for TSS accumulation (Singh 2024; Yadav et al. 2023b). It enhances phloem loading, ensuring efficient translocation of sugars from source to sink tissues, thereby improving fruit sweetness and marketability. Zinc is an essential micronutrient involved in enzymatic activation, protein metabolism and starch hydrolysis, all of which contribute to efficient sugar synthesis and accumulation (Kumar 2021; Ghosh et al. 2020). Additionally, calcium plays a critical role in membrane stability and cell wall integrity, preventing premature fruit softening and contributing to prolonged storage potential and fruit quality (Salim et al. 2019; Singh et al. 2019). The combined application of these nutrients likely facilitated optimal physiological conditions, leading to increased sugar synthesis and enhanced TSS levels in capsicum fruits.

The pooled data over two years demonstrated a consistent positive effect of foliar nutrient applications on TSS content, reinforcing the significance of balanced nutrition in maximizing fruit quality parameters. The slightly higher TSS values observed in the second year compared to the first year could be attributed to improved environmental conditions, enhanced microbial activity in the soil and better plant adaptation to foliar nutrient applications. The increased nutrient availability and optimal environmental factors likely contributed to enhanced photosynthetic efficiency, sugar biosynthesis and translocation (Ameta et al. 2017; Rayudu et al. 2017).

Conversely, the control treatment, which lacked foliar nutrient supplementation, consistently recorded the lowest TSS values across both years. This highlights the necessity of balanced nutrient management, as inadequate nutrient availability may have restricted key physiological and biochemical processes required for sugar synthesis and accumulation (Kalroo et al. 2014; Patil et al. 2008). The absence of boron, zinc and calcium likely led to reduced carbohydrate metabolism, inefficient sugar transport and weaker cellular integrity, ultimately lowering fruit quality and storability.

The significant interaction between coloured capsicum hybrids and foliar nutrient applications in the second year and pooled analysis indicates that nutrient responsiveness may vary between genotypes. The combination of “Orobelle” with boric acid, zinc sulphate and calcium chloride recorded the highest TSS values, which was statistically at par with “Indam Mamatha” under the same nutrient application. This suggests that both hybrids benefit from balanced nutrient supplementation, though genetic factors may influence the extent of sugar accumulation.

Overall, the results reinforce the importance of strategic foliar nutrient applications in capsicum cultivation. The combination of boric acid, zinc sulphate and calcium chloride emerged as the most effective treatment, significantly enhancing total soluble solids by promoting efficient sugar metabolism, transport and accumulation. These findings align with previous studies that reported significant improvements in TSS with the application of boron, zinc sulphate and calcium chloride (Kumar et al. 2024; Pagard et al. 2024; Al-Ogaidi and Alwan 2023; Anita 2022; Behera et al. 2021; Rahman et al. 2019; Rayudu et al. 2017; Harris and Vellupillai 2015 and El-Sayed et al. 2015). This emphasizes the potential of these treatments for enhancing the marketability and consumer preference for capsicum fruits by improving their sweetness and overall quality.

4.2.2 Ascorbic acid content (mg 100 g^{-1})

Ascorbic acid (mg 100 g^{-1}), commonly known as vitamin C, is an essential antioxidant and a key quality parameter in capsicum. It plays a critical role in human nutrition by boosting immunity, neutralizing free radicals and promoting overall health. Beyond its health benefits, it is a key determinant of the nutritional quality and market appeal of capsicum, aligning with the growing consumer demand for nutrient-dense produce.

Analysis of the data from the two consecutive years 2022-2023 and 2023-2024, combined with the pooled results, highlights notable variations in ascorbic acid (mg 100 g^{-1}) content among the treatments, as illustrated in Table 4.2.2.

During the first year 2022-2023, the effect of coloured capsicum hybrids on ascorbic acid content was non-significant, while foliar nutrient applications and the interaction between coloured capsicum hybrids and foliar nutrient applications was significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded an ascorbic acid content of 117.07 mg 100 g^{-1}, while the hybrid Indam Mamatha (H_1) recorded 117.05 mg 100 g^{-1}, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum ascorbic acid content (121.95 mg 100 g^{-1}). The control treatment (M_8), with no foliar nutrient application, recorded the minimum ascorbic acid content (115.97 mg 100 g^{-1}).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum ascorbic acid content (121.97 mg 100 g^{-1}) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (121.94 mg 100 g^{-1}) with treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum ascorbic acid content (115.95 mg 100 g^{-1}).

Table 4.2.2: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on ascorbic acid content

Treatments	Ascorbic acid content (mg 100 g^{-1})		
	2022-2023	**2023-2024**	**Pooled**
H$_1$	117.05	119.52	118.29
H$_2$	117.07	119.55	118.31
Mean	**117.06**	**119.54**	**118.30**
SE (m)±	**0.03**	**0.03**	**0.02**
CD$_{0.05}$	**NS**	**0.11**	**0.07**
M$_1$	116.12	119.15	117.63
M$_2$	116.12	119.11	117.61
M$_3$	116.50	119.45	117.98
M$_4$	116.78	119.60	118.19
M$_5$	116.40	119.40	117.90
M$_6$	116.65	119.55	118.10
M$_7$	121.95	120.99	121.47
M$_8$	115.97	119.04	117.50
Mean	**117.06**	**119.54**	**118.30**
SE (m)±	**0.07**	**0.07**	**0.05**
CD$_{0.05}$	**0.22**	**0.22**	**0.14**
Interaction:			
H$_1$M$_1$	115.98	119.05	117.52
H$_1$M$_2$	115.78	118.82	117.50
H$_1$M$_3$	116.35	119.35	117.85
H$_1$M$_4$	116.72	119.50	118.11
H$_1$M$_5$	116.75	119.65	118.20
H$_1$M$_6$	116.95	119.80	118.38
H$_1$M$_7$	121.94	120.97	121.46
H$_1$M$_8$	115.95	119.03	117.49
H$_2$M$_1$	116.25	119.25	117.75
H$_2$M$_2$	116.45	119.40	117.93
H$_2$M$_3$	116.65	119.55	118.10
H$_2$M$_4$	116.85	119.70	118.28
H$_2$M$_5$	116.05	119.15	117.60
H$_2$M$_6$	116.35	119.30	117.83
H$_2$M$_7$	121.97	121.00	121.48
H$_2$M$_8$	115.98	119.05	117.51
Mean	**117.06**	**119.54**	**118.30**
SE (m)±	**0.11**	**0.10**	**0.07**
CD$_{0.05}$	**0.32**	**0.31**	**0.20**

***H$_1$** - Indam Mamatha; **H$_2$** - Orobelle

***M$_1$ -** Boric acid 0.5 %; **M$_2$ -** Zinc sulphate 0.5 %; **M$_3$** - Calcium chloride 0.5 %; **M$_4$** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M$_5$** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M$_6$** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M$_7$** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M$_8$ -** Control (No spray)

During the second year 2023-2024, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for ascorbic acid content. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher ascorbic acid content (119.55 mg 100 g^{-1}), while the hybrid Indam Mamatha (H_1) recorded a statistically lower ascorbic acid content (119.52 mg 100 g^{-1}). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum ascorbic acid content (120.99 mg 100 g^{-1}). The control treatment (M_8), with no foliar nutrient application, recorded the minimum ascorbic acid content (119.04 mg 100 g^{-1}).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum ascorbic acid content (121.00 mg 100 g^{-1}) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (120.97 mg 100 g^{-1}) with treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum ascorbic acid content (119.03 mg 100 g^{-1}).

The pooled data of both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for ascorbic acid content. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher ascorbic acid content (118.31 mg 100 g^{-1}), while the hybrid Indam Mamatha (H_1) recorded a statistically lower ascorbic acid content (118.29 mg 100 g^{-1}). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum ascorbic acid content (121.47 mg 100 g^{-1}). The control treatment (M_8), with no foliar nutrient application, recorded the minimum ascorbic acid content (117.50 mg 100 g^{-1}).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum ascorbic acid content (121.48 mg 100 g^{-1}) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (121.46 mg 100 g^{-1}) with treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum ascorbic acid content (117.49 mg 100 g^{-1}).

The significant variations observed in ascorbic acid content across treatments emphasize the critical role of foliar nutrient applications in enhancing the nutritional quality of coloured capsicum hybrids. The highest ascorbic acid content recorded in treatments incorporating boric acid, zinc sulphate and calcium chloride can be attributed to the synergistic effects of these nutrients in improving metabolic efficiency and antioxidant synthesis. Among the hybrids, "Orobelle" exhibited consistently higher ascorbic acid content compared to "Indam Mamatha," suggesting potential genetic differences in antioxidant production and nutrient responsiveness.

Zinc plays a crucial role as a cofactor for several enzymes involved in metabolic processes, including those responsible for antioxidant synthesis (Kumar et al. 2024; Ahmed et al. 2024). It enhances enzymatic activation and protein metabolism, ultimately leading to increased biosynthesis of ascorbic acid. Boron contributes to carbohydrate metabolism and sugar translocation, which are precursors for ascorbic acid biosynthesis, ensuring efficient nutrient transport and utilization (Saha et al. 2023; Pagard et al. 2024). Calcium, on the other hand, maintains membrane stability and reduces oxidative stress, thereby preserving fruit quality and enhancing antioxidant content (Anita 2022; Behera et al. 2021; Harris and Vellupillai 2015).

The pooled data over two years demonstrated a consistent positive effect of foliar nutrient applications on ascorbic acid content, reinforcing the importance of balanced nutrient supplementation in maximizing fruit quality parameters. The slightly higher ascorbic acid content observed in the second year compared to the first year could be attributed to improved environmental conditions, enhanced soil microbial activity and better plant adaptation to foliar nutrient applications. These factors likely contributed to increased nutrient availability, enhanced photosynthetic efficiency and improved antioxidant biosynthesis (Kumar et al. 2024; Rahman et al. 2019; Rayudu et al. 2017).

Conversely, the control treatment, which lacked foliar nutrient supplementation, consistently recorded the lowest ascorbic acid content across both years. This highlights the necessity of balanced nutrient management, as inadequate nutrient availability may have restricted essential physiological and biochemical processes required for antioxidant production and fruit quality maintenance (Ahmed et al. 2024; Kalroo et al. 2014; Patil et al. 2008). The absence of boron, zinc and calcium likely led to reduced enzymatic activation, inefficient metabolic processes and weaker cellular integrity, ultimately lowering fruit quality and storage potential.

The significant interaction between coloured capsicum hybrids and foliar nutrient applications in the second year and pooled analysis indicates that nutrient responsiveness may vary between genotypes. The combination of "Orobelle" with boric acid, zinc sulphate and calcium chloride recorded the highest ascorbic acid content, which was statistically at par with "Indam Mamatha" under the same nutrient application. This suggests that both hybrids benefit from balanced nutrient supplementation, though genetic factors may influence the extent of antioxidant synthesis and accumulation.

Overall, the results reinforce the importance of strategic foliar nutrient applications in capsicum cultivation. The combination of boric acid, zinc sulphate and calcium chloride emerged as the most effective treatment, significantly enhancing ascorbic acid content by promoting efficient metabolic activity, nutrient translocation and antioxidant biosynthesis. These findings align with previous studies that reported significant improvements in ascorbic acid content with the application of boron, zinc sulphate and calcium chloride (Kumar et al. 2024; Pagard et al. 2024; Al-Ogaidi and Alwan 2023; Anita 2022; Behera et al. 2021; Rahman et al. 2019; Rayudu et al. 2017; Harris and Vellupillai 2015; El-Sayed et al. 2015). This emphasizes the potential of these treatments for improving the nutritional quality, marketability and consumer preference for capsicum fruits by enhancing their antioxidant content and overall quality.

4.2.3 Carotenoid content (mg 100 g^{-1})

Carotenoid content (mg 100 g^{-1}) is a vital quality parameter in capsicum, contributing significantly to its vibrant coloration and nutritional value. Carotenoids are a group of naturally occurring pigments that include compounds such as β-carotene, lutein and capsanthin, which are responsible for the red, yellow and orange hues of capsicum fruits. These compounds are powerful antioxidants, playing a crucial role in protecting cells against oxidative stress, supporting immune function and promoting eye health.

Analysis of the data from the two consecutive years 2022-2023 and 2023-2024, combined with the pooled results, highlights notable variations in carotenoid content among the treatments, as illustrated in Table 4.2.3.

During the first year 2022-2023, the effect of coloured capsicum hybrids on carotenoid content was non-significant, while foliar nutrient applications and the interaction between coloured capsicum hybrids and foliar nutrient applications was significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a carotenoid content of 1.91 mg 100 g^{-1}, while the hybrid Indam Mamatha (H_1) recorded 1.90 mg 100 g^{-1}, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum carotenoid content (2.08 mg 100 g^{-1}). The control treatment (M_8), with no foliar nutrient application, recorded the minimum carotenoid content (1.80 mg 100 g^{-1}).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum ascorbic acid content (2.08 mg 100 g^{-1}) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (2.07 mg 100 g^{-1}) with treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum ascorbic acid content (1.73 mg 100 g^{-1}).

During the second year 2023-2024, the effect of coloured capsicum hybrids on carotenoid content was non-significant, while foliar nutrient applications had a significant effect. However, the interaction between coloured capsicum hybrids and foliar nutrient applications was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a carotenoid content of 1.99 mg 100 g^{-1}, while the hybrid Indam Mamatha (H_1) recorded 1.98 mg 100 g^{-1}, with no significant difference between them.

In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum carotenoid content (2.15 mg 100 g^{-1}). The control treatment (M_8), with no foliar nutrient application, recorded the minimum carotenoid content (1.87 mg 100 g^{-1}). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant and the values ranged from 1.78 to 2.15 mg 100 g^{-1}.

The pooled data of both the years revealed that the effect of coloured capsicum hybrids on carotenoid content was non-significant, while foliar nutrient applications and the interaction between coloured capsicum hybrids and foliar nutrient applications was significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a carotenoid content of 1.95 mg 100 g^{-1}, while the hybrid Indam Mamatha (H_1) recorded 1.94 mg 100 g^{-1}, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum carotenoid content (2.11 mg 100 g^{-1}). The control treatment (M_8), with no foliar nutrient application, recorded the minimum carotenoid content (1.83 mg 100 g^{-1}).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum ascorbic acid content (2.12 mg 100 g^{-1}) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (2.11 mg 100 g^{-1}) with treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum ascorbic acid content (1.76 mg 100 g^{-1}).

The significant variations in carotenoid content across treatments emphasize the critical role of foliar nutrient applications in enhancing pigment biosynthesis in coloured capsicum hybrids. The highest carotenoid content recorded in treatments incorporating boric acid, zinc sulphate and calcium chloride can be attributed to the synergistic effects of these nutrients in improving enzymatic activity and metabolic efficiency. Among the hybrids, “Orobelle” consistently exhibited higher carotenoid content than “Indam Mamatha,” suggesting potential genetic differences in pigment accumulation and nutrient responsiveness.

Boron plays a crucial role in carotenoid biosynthesis by improving enzyme activity, maintaining cell wall integrity and facilitating metabolite transport, directly influencing pigment accumulation (Saha et al. 2023; Pagard et al. 2024).

Zinc is an essential cofactor for multiple enzymes involved in metabolic pathways, including those regulating photosynthesis and pigment synthesis. It enhances photosynthetic efficiency and chlorophyll content, indirectly promoting the accumulation of carotenoids (Kumar et al. 2024; Ahmed et al. 2024). Calcium, on the other hand, contributes to cell membrane stability, reduces oxidative stress and ensures uniform nutrient distribution during fruit development, further enhancing carotenoid content (Anita 2022; Behera et al. 2021; Harris and Vellupillai 2015).

Table 4.2.3.: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on carotenoid content

Treatments	Carotenoid content (mg 100 g^{-1})		
	2022-2023	**2023-2024**	**Pooled**
H_1	1.90	1.98	1.94
H_2	1.91	1.99	1.95
Mean	**1.91**	**1.98**	**1.95**
SE (m)±	**0.01**	**0.01**	**0.01**
$CD_{0.05}$	**NS**	**NS**	**NS**
M_1	1.82	1.90	1.86
M_2	1.88	1.96	1.92
M_3	1.91	1.99	1.95
M_4	1.94	2.02	1.98
M_5	1.90	1.98	1.94
M_6	1.93	2.01	1.97
M_7	2.08	2.15	2.11
M_8	1.80	1.87	1.83
Mean	**1.91**	**1.98**	**1.95**
SE (m)±	**0.01**	**0.01**	**0.01**
$CD_{0.05}$	**0.03**	**0.04**	**0.03**
Interaction:			
H_1M_1	1.82	1.90	1.86
H_1M_2	1.86	1.94	1.90
H_1M_3	1.89	1.97	1.93
H_1M_4	1.92	2.00	1.96
H_1M_5	1.95	2.03	1.99
H_1M_6	1.98	2.06	2.02
H_1M_7	2.07	2.14	2.11
H_1M_8	1.73	1.78	1.76
H_2M_1	1.87	1.95	1.91
H_2M_2	1.90	1.98	1.94
H_2M_3	1.93	2.01	1.97
H_2M_4	1.96	2.04	2.00
H_2M_5	1.85	1.93	1.89
H_2M_6	1.88	1.96	1.92
H_2M_7	2.08	2.15	2.12
H_2M_8	1.82	1.90	1.86
Mean	**1.91**	**1.98**	**1.95**
SE (m)±	**0.01**	**0.02**	**0.01**
$CD_{0.05}$	**0.04**	**NS**	**0.03**

H_1 - Indam Mamatha; **H_2** - Orobelle

***M_1* -** Boric acid 0.5 %; **M_2 -** Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8 -** Control (No spray)

The pooled data over two years demonstrated a consistent positive effect of foliar nutrient applications on carotenoid content, reinforcing the importance of balanced nutrient supplementation in maximizing fruit quality. The slightly higher carotenoid content observed in the second year compared to the first year could be attributed to environmental variations such as light intensity and temperature, which are known to regulate pigment synthesis in plants (Rahman et al. 2019; Rayudu et al. 2017). Light exposure, in particular, plays a vital role in modulating the expression of genes associated with the carotenoid biosynthetic pathway, potentially contributing to increased pigment accumulation.

Conversely, the control treatment, which lacked foliar nutrient supplementation, consistently recorded the lowest carotenoid content across both years. This highlights the necessity of balanced nutrient management, as inadequate nutrient availability likely restricted essential physiological and biochemical processes required for carotenoid biosynthesis and fruit quality maintenance (Ahmed et al. 2024; Kalroo et al. 2014; Patil et al. 2008). The absence of boron, zinc and calcium in the control treatment likely resulted in reduced enzymatic activation, inefficient metabolic processes and weaker cellular integrity, ultimately leading to lower pigment accumulation and diminished fruit quality.

The significant interaction between coloured capsicum hybrids and foliar nutrient applications in the first year and pooled analysis indicates that nutrient responsiveness may vary between genotypes. The combination of "Orobelle" with boric acid, zinc sulphate and calcium chloride recorded the highest carotenoid content, which was statistically at par with "Indam Mamatha" under the same nutrient application. This suggests that while both hybrids benefit from balanced nutrient supplementation, genetic factors may influence the extent of carotenoid synthesis and accumulation.

Overall, the results reinforce the importance of strategic foliar nutrient applications in capsicum cultivation. The combination of boric acid, zinc sulphate and calcium chloride emerged as the most effective treatment, significantly enhancing carotenoid content by promoting efficient metabolic activity, nutrient translocation and pigment biosynthesis. These findings align with previous studies that reported significant improvements in carotenoid accumulation with the application of boron, zinc sulphate and calcium chloride (Pagard et al. 2024; Saha et al. 2023; Rahman et al. 2019; Salim et al. 2019; Akladious and Mohamed 2018; Buczkowska et al. 2016; El-Said 2009). This emphasizes the potential of these treatments for improving the nutritional quality, marketability and consumer preference for capsicum fruits by enhancing their pigment concentration and overall fruit quality.

4.3 Incidence and severity of economically important diseases of capsicum

4.3.1 Incidence of collar rot (%)

Collar rot in capsicum is a devastating disease which primarily affects the collar region of the plant, leading to symptoms such as basal stem discoloration, rotting and eventual wilting or collapse of the plant. The pathogen thrives under warm, moist conditions and is aggravated by factors like poor drainage, high soil moisture and excessive humidity. The incidence of collar rot is calculated as the percentage of infected plants in relation to the total number of plants observed in a given area. Accurate assessment of disease incidence is crucial for evaluating the severity of the problem and implementing appropriate control measures.

Analysis of the data from the two consecutive years, 2022-2023 and 2023-2024, along with the pooled results, revealed significant variations in the incidence of collar rot (%) among the treatments, as presented in Table 4.3.1.

In the first year 2022–2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a significant effect on incidence of collar rot (%). Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower incidence of collar rot (8.47 %), while the hybrid Orobelle (H_2) recorded a statistically higher incidence of collar rot (10.97 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum incidence of collar rot (3.89 %). The control treatment (M_8), with no foliar nutrient application, recorded the maximum incidence of collar rot (17.78 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum incidence of collar rot (3.33 %) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum incidence of collar rot (18.89 %).

During the second year 2023-2024, the effect of coloured capsicum hybrids on incidence of collar rot was non-significant, while foliar nutrient applications had a significant effect. However, the interaction between coloured capsicum hybrids and foliar nutrient applications was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a collar rot incidence of 9.03 %, while the hybrid Orobelle (H_2) recorded 9.72 %, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum incidence of collar rot (6.11 %). The control treatment (M_8), with no foliar nutrient application, recorded the maximum incidence of collar rot (13.89 %). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant and the values ranged from 5.56 to 14.44 %.

The pooled data for both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a significant effect on incidence of collar rot (%). Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower incidence of collar rot (8.75 %), while the hybrid Orobelle (H_2) recorded a statistically higher incidence of collar rot (10.35 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum incidence of collar rot (5.00 %). The control treatment (M_8), with no foliar nutrient application, recorded the maximum incidence of collar rot (15.83 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum incidence of collar rot (4.44 %) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum incidence of collar rot (16.67 %).

The findings of the study emphasize the crucial role of foliar nutrient applications, particularly boric acid, zinc sulphate and calcium chloride, in reducing collar rot incidence in coloured capsicum hybrids. The pooled data across two years demonstrated that these nutrients significantly minimized disease occurrence, with the lowest incidence recorded in the hybrid “Indam Mamatha” treated with the combined nutrient application. The highest incidence was observed in “Orobelle” under control conditions, reinforcing the protective effects of nutrient supplementation.

Table 4.3.1: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on incidence of collar rot

Treatments	Incidence of collar rot (%)		
	2022-2023	2023-2024	Pooled
H_1	8.47 (2.91)	9.03 (3.00)	8.75 (2.96)
H_2	10.97 (3.31)	9.72 (3.12)	10.35 (3.22)
Mean	**9.72 (3.12)**	**9.37 (3.06)**	**9.55 (3.09)**
SE (m)±	**0.10**	**0.12**	**0.07**
$CD_{0.05}$	**0.28**	**NS**	**0.22**
M_1	6.67 (2.58)	8.34 (2.89)	7.50 (2.74)
M_2	8.89 (2.98)	7.22 (2.69)	8.06 (2.84)
M_3	8.33 (2.89)	9.44 (3.07)	8.89 (2.98)
M_4	9.45 (3.07)	8.89 (2.98)	9.17 (3.03)
M_5	12.22 (3.5)	11.11 (3.33)	11.67 (3.42)
M_6	10.56 (3.25)	10.00 (3.16)	10.28 (3.21)
M_7	3.89 (1.97)	6.11 (2.47)	5.00 (2.24)
M_8	17.78 (4.22)	13.89 (3.73)	15.83 (3.98)
Mean	**9.72 (3.12)**	**9.37 (3.06)**	**9.55 (3.09)**
SE (m)±	**0.20**	**0.24**	**0.14**
$CD_{0.05}$	**0.57**	**0.68**	**0.44**
Interaction:			
H_1M_1	7.78 (2.79)	8.89 (2.98)	8.33 (2.89)
H_1M_2	6.67 (2.58)	7.78 (2.79)	7.22 (2.69)
H_1M_3	7.78 (2.79)	10.00 (3.16)	8.89 (2.98)
H_1M_4	10.00 (3.16)	8.89 (2.98)	9.45 (3.07)
H_1M_5	8.89 (2.98)	11.11 (3.33)	10.00 (3.16)
H_1M_6	6.67 (2.58)	6.67 (2.58)	6.67 (2.58)
H_1M_7	3.33 (1.82)	5.56 (2.36)	4.44 (2.11)
H_1M_8	16.67 (4.08)	13.33 (3.65)	15.00 (3.87)
H_2M_1	5.56 (2.36)	7.78 (2.79)	6.67 (2.58)
H_2M_2	11.11 (3.33)	6.67 (2.58)	8.89 (2.98)
H_2M_3	8.89 (2.98)	8.89 (2.98)	8.89 (2.98)
H_2M_4	8.89 (2.98)	8.89 (2.98)	8.89 (2.98)
H_2M_5	15.55 (3.94)	11.11 (3.33)	13.33 (3.65)
H_2M_6	14.44 (3.8)	13.33 (3.65)	13.89 (3.73)
H_2M_7	4.44 (2.11)	6.67 (2.58)	5.56 (2.36)
H_2M_8	18.89 (4.35)	14.44 (3.8)	16.67 (4.08)
Mean	**9.72 (3.12)**	**9.38 (3.06)**	**9.55 (3.09)**
SE (m)±	**0.28**	**0.34**	**0.20**
$CD_{0.05}$	**0.81**	**NS**	**0.62**

H_1 - Indam Mamatha; **H_2** - Orobelle

***M_1* -** Boric acid 0.5 %; **M_2 -** Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8 -** Control (No spray)

Boron, zinc and calcium contribute to disease resistance through multiple mechanisms. Boron strengthens the structural integrity of cell walls by promoting the synthesis of pectins and lignins, forming a physical barrier against pathogen invasion. Zinc plays a key role in maintaining membrane stability and activating defense-related enzymes that enhance stress tolerance and pathogen resistance. Calcium fortifies cell walls and stabilizes cell membranes, reducing tissue degradation and pathogen colonization (Haleema et al. 2024). The synergistic action of these nutrients improves plant defense mechanisms, thereby reducing susceptibility to collar rot.

Environmental factors such as high soil moisture, temperature fluctuations and poor drainage can exacerbate collar rot incidence, particularly in untreated plants. However, the consistent reduction in disease occurrence across both years in nutrient-supplemented treatments suggests that these nutrients also enhance plant resilience to environmental stress. While the interaction between hybrids and nutrient applications was significant in the first year and pooled data, it was non-significant in the second year, indicating potential variations in genetic responsiveness and environmental influences. Nonetheless, the overall trend highlights the efficacy of boric acid, zinc sulphate and calcium chloride in mitigating collar rot incidence in capsicum.

These findings align with previous reports emphasizing the importance of nutrient management in improving plant health and disease resistance (Haleema et al. 2024). The application of these nutrients not only reduces disease occurrence but also enhances physiological and biochemical processes essential for overall plant vigour.

4.3.2 Incidence of anthracnose (%)

Anthracnose, caused by *Colletotrichum* species, is a significant fungal disease in capsicum. It leads to dark, sunken lesions on fruits, reducing yield and fruit quality. The disease thrives in humid conditions and can spread rapidly through rain, wind or handling.

Analysis of the data from the two consecutive years, 2022-2023 and 2023-2024, along with the pooled results, revealed significant variations in the incidence of anthracnose (%) among the treatments, as presented in Table 4.3.2.

In the first year 2022–2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a non-significant effect on incidence of anthracnose

(%). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded an anthracnose incidence of 5.93 %, while the hybrid Indam Mamatha (H_1) recorded 5.95 %, with no significant difference between them. The effect of foliar nutrient applications was non-significant with values ranging from 3.34 to 8.09 %. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was also non-significant with values ranging from 2.86 to 8.57 %.

In the second year 2023–2024, the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a non-significant effect on incidence of anthracnose (%). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded an anthracnose incidence of 4.59 %, while the hybrid Indam Mamatha (H_1) recorded 5.13 %, with no significant difference between them. The effect of foliar nutrient applications was non-significant with values ranging from 2.99 to 8.12 %. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was also non-significant with values ranging from 2.56 to 8.55 %.

The pooled data for both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a non-significant effect on incidence of anthracnose (%). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded an anthracnose incidence of 5.27 %, while the hybrid Indam Mamatha (H_1) recorded 5.53 %, with no significant difference between them. The effect of foliar nutrient applications was non-significant with values ranging from 3.16 to 8.11 %. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was also non-significant with values ranging from 2.71 to 8.56 %.

The findings of this study indicate that the incidence of anthracnose in coloured capsicum hybrids remained relatively low, with values ranging between 2.56 % and 8.57 % across treatments. The lack of significant differences in disease incidence among the different treatments suggests that the applied foliar nutrient applications, including boric acid, zinc sulphate and calcium chloride, did not have a substantial impact on reducing anthracnose occurrence. Additionally, the non-significant interaction between coloured capsicum hybrids and nutrient applications reinforces the conclusion that genetic variations in the hybrids did not play a major role in disease resistance.

The pooled data further supports the observation that environmental conditions within the polyhouse may have had a more pronounced influence on anthracnose incidence than the treatments themselves. High relative humidity and favourable conditions for fungal infection

Table 4.3.2: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on incidence of anthracnose

Treatments	Incidence of anthracnose (%)		
	2022-2023	2023-2024	Pooled
H_1	5.95 (2.44)	5.13 (2.26)	5.53 (2.35)
H_2	5.93 (2.44)	4.59 (2.14)	5.27 (2.30)
Mean	**5.94 (2.44)**	**4.86 (2.20)**	**5.40 (2.32)**
SE (m)±	**0.19**	**0.20**	**0.05**
$CD_{0.05}$	**NS**	**NS**	**NS**
M_1	6.11 (2.47)	4.70 (2.17)	5.41 (2.33)
M_2	5.72 (2.39)	5.55 (2.36)	5.63 (2.37)
M_3	4.76 (2.18)	3.42 (1.85)	4.09 (2.02)
M_4	7.14 (2.67)	4.70 (2.17)	5.92 (2.43)
M_5	5.72 (2.39)	4.27 (2.07)	4.99 (2.23)
M_6	6.66(2.58)	5.13 (2.26)	5.90 (2.43)
M_7	3.34 (1.83)	2.99 (1.73)	3.16 (1.78)
M_8	8.09 (2.84)	8.12 (2.85)	8.11 (2.85)
Mean	**5.94 (2.44)**	**4.86 (2.20)**	**5.40 (2.32)**
SE (m)±	**0.40**	**0.41**	**0.10**
$CD_{0.05}$	**NS**	**NS**	**NS**
Interaction:			
H_1M_1	5.56 (2.36)	5.98 (2.45)	5.77 (2.40)
H_1M_2	5.72 (2.39)	4.27 (2.07)	4.99 (2.23)
H_1M_3	4.76 (2.18)	3.42 (1.85)	4.09 (2.02)
H_1M_4	7.62 (2.76)	5.13 (2.26)	6.37 (2.52)
H_1M_5	5.71 (2.39)	5.98 (2.45)	5.85 (2.42)
H_1M_6	6.66 (2.58)	5.13 (2.26)	5.90 (2.43)
H_1M_7	2.86 (1.69)	2.56 (1.60)	2.71 (1.65)
H_1M_8	8.57 (2.93)	8.55 (2.92)	8.56 (2.93)
H_2M_1	6.67 (2.58)	3.42 (1.85)	5.04 (2.25)
H_2M_2	5.71 (2.39)	6.84 (2.61)	6.28 (2.50)
H_2M_3	4.76 (2.18)	3.42 (1.85)	4.09 (2.02)
H_2M_4	6.67 (2.58)	4.27 (2.07)	5.47 (2.34)
H_2M_5	5.72 (2.39)	2.56 (1.60)	4.14 (2.03)
H_2M_6	6.66 (2.58)	5.13 (2.26)	5.90 (2.43)
H_2M_7	3.81 (1.95)	3.42 (1.85)	3.61 (1.90)
H_2M_8	7.62(2.76)	7.69 (2.77)	7.65 (2.77)
Mean	**5.94 (2.44)**	**4.86 (2.20)**	**5.40 (2.32)**
SE (m)±	**0.55**	**0.56**	**0.15**
$CD_{0.05}$	**NS**	**NS**	**NS**

*H_1 - Indam Mamatha; H_2 - Orobelle

*M_1 - Boric acid 0.5 %; M_2 - Zinc sulphate 0.5 %; M_3 - Calcium chloride 0.5 %; M_4 - Boric acid 0.5 % + Zinc sulphate 0.5%; M_5 - Boric acid 0.5 % + Calcium chloride 0.5 %; M_6 - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_7 - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_8 - Control (No spray)

during both years could have contributed to disease persistence, regardless of the nutrient applications. This aligns with previous findings that environmental stressors can sometimes outweigh the protective effects of nutrient supplementation in disease management (Saxena et al. 2016).

While boron, zinc and calcium are known to enhance plant defense mechanisms by improving cell wall integrity, membrane stability and enzymatic activity, their effects on anthracnose suppression in this study were minimal. The non-significant year-to-year variation in disease incidence further supports the notion that environmental factors, rather than nutrient applications, played a dominant role in influencing anthracnose occurrence.

This suggests that while foliar nutrient applications can enhance overall plant health, additional disease management strategies, such as improved ventilation and moisture control, may be necessary to effectively mitigate anthracnose in capsicum cultivation.

4.3.3 Severity of powdery mildew (%)

Powdery mildew is a fungal disease that affects capsicum, characterized by the appearance of white, powdery fungal growth on the leaves, stems and fruits. This disease can lead to chlorosis, premature leaf drop, stunted growth and reduced yield and quality in capsicum plants. Powdery mildew thrives in warm, dry conditions with high humidity.

Analysis of the data from the two consecutive years, 2022-2023 and 2023-2024, along with the pooled results, revealed significant variations in the severity of powdery mildew (%) among the treatments, as presented in Table 4.3.3.

In the first year 2022–2023, the effect of coloured capsicum hybrids and foliar nutrient applications was significant whereas their interaction had a non-significant effect on severity of powdery mildew (%). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically lower severity of powdery mildew (7.90 %), while the hybrid Indam Mamatha (H_1) recorded a statistically higher severity of powdery mildew (8.77 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum severity of powdery mildew (7.05 %). The control treatment (M_8), with no foliar nutrient application, recorded severity of powdery mildew (9.11 %). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant and the values ranged from 6.88 to 9.60 %.

Table 4.3.3: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on severity of powdery mildew

Treatments	**Severity of powdery mildew (%)**		
	2022-2023	**2023-2024**	**Pooled**
H_1	8.77 (2.96)	11.53 (3.39)	10.15 (3.19)
H_2	7.90 (2.81)	10.32(3.21)	9.11 (3.02)
Mean	**8.34 (2.89)**	**10.92 (3.30)**	**9.63 (3.10)**
SE (m)±	**0.03**	**0.03**	**0.01**
$CD_{0.05}$	**0.09**	**0.10**	**0.03**
M_1	8.56 (2.93)	11.32 (3.36)	9.94 (3.15)
M_2	8.64 (2.94)	11.23 (3.35)	9.93 (3.15)
M_3	8.62 (2.94)	11.41 (3.38)	10.01 (3.16)
M_4	8.26 (2.87)	10.83 (3.29)	9.55 (3.09)
M_5	8.34 (2.89)	10.91 (3.30)	9.62 (3.10)
M_6	8.13 (2.85)	10.60 (3.26)	9.36 (3.06)
M_7	7.05 (2.66)	9.20 (3.03)	8.13 (2.85)
M_8	9.11 (3.02)	11.89 (3.45)	10.50 (3.24)
Mean	**8.34 (2.89)**	**10.92 (3.30)**	**9.63 (3.10)**
SE (m)±	**0.06**	**0.07**	**0.02**
$CD_{0.05}$	**0.18**	**0.20**	**0.06**
Interaction:			
H_1M_1	9.60 (3.10)	12.78 (3.57)	11.19 (3.35)
H_1M_2	9.33 (3.05)	12.36 (3.52)	10.85 (3.29)
H_1M_3	9.47 (3.08)	12.37 (3.52)	10.92 (3.30)
H_1M_4	8.26 (2.87)	10.83 (3.29)	9.55 (3.09)
H_1M_5	8.75 (2.96)	11.42 (3.38)	10.08 (3.18)
H_1M_6	8.63 (2.94)	11.20 (3.35)	9.92 (3.15)
H_1M_7	7.22 (2.69)	9.44 (3.07)	8.33 (2.89)
H_1M_8	8.91 (2.99)	11.81 (3.44)	10.36 (3.22)
H_2M_1	7.51 (2.74)	9.86 (3.14)	8.69 (2.95)
H_2M_2	7.94 (2.82)	10.09 (3.18)	9.02 (3.00)
H_2M_3	8.75 (2.96)	11.42 (3.38)	10.08 (3.18)
H_2M_4	8.26 (2.87)	10.83 (3.29)	9.55 (3.09)
H_2M_5	7.93 (2.82)	10.39 (3.22)	9.16 (3.03)
H_2M_6	7.62 (2.76)	10.00 (3.16)	8.81 (2.97)
H_2M_7	6.88 (2.62)	8.96 (2.99)	7.92 (2.81)
H_2M_8	8.33 (2.89)	11.00 (3.32)	9.67 (3.11)
Mean	**8.34 (2.89)**	**10.92 (3.30)**	**9.63 (3.10)**
SE (m)±	**0.09**	**0.10**	**0.03**
$CD_{0.05}$	**NS**	**NS**	**NS**

*H_1 - Indam Mamatha; H_2 - Orobelle

*M_1 - Boric acid 0.5 %; M_2 - Zinc sulphate 0.5 %; M_3 - Calcium chloride 0.5 %; M_4 - Boric acid 0.5 % + Zinc sulphate 0.5%; M_5 - Boric acid 0.5 % + Calcium chloride 0.5 %; M_6 - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_7 - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_8 - Control (No spray)

In the second year 2023–2024, the effect of coloured capsicum hybrids and foliar nutrient applications was significant whereas their interaction had a non-significant effect on severity of powdery mildew (%). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically lower severity of powdery mildew (10.32 %), while the hybrid Indam Mamatha (H_1) recorded a statistically higher severity of powdery mildew (11.53 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum severity of powdery mildew (9.20 %). The control treatment (M_8), with no foliar nutrient application, recorded severity of powdery mildew (11.89 %). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant and the values ranged from 8.96 to 12.78 %.

The pooled data for both the years revealed that the effect of coloured capsicum hybrids and foliar nutrient applications was significant whereas their interaction had a non-significant effect on severity of powdery mildew (%). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically lower severity of powdery mildew (9.11 %), while the hybrid Indam Mamatha (H_1) recorded a statistically higher severity of powdery mildew (10.15 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum severity of powdery mildew (8.13 %). The control treatment (M_8), with no foliar nutrient application, recorded severity of powdery mildew (10.50 %). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant and the values ranged from 7.92 to 11.19 %.

The study revealed that foliar nutrient applications significantly reduced the severity of powdery mildew in coloured capsicum hybrids. The combined application of boric acid, zinc sulphate and calcium chloride consistently recorded the lowest disease severity across both years, reinforcing the role of these nutrients in enhancing plant defense. In contrast, the control treatment exhibited the highest severity, indicating that the absence of essential nutrients weakens plant resistance.

Boron contributes to cell wall reinforcement, zinc aids in metabolic processes linked to plant defense and calcium strengthens membrane integrity, collectively improving disease resistance (Awad et al. 2015). The findings align with previous studies in capsicum and tomato, which demonstrated reduced powdery mildew severity following nutrient supplementation (Awad et al. 2015; Ehret et al. 2002). While genetic differences between hybrids were significant, with hybrid "Orobelle" showing lower disease severity than "Indam Mamatha", the interaction between hybrids and nutrient applications remained non-significant.

The second year recorded higher disease severity, likely due to environmental conditions favouring fungal proliferation. However, the consistent effectiveness of nutrient applications across both years suggests their role in mitigating disease stress despite variable environmental factors. These results emphasize the importance of nutrient management in integrated disease control strategies for capsicum cultivation.

4.4 Soil analysis

4.4.1 Soil pH

Soil pH is a critical factor influencing plant growth, soil health and nutrient availability. It measures the acidity or alkalinity of the soil on a scale from 0 to 14. The ideal soil pH range for most crops, including capsicum, lies between 6.0 and 7.5, as this range ensures optimal nutrient solubility and microbial activity. The pH influences soil microbial populations, organic matter decomposition and the activity of beneficial microbes such as nitrogen-fixing bacteria. Soil pH plays a crucial role in determining the availability of essential nutrients to plants.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, combined with the pooled results, highlights notable differences in soil pH across the treatments, as illustrated in Table 4.4.1.

During the first year 2022-2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a non-significant effect on soil pH. The effect of coloured capsicum hybrids was non-significant with a mean value of 7.49. The effect of foliar nutrient applications was non-significant with values ranging from 7.48 to 7.51. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was also non-significant and the values ranged from 7.48 to 7.52.

During the second year 2023-2024, the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a non-significant effect on soil pH. The effect of coloured capsicum hybrids was non-significant with a mean value of 7.40.

Table 4.4.1: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on soil pH

Treatments	Soil pH		
	2022-2023	2023-2024	Pooled
H_1	7.49	7.40	7.44
H_2	7.49	7.40	7.45
Mean	**7.49**	**7.40**	**7.45**
SE (m)±	**0.01**	**0.01**	**0.01**
$CD_{0.05}$	**NS**	**NS**	**NS**
M_1	7.49	7.40	7.45
M_2	7.51	7.39	7.45
M_3	7.49	7.41	7.45
M_4	7.49	7.40	7.44
M_5	7.48	7.39	7.44
M_6	7.48	7.42	7.45
M_7	7.50	7.38	7.44
M_8	7.49	7.41	7.45
Mean	**7.49**	**7.40**	**7.45**
SE (m)±	**0.01**	**0.01**	**0.01**
$CD_{0.05}$	**NS**	**NS**	**NS**
Interaction:			
H_1M_1	7.49	7.39	7.44
H_1M_2	7.50	7.40	7.45
H_1M_3	7.47	7.41	7.44
H_1M_4	7.49	7.39	7.44
H_1M_5	7.49	7.36	7.43
H_1M_6	7.49	7.44	7.46
H_1M_7	7.49	7.39	7.44
H_1M_8	7.50	7.41	7.46
H_2M_1	7.49	7.41	7.45
H_2M_2	7.52	7.38	7.45
H_2M_3	7.51	7.40	7.46
H_2M_4	7.48	7.41	7.44
H_2M_5	7.47	7.43	7.45
H_2M_6	7.48	7.40	7.44
H_2M_7	7.51	7.38	7.44
H_2M_8	7.48	7.42	7.45
Mean	**7.49**	**7.40**	**7.45**
SE (m)±	**0.01**	**0.02**	**0.02**
$CD_{0.05}$	**NS**	**NS**	**NS**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1** - Boric acid 0.5 %; **M_2** - Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8** - Control (No spray)

The effect of foliar nutrient applications was non-significant with values ranging from 7.38 to 7.42. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was also non-significant and the values ranged from 7.38 to 7.44.

The pooled data from both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a non-significant effect on soil pH. The effect of coloured capsicum hybrids was non-significant with a mean value of 7.45. The effect of foliar nutrient applications was non-significant with values ranging from 7.38 to 7.42. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was also non-significant and the values ranged from 7.36 to 7.44.

The results of the study indicate that the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction on soil pH was non-significant across both years. The observed soil pH values exhibited minimal variation, with pooled data showing a mean value of 7.45. The applied nutrient treatments, including boric acid, zinc sulphate and calcium chloride, did not significantly influence soil acidity or alkalinity, suggesting that these nutrients were absorbed by plants without altering the overall soil pH balance.

Soil pH is a fundamental factor affecting nutrient availability, microbial activity and overall soil health. The stability in soil pH observed in this study is advantageous, as it ensures optimal nutrient uptake by plants. This finding aligns with previous research indicating that nutrient applications, when used at appropriate concentrations, do not significantly disrupt soil pH levels. The neutral pH range observed further supports the notion that the soil possesses a strong buffering capacity, preventing drastic shifts in acidity or alkalinity.

The non-significant year-to-year variation suggests that environmental factors and agronomic practices, such as irrigation and organic matter decomposition, played a role in maintaining soil pH stability. Minor fluctuations in pH remained within a narrow range, reinforcing the resilience of the soil system against potential acidifying or alkalizing effects from external inputs.

These findings highlight the importance of balanced nutrient management in capsicum crop production. While foliar applications of boric acid, zinc sulphate and calcium chloride can enhance plant health and productivity, their negligible impact on soil pH suggests that they do not contribute to long-term soil degradation.

4.4.2 Soil EC (dSm^{-1})

Soil electrical conductivity (EC) is a key indicator of soil salinity, which directly influences nutrient availability, water uptake and overall plant health. It reflects the concentration of soluble salts in the soil, playing a crucial role in determining the soil's fertility and its suitability for crop production.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, combined with the pooled results, highlights notable differences in soil EC across the treatments, as illustrated in Table 4.4.2.

During the first year 2022-2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a non-significant effect on soil EC (dSm^{-1}). The effect of coloured capsicum hybrids was non-significant with a mean value of 0.243 dSm^{-1}. The effect of foliar nutrient applications was non-significant with values ranging from 0.227 to 0.250 dSm^{-1}. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was also non-significant and the values ranged from 0.223 to 0.260 dSm^{-1}.

During the second year 2023-2024, the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a non-significant effect on soil EC. The effect of coloured capsicum hybrids was non-significant with a mean value of 0.254 dSm^{-1}. The effect of foliar nutrient applications was non-significant with values ranging from 0.245 to 0.263 dSm^{-1}. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was also non-significant and the values ranged from 0.237 to 0.267 dSm^{-1}.

The pooled data from both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a non-significant effect on soil EC. The effect of coloured capsicum hybrids was non-significant with a mean value of 0.248 dSm^{-1}. The effect of foliar nutrient applications was non-significant with values ranging from 0.237 to 0.256 dSm^{-1}. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was also non-significant and the values ranged from 0.237 to 0.258 dSm^{-1}.

The findings of this study indicate that soil electrical conductivity (EC) remained stable across the different treatments, years and their interactions, with no significant variations observed.

Table 4.4.2.: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on soil EC

Treatments	Soil EC (dSm^{-1})		
	2022-2023	**2023-2024**	**Pooled**
H_1	0.241	0.252	0.246
H_2	0.244	0.255	0.250
Mean	**0.243**	**0.254**	**0.248**
SE (m)±	**0.003**	**0.003**	**0.003**
$CD_{0.05}$	**NS**	**NS**	**NS**
M_1	0.227	0.262	0.244
M_2	0.245	0.263	0.254
M_3	0.248	0.263	0.256
M_4	0.248	0.253	0.251
M_5	0.250	0.247	0.248
M_6	0.243	0.245	0.244
M_7	0.250	0.248	0.249
M_8	0.228	0.245	0.237
Mean	**0.242**	**0.253**	**0.248**
SE (m)±	**0.006**	**0.006**	**0.005**
$CD_{0.05}$	**NS**	**NS**	**NS**
Interaction:			
H_1M_1	0.223	0.260	0.242
H_1M_2	0.233	0.267	0.250
H_1M_3	0.243	0.267	0.255
H_1M_4	0.250	0.250	0.250
H_1M_5	0.260	0.240	0.250
H_1M_6	0.250	0.237	0.243
H_1M_7	0.240	0.247	0.243
H_1M_8	0.227	0.247	0.237
H_2M_1	0.230	0.263	0.247
H_2M_2	0.257	0.260	0.258
H_2M_3	0.253	0.260	0.257
H_2M_4	0.247	0.257	0.252
H_2M_5	0.240	0.253	0.247
H_2M_6	0.237	0.253	0.245
H_2M_7	0.260	0.250	0.255
H_2M_8	0.230	0.243	0.237
Mean	**0.243**	**0.253**	**0.248**
SE (m)±	**0.009**	**0.009**	**0.007**
$CD_{0.05}$	**NS**	**NS**	**NS**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1** - Boric acid 0.5 %; **M_2** - Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8** - Control (No spray)

The EC values ranged within a narrow margin, suggesting that the applied foliar nutrient treatments did not introduce substantial changes to the soil's soluble salt content. This stability is beneficial, as excessive fluctuations in soil EC can negatively impact nutrient availability and plant growth.

Soil EC is a critical indicator of soil fertility, as it reflects the concentration of dissolved ions that influence nutrient uptake. The recorded values in this study suggest that the soil maintained moderate salinity levels, ensuring the availability of key nutrients such as calcium, potassium and sodium without posing risks of toxicity or osmotic stress. This aligns with previous studies indicating that controlled nutrient applications do not necessarily alter soil EC significantly, particularly in short-term experiments.

The absence of significant variation in EC across treatments can be attributed to the mode of nutrient application. Since foliar nutrients are directly absorbed by plant leaves, their influence on the soil's ionic composition is minimized.

This method of nutrient supplementation reduces dependency on root-mediated absorption, thereby preventing excessive salt accumulation in the root zone. As a result, soil EC remained within an optimal range across all treatments. Furthermore, the controlled environmental conditions of the polyhouse likely played a role in maintaining soil EC stability. Regulated irrigation practices prevented excessive leaching or accumulation of salts, ensuring consistent ionic balance in the root zone. The uniformity in soil moisture levels further contributed to the absence of significant fluctuations in EC, reinforcing the reliability of the observed results.

4.4.3 Organic carbon (%)

Soil organic carbon (%) is a critical component of soil organic matter, playing a vital role in maintaining soil health and fertility. It is a key determinant of soil structure, water retention, nutrient cycling and microbial activity. Organic carbon serves as a reservoir of essential nutrients, such as nitrogen, phosphorus and sulphur, which are gradually released into the soil through microbial decomposition. In the context of plant growth, organic carbon enhances the soil's cation exchange capacity, thereby improving the availability of nutrients to plants. Additionally, it plays a significant role in improving soil aeration and moisture retention, both of which are crucial for optimal root development.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, combined with the pooled results, highlights notable differences in soil organic carbon (%) across the treatments, as illustrated in Table 4.4.3.

During the first year 2022-2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a non-significant effect on soil organic carbon. The effect of coloured capsicum hybrids was non-significant with a mean value of 1.33 %. The effect of foliar nutrient applications was non-significant with values ranging from 1.30 to 1.35 %. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was also non-significant and the values ranged from 1.29 to 1.36 %.

During the second year 2023-2024, the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a non-significant effect on soil organic carbon. The effect of coloured capsicum hybrids was non-significant with a mean value of 1.32 %. The effect of foliar nutrient applications was non-significant with values ranging from 1.29 to 1.35 %. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was also non-significant and the values ranged from 1.29 to 1.36 %.

The pooled data from both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a non-significant effect on soil organic carbon. The effect of coloured capsicum hybrids was non-significant with a mean value of 1.32 %. The effect of foliar nutrient applications was non-significant with values ranging from 1.30 to 1.35 %. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was also non-significant and the values ranged from 1.29 to 1.35 %.

The results of the study indicate that soil organic carbon (OC) content remained stable across different treatments, years and their interactions, as evidenced by the consistently narrow range of values observed. The non-significant variation in OC suggests that foliar nutrient applications, which included boric acid, zinc sulphate and calcium chloride, had minimal impact on soil organic matter dynamics. This aligns with previous findings that foliar applications primarily influence plant nutrient uptake rather than soil characteristics.

Soil organic carbon plays a vital role in maintaining soil fertility, influencing nutrient availability, microbial activity and soil structure. The recorded OC values in this study remained within a moderate to high range, indicating a well-maintained soil environment conducive to plant growth.

Table 4.4.3: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on organic carbon

Treatments	**Organic carbon (%)**		
	2022-2023	**2023-2024**	**Pooled**
H_1	1.33	1.31	1.32
H_2	1.33	1.33	1.33
Mean	**1.33**	**1.32**	**1.32**
SE (m)±	**0.01**	**0.01**	**0.01**
$CD_{0.05}$	**NS**	**NS**	**NS**
M_1	1.30	1.29	1.30
M_2	1.31	1.30	1.31
M_3	1.32	1.31	1.32
M_4	1.33	1.32	1.33
M_5	1.32	1.32	1.32
M_6	1.33	1.33	1.33
M_7	1.34	1.34	1.34
M_8	1.35	1.35	1.35
Mean	**1.33**	**1.32**	**1.32**
SE (m)±	**0.02**	**0.02**	**0.01**
$CD_{0.05}$	**NS**	**NS**	**NS**
Interaction:			
H_1M_1	1.29	1.29	1.29
H_1M_2	1.30	1.30	1.30
H_1M_3	1.31	1.31	1.31
H_1M_4	1.32	1.32	1.32
H_1M_5	1.33	1.30	1.32
H_1M_6	1.34	1.31	1.33
H_1M_7	1.35	1.32	1.34
H_1M_8	1.36	1.33	1.35
H_2M_1	1.32	1.29	1.30
H_2M_2	1.33	1.30	1.31
H_2M_3	1.34	1.31	1.32
H_2M_4	1.35	1.32	1.33
H_2M_5	1.30	1.33	1.32
H_2M_6	1.31	1.34	1.33
H_2M_7	1.32	1.35	1.34
H_2M_8	1.33	1.36	1.35
Mean	**1.33**	**1.32**	**1.32**
SE (m)±	**0.03**	**0.02**	**0.02**
$CD_{0.05}$	**NS**	**NS**	**NS**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1 -** Boric acid 0.5 %; **M_2 -** Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8 -** Control (No spray)

The stability of OC across years suggests that environmental conditions, such as temperature and moisture regulation within the polyhouse, contributed to minimizing fluctuations in organic matter decomposition and accumulation.

The polyhouse conditions likely played a role in preserving organic carbon levels by preventing excessive microbial mineralization or leaching losses, which are common in open-field conditions. Additionally, the absence of significant differences among treatments suggests that nutrient supplementation through foliar application did not contribute directly to organic matter buildup or depletion in the soil. This stability is beneficial as it ensures consistent nutrient cycling and retention, which are critical for sustained plant growth and productivity. Overall, the findings highlight that while foliar nutrient applications support plant health, they do not significantly alter soil organic carbon content.

4.4.4 Available N, P and K content in soil before planting and after termination of experiment (kg ha^{-1})

4.4.4.1 Available N (kg ha^{-1}) content in soil after termination of experiment

Nitrogen (N) is an essential macronutrient critical for plant growth and development. It is a key component of chlorophyll, proteins and various metabolic processes, directly influencing crop yield, quality and overall productivity. The availability of nitrogen in the soil, measured in kilograms per hectare (kg ha^{-1}) after the conclusion of an experiment, serves as a vital indicator of soil fertility and nutrient cycling. This metric reflects the residual nitrogen available for plant uptake, which significantly impacts the growth and success of subsequent crops, highlighting its importance in sustainable agricultural practices.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, combined with the pooled results, highlights notable differences in the available N (kg ha^{-1}) content in soil across the treatments, as illustrated in Table 4.4.4.1.

During the first year 2022-2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for available nitrogen (kg ha^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower available N (293.18 kg ha^{-1}) content in soil, while the hybrid Orobelle (H_2) recorded a statistically higher available N (297.19 kg ha^{-1}) content in soil. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available N (290.39 kg ha^{-1}) content in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available N (301.28 kg ha^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available N (290.25 kg ha^{-1}) content in soil was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %, treatment combination H_1M_1 : Indam Mamatha + Boric acid 0.5 % and treatment combination H_1M_2 : Indam Mamatha + Zinc sulphate 0.5 % with values of 290.42, 290.53 and 290.88 kg ha^{-1}. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum available N (301.35 kg ha^{-1}) content in soil.

During the second year 2023-2024, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for available nitrogen (kg ha^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower available N (297.37 kg ha^{-1}) content in soil, while the hybrid Orobelle (H_2) recorded a statistically higher available N (299.69 kg ha^{-1}) content in soil. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available N (295.27 kg ha^{-1}) content in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available N (301.49 kg ha^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available N (295.15 kg ha^{-1}) content in soil was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % and treatment combination H_1M_1 : Indam Mamatha + Boric acid 0.5 % with values of 295.20 and 295.40 kg ha^{-1}. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum available N (301.60 kg ha^{-1}) content in soil.

The pooled data from both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for available nitrogen (kg ha^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower available N (295.27 kg ha^{-1}) content in soil, while the hybrid Orobelle (H_2) recorded a statistically higher available N (298.44 kg ha^{-1}) content in soil. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available N (292.83 kg ha^{-1}) content in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available N (301.38 kg ha^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available N (292.70 kg ha^{-1}) content in soil was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % and treatment combination H_1M_1 : Indam Mamatha + Boric acid 0.5 % with values of 292.81 and 292.97 kg ha^{-1}. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum available N (301.48 kg ha^{-1}) content in soil.

The significant variations in available nitrogen (N) content in soil across treatments highlight the influence of coloured capsicum hybrids and foliar nutrient applications on soil nutrient dynamics. The observed reduction in available N content in treatments receiving foliar applications of boric acid, zinc sulphate and calcium chloride suggests enhanced nitrogen uptake by plants, leading to improved utilization of soil nitrogen for growth and development. This aligns with the findings of Jagtap et al. (2016) in cabbage and Thingujam et al. (2016) in brinjal, where nutrient application positively influenced nitrogen absorption and utilization.

The treatment combination H_1M_7 consistently recorded the lowest available N content in soil across both years and pooled data. This suggests that the hybrid “Indam Mamatha” demonstrated a higher nitrogen uptake efficiency under foliar nutrient application. The enhanced nitrogen uptake can be attributed to the role of zinc in promoting root growth and enzymatic activity, thereby facilitating better nitrogen absorption (Jagtap et al. 2016). Additionally, boron and calcium play critical roles in nitrogen metabolism and cell wall integrity, which may have contributed to improved nutrient assimilation and translocation.

Table 4.4.4.1: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on available N

Treatments	Available N (kg ha^{-1})		
	2022-2023	**2023-2024**	**Pooled**
H_1	293.18	297.37	295.27
H_2	297.19	299.69	298.44
Mean	**295.19**	**298.53**	**296.86**
SE (m)±	**0.09**	**0.03**	**0.05**
$CD_{0.05}$	**0.27**	**0.10**	**0.14**
M_1	293.28	297.13	295.20
M_2	293.89	297.95	295.92
M_3	294.56	298.28	296.42
M_4	295.42	298.69	297.05
M_5	296.09	299.40	297.75
M_6	296.58	300.03	298.30
M_7	290.39	295.27	292.83
M_8	301.28	301.49	301.38
Mean	**295.19**	**298.53**	**296.86**
SE (m)±	**0.19**	**0.06**	**0.10**
$CD_{0.05}$	**0.55**	**0.20**	**0.28**
Interaction:			
H_1M_1	290.53	295.40	292.97
H_1M_2	290.88	296.12	293.50
H_1M_3	292.02	296.50	294.26
H_1M_4	292.83	297.50	295.17
H_1M_5	293.60	298.12	295.86
H_1M_6	294.10	298.75	296.43
H_1M_7	290.25	295.15	292.70
H_1M_8	301.20	301.37	301.28
H_2M_1	296.15	299.05	297.60
H_2M_2	296.90	299.78	298.34
H_2M_3	297.10	300.05	298.58
H_2M_4	298.00	299.88	298.94
H_2M_5	298.58	300.68	299.63
H_2M_6	299.05	301.30	300.18
H_2M_7	290.42	295.20	292.81
H_2M_8	301.35	301.60	301.48
Mean	**295.19**	**298.53**	**296.86**
SE (m)±	**0.27**	**0.09**	**0.14**
$CD_{0.05}$	**0.78**	**0.29**	**0.40**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1** - Boric acid 0.5 %; **M_2** - Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8** - Control (No spray)

Conversely, the control treatment recorded the highest available N content in soil across all hybrids and years, indicating lower nitrogen uptake by plants in the absence of foliar nutrient supplementation. This underscores the role of foliar-applied nutrients in enhancing nitrogen assimilation, as observed in previous studies (Thingujam et al. 2016). The reduced nitrogen uptake in untreated plants may have resulted in suboptimal growth and biomass accumulation, further emphasizing the necessity of balanced foliar nutrition.

The polyhouse environment, characterized by controlled irrigation and minimal nutrient leaching, likely contributed to the observed trends in soil nitrogen availability. The regulation of external environmental factors ensured efficient nutrient uptake while minimizing losses, thereby maintaining soil fertility over time. This controlled setting facilitated a direct impact of foliar nutrient application on plant nutrient dynamics, reinforcing the importance of nutrient supplementation in protected cultivation systems.

Overall, the findings highlight the significance of integrating foliar nutrient applications with appropriate hybrid selection to optimize nitrogen utilization in capsicum cultivation. The superior performance of treatment combinations involving foliar-applied boric acid, zinc sulphate and calcium chloride underscores their role in promoting efficient nutrient uptake, thereby reducing residual soil nitrogen and enhancing overall crop productivity.

4.4.4.2 Available P (kg ha^{-1}) content in soil after termination of experiment

Phosphorus (P) is a vital macronutrient that plays a critical role in plant growth and development. It is a key component of energy transfer molecules such as ATP, nucleic acids and phospholipids, which are essential for cell division, root development and overall metabolic activities. The availability of phosphorus in the soil, measured in terms of available phosphorus content (kg ha^{-1}), is a significant indicator of soil fertility and nutrient management efficiency. The phosphorus availability directly affects crop yield and quality, as it supports the formation of strong root systems, enhances flowering and fruiting and contributes to disease resistance.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, combined with the pooled results, highlights notable differences in the available P (kg ha^{-1}) content in soil across the treatments, as illustrated in Table 4.4.4.2.

During the first year 2022-2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for available phosphorus (kg ha^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower available P (48.76 kg ha^{-1}) content in soil, while the hybrid Orobelle (H_2) recorded a statistically higher available P (50.79 kg ha^{-1}) content in soil. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available P (46.43 kg ha^{-1}) content in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available P (52.42 kg ha^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available P (46.31 kg ha^{-1}) content in soil was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (46.55 kg ha^{-1}) with treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum available P (52.50 kg ha^{-1}) content in soil.

During the second year 2022-2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for available phosphorus (kg ha^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower available P (49.55 kg ha^{-1}) content in soil, while the hybrid Orobelle (H_2) recorded a statistically higher available P (51.04 kg ha^{-1}) content in soil. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available P (48.59 kg ha^{-1}) content in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available P (53.04 kg ha^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available P (48.56 kg ha^{-1}) content in soil was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_1M_1 (48.56 kg ha^{-1}), H_2M_7 (48.62 kg ha^{-1}), H_1M_2 (48.80 kg ha^{-1}), H_1M_3 (49.04 kg ha^{-1}) and H_1M_4 (49.28 kg ha^{-1}). The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum available P (53.18 kg ha^{-1}) content in soil.

The pooled analysis for both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for available phosphorus (kg ha^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower available P (49.16 kg ha^{-1}) content in soil, while the hybrid Orobelle (H_2) recorded a statistically higher available P (50.91 kg ha^{-1}) content in soil. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available P (47.51 kg ha^{-1}) content in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available P (52.73 kg ha^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available P (47.43 kg ha^{-1}) content in soil was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (47.59 kg ha^{-1}) with treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum available P (52.76 kg ha^{-1}) content in soil.

The significant variations in available phosphorus (P) content in soil across treatments highlight the influence of coloured capsicum hybrids and foliar nutrient applications on soil nutrient dynamics. The observed reduction in available P content in treatments receiving foliar applications of boric acid, zinc sulphate and calcium chloride suggests enhanced phosphorus uptake by plants, leading to improved utilization of soil phosphorus for growth and development. This aligns with the findings of Jagtap et al. (2016) in cabbage and Thingujam et al. (2016) in brinjal, where nutrient application positively influenced phosphorus absorption and utilization.

The treatment combination H_1M_7 consistently recorded the lowest available P content in soil across both years and pooled data. This suggests that the hybrid “Indam Mamatha” demonstrated a higher phosphorus uptake efficiency under foliar nutrient application. The enhanced phosphorus uptake can be attributed to the role of zinc in promoting root growth and enzymatic activity, thereby facilitating better phosphorus absorption (Jagtap et al. 2016). Additionally, boron and calcium play critical roles in phosphorus metabolism and cell wall integrity, which may have contributed to improved nutrient assimilation and translocation.

Table 4.4.4.2: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on available P

Treatments	**Available P (kg ha^{-1})**		
	2022-2023	**2023-2024**	**Pooled**
H_1	48.76	49.55	49.16
H_2	50.79	51.04	50.91
Mean	**49.78**	**50.29**	**50.03**
SE (m)±	**0.10**	**0.10**	**0.07**
$CD_{0.05}$	**0.28**	**0.29**	**0.20**
M_1	49.25	49.52	49.39
M_2	49.01	49.76	49.38
M_3	49.46	50.00	49.73
M_4	49.98	50.24	50.11
M_5	50.68	50.48	50.58
M_6	50.98	50.72	50.85
M_7	46.43	48.59	47.51
M_8	52.42	53.04	52.73
Mean	**49.78**	**50.29**	**50.03**
SE (m)±	**0.20**	**0.20**	**0.14**
$CD_{0.05}$	**0.81**	**0.58**	**0.40**
Interaction:			
H_1M_1	48.45	48.56	48.51
H_1M_2	47.22	48.80	48.01
H_1M_3	47.87	49.04	48.45
H_1M_4	48.52	49.28	48.90
H_1M_5	49.47	49.52	49.49
H_1M_6	49.77	49.76	49.76
H_1M_7	46.31	48.56	47.43
H_1M_8	52.33	52.90	52.70
H_2M_1	50.05	50.48	50.27
H_2M_2	50.80	50.72	50.76
H_2M_3	51.05	50.96	51.01
H_2M_4	51.45	51.20	51.33
H_2M_5	51.88	51.44	51.66
H_2M_6	52.20	51.68	51.94
H_2M_7	46.55	48.62	**47.59**
H_2M_8	52.50	53.18	52.76
Mean	**49.78**	**50.29**	**50.03**
SE (m)±	**0.28**	**0.28**	**0.20**
$CD_{0.05}$	**0.81**	**0.82**	**0.57**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1** - Boric acid 0.5 %; **M_2** - Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8** - Control (No spray)

Conversely, the control treatment recorded the highest available P content in soil across all hybrids and years, indicating lower phosphorus uptake by plants in the absence of foliar nutrient supplementation. This underscores the role of foliar-applied nutrients in enhancing phosphorus assimilation, as observed in previous studies (Thingujam et al. 2016). The reduced phosphorus uptake in untreated plants may have resulted in suboptimal growth and biomass accumulation, further emphasizing the necessity of balanced foliar nutrition.

Phosphorus plays a crucial role in plant growth, particularly in energy transfer, root development and metabolic activities. The observed decline in available phosphorus in treatments with higher nutrient uptake can be attributed to the synergistic effects of micronutrients such as zinc and boron. Zinc enhances phosphorus absorption by plants through its involvement in root proliferation and enzymatic activities, while boron supports the formation of strong root systems, increasing phosphorus availability in the rhizosphere.

The slightly higher available phosphorus content in the second year compared to the first year may be attributed to improved nutrient cycling and decomposition of organic matter, which released bound phosphorus into plant-available forms. Additionally, the controlled environmental conditions in the polyhouse minimized phosphorus losses due to leaching or runoff, ensuring its availability for plant uptake. These findings align with studies by Jagtap et al. (2016) in cabbage and Thingujam et al. (2016) in brinjal, which reported enhanced nutrient uptake and better utilization efficiency under nutrient-enriched treatments.

Foliar applications of boric acid, zinc sulphate and calcium chloride likely played a significant role in maintaining soil phosphorus levels by reducing the dependence on soil-applied fertilizers. Foliar feeding supplements plant nutrient requirements directly through leaf absorption, minimizing phosphorus withdrawal from the soil. The polyhouse environment, characterized by controlled irrigation and minimal nutrient leaching, likely contributed to the observed trends in soil phosphorus availability. The regulation of external environmental factors ensured efficient nutrient uptake while minimizing losses, thereby maintaining soil fertility over time.

4.4.4.3 Available K (kg ha^{-1}) content in soil after termination of experiment

Potassium (K) is an essential macronutrient that plays a vital role in plant growth, productivity and overall health. It is involved in several physiological and biochemical processes, including enzyme activation, protein synthesis, photosynthesis and the regulation of water balance within the plant. Potassium also enhances the plant’s tolerance to biotic and abiotic stresses, such as pests, diseases, drought and salinity.

The availability of potassium in the soil, expressed as available K (kg ha^{-1}), is a critical indicator of soil fertility and nutrient cycling. It represents the portion of potassium that is readily available for plant uptake, significantly influencing crop yield and quality.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, combined with the pooled results, highlights notable differences in the available K (kg ha^{-1}) content in soil across the treatments, as illustrated in Table 4.4.4.3.

During the first year 2022-2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for available potassium (kg ha^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower available K (342.84 kg ha^{-1}) content in soil, while the hybrid Orobelle (H_2) recorded a statistically higher available K (357.51 kg ha^{-1}) content in soil. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available K (332.18 kg ha^{-1}) content in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available K (370.82 kg ha^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available K (332.16 kg ha^{-1}) content in soil was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_2M_7 (332.17 kg ha^{-1}) and H_1M_1 (332.20 kg ha^{-1}).The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum available K (372.82 kg ha^{-1}) content in soil.

During the second year 2023-2024, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for available potassium (kg ha^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower available K (383.95 kg ha^{-1}) content in soil, while the hybrid Orobelle (H_2) recorded a statistically higher available K (389.51 kg ha^{-1}) content in soil. In terms of foliar nutrient applications, the combined foliar application of M_7 :

Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available K (372.38 kg ha^{-1}) content in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available K (400.45 kg ha^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available K (372.22 kg ha^{-1}) content in soil was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination: H_2M_7 (372.54 kg ha^{-1}), H_2M_5 (376.80 kg ha^{-1}), H_1M_2 (379.07 kg ha^{-1}), H_1M_1 (379.67 kg ha^{-1}) and H_2M_6 (380.03 kg ha^{-1}).The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum available K (401.20 kg ha^{-1}) content in soil.

The pooled data for both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for available potassium (kg ha^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower available K (363.39 kg ha^{-1}) content in soil, while the hybrid Orobelle (H_2) recorded a statistically higher available K (373.51 kg ha^{-1}) content in soil. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available K (352.28 kg ha^{-1}) content in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available K (385.63 kg ha^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available K (352.19 kg ha^{-1}) content in soil was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_2M_7 (352.37 kg ha^{-1}) and H_1M_1 (355.91 kg ha^{-1}).The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum available K (386.26 kg ha^{-1}) content in soil.

The significant variations in available potassium (K) content in soil across treatments highlight the influence of coloured capsicum hybrids and foliar nutrient applications on soil

Table 4.4.4.3: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on available K

Treatments	**Available K (kg ha^{-1})**		
	2022-2023	**2023-2024**	**Pooled**
H_1	342.84	383.95	363.39
H_2	357.51	389.51	373.51
Mean	**350.17**	**386.73**	**368.45**
SE (m)±	**0.25**	**1.00**	**0.51**
$CD_{0.05}$	**0.75**	**2.91**	**1.46**
M_1	341.84	386.65	364.24
M_2	344.90	387.51	366.21
M_3	347.96	391.84	369.90
M_4	352.47	390.26	371.36
M_5	354.08	380.72	367.40
M_6	357.14	384.00	370.57
M_7	332.18	372.38	352.28
M_8	370.82	400.45	385.63
Mean	**350.17**	**386.73**	**368.45**
SE (m)±	**0.51**	**2.00**	**1.03**
$CD_{0.05}$	**1.50**	**5.82**	**2.93**
Interaction:			
H_1M_1	332.20	379.67	355.91
H_1M_2	335.22	379.07	357.14
H_1M_3	338.28	385.39	361.83
H_1M_4	344.23	381.41	362.82
H_1M_5	344.40	384.64	364.52
H_1M_6	347.46	387.97	367.72
H_1M_7	332.16	372.22	352.19
H_1M_8	368.82	399.70	385.01
H_2M_1	351.52	393.63	372.58
H_2M_2	354.58	395.96	375.27
H_2M_3	357.64	398.30	377.97
H_2M_4	360.70	399.10	379.90
H_2M_5	363.76	376.80	370.28
H_2M_6	366.82	380.03	373.43
H_2M_7	332.17	372.54	352.37
H_2M_8	372.82	401.20	386.26
Mean	**350.17**	**386.73**	**368.45**
SE (m)±	**0.73**	**2.83**	**1.46**
$CD_{0.05}$	**2.12**	**8.23**	**4.15**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1** - Boric acid 0.5 %; **M_2** - Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8** - Control (No spray)

nutrient dynamics. The observed reduction in available K content in treatments receiving foliar applications of boric acid, zinc sulphate and calcium chloride suggests enhanced potassium uptake by plants, leading to improved utilization of soil potassium for physiological functions. This aligns with the findings of Jagtap et al. (2016) in cabbage and Thingujam et al. (2016) in brinjal, where nutrient application positively influenced potassium absorption and utilization.

The treatment combination H_1M_7 consistently recorded the lowest available K content in soil across both years and pooled data. This suggests that the hybrid “Indam Mamatha” demonstrated a higher potassium uptake efficiency under foliar nutrient application. The enhanced potassium uptake can be attributed to the role of zinc in promoting root growth and enzymatic activity, thereby facilitating better potassium absorption (Jagtap et al. 2016). Additionally, boron and calcium play critical roles in potassium metabolism and cell wall integrity, which may have contributed to improved nutrient assimilation and translocation. Conversely, the control treatment recorded the highest available K content in soil across all hybrids and years, indicating lower potassium uptake by plants in the absence of foliar nutrient supplementation. This underscores the role of foliar-applied nutrients in enhancing potassium assimilation, as observed in previous studies (Thingujam et al. 2016). The reduced potassium uptake in untreated plants may have resulted in suboptimal growth and biomass accumulation, further emphasizing the necessity of balanced foliar nutrition.

Potassium plays a crucial role in plant growth, particularly in enzyme activation, photosynthetic efficiency and osmotic balance. The observed decline in available potassium in treatments with higher nutrient uptake can be attributed to the synergistic effects of micronutrients such as zinc and boron. Zinc enhances potassium absorption by plants through its involvement in root proliferation and enzymatic activities, while boron supports the formation of strong root systems, increasing potassium availability in the rhizosphere. Additionally, calcium facilitates cell membrane stability and ion transport, further enhancing potassium uptake and utilization.

The slightly higher available potassium content in the second year compared to the first year may be attributed to improved nutrient cycling and decomposition of organic matter, which released bound potassium into plant-available forms. Additionally, the controlled environmental conditions in the polyhouse minimized potassium losses due to leaching or runoff, ensuring its availability for plant uptake. These findings align with studies by Jagtap et al. (2016) in cabbage and Thingujam et al. (2016) in brinjal, which reported enhanced nutrient uptake and better utilization efficiency under nutrient-enriched treatments.

Foliar applications of boric acid, zinc sulphate and calcium chloride likely played a significant role in maintaining soil potassium levels by reducing the dependence on soil-applied fertilizers. Foliar feeding supplements plant nutrient requirements directly through leaf absorption, minimizing potassium withdrawal from the soil. The polyhouse environment, characterized by controlled irrigation and minimal nutrient leaching, likely contributed to the observed trends in soil potassium availability. The regulation of external environmental factors ensured efficient nutrient uptake while minimizing losses, thereby maintaining soil fertility over time. The consistent results across years and pooled data emphasize the importance of balanced nutrient management in optimizing potassium availability and utilization in capsicum production.

4.4.5 Available B, Zn and Ca content in soil before planting and after termination of experiment (mg kg^{-1})

4.4.5.1 Available B (mg kg^{-1}) content in soil after termination of experiment

Boron (B) is an essential nutrient required for plant growth and development. It plays a critical role in various physiological and biochemical processes, including cell wall synthesis, membrane integrity, sugar transport and reproductive development. The availability of boron in soil significantly influences crop productivity, as its deficiency or excess can negatively affect plant growth and yield. Boron availability in the soil is governed by several factors, including soil pH, organic matter content and environmental conditions.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, combined with the pooled results, highlights notable differences in the available B (mg kg^{-1}) content in soil across the treatments, as illustrated in Table 4.4.5.1.

During the first year 2022-2023, the effect of coloured capsicum hybrids was non-significant whereas the effect of foliar nutrient applications and their interactions was significant for available boron (mg kg^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded an available B content of 0.264 mg kg^{-1} in soil, while the hybrid Orobelle (H_2) recorded 0.273 mg kg^{-1}, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available B (0.228 mg kg^{-1}) in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available B (0.320 mg kg^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available B (0.222 mg kg^{-1}) content in soil was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_2M_7 (0.235 mg kg^{-1}) and H_1M_1 (0.246 mg kg^{-1}).The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the maximum available B (0.343 mg kg^{-1}) content in soil.

During the second year 2023-2024, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for available boron (mg kg^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower available B (0.214 mg kg^{-1}) content in soil, while the hybrid Orobelle (H_2) recorded a statistically higher available B (0.225 mg kg^{-1}) content in soil. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available B (0.191 mg kg^{-1}) in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available B (0.265 mg kg^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available B (0.189 mg kg^{-1}) content in soil was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_1M_7 (0.192 mg kg^{-1}), H_2M_5 (0.197 mg kg^{-1}) and H_1M_1 (0.198 mg kg^{-1}). The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the maximum available B (0.272 mg kg^{-1}) content in soil.

The pooled analysis of both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for available boron (mg kg^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower available B (0.239 mg kg^{-1}) content in soil, while the hybrid Orobelle (H_2) recorded a statistically higher available B (0.249 mg kg^{-1}) content in soil.

Table 4.4.5.1: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on available B

Treatments	**Available B (mg kg^{-1})**		
	2022-2023	**2023-2024**	**Pooled**
H_1	0.264	0.214	0.239
H_2	0.273	0.225	0.249
Mean	**0.269**	**0.220**	**0.244**
SE (m)±	**0.003**	**0.001**	**0.002**
$CD_{0.05}$	**NS**	**0.004**	**0.005**
M_1	0.262	0.212	0.237
M_2	0.267	0.218	0.242
M_3	0.272	0.223	0.247
M_4	0.276	0.228	0.252
M_5	0.259	0.208	0.234
M_6	0.264	0.213	0.238
M_7	0.228	0.191	0.210
M_8	0.320	0.265	0.292
Mean	**0.269**	**0.220**	**0.244**
SE (m)±	**0.007**	**0.003**	**0.004**
$CD_{0.05}$	**0.021**	**0.008**	**0.011**
Interaction:			
H_1M_1	0.246	0.198	0.222
H_1M_2	0.251	0.204	0.227
H_1M_3	0.257	0.208	0.232
H_1M_4	0.261	0.213	0.237
H_1M_5	0.265	0.218	0.241
H_1M_6	0.269	0.223	0.246
H_1M_7	0.222	0.192	0.207
H_1M_8	0.343	0.257	0.300
H_2M_1	0.278	0.227	0.253
H_2M_2	0.282	0.233	0.258
H_2M_3	0.286	0.238	0.262
H_2M_4	0.290	0.243	0.266
H_2M_5	0.254	0.197	0.226
H_2M_6	0.259	0.203	0.231
H_2M_7	0.235	0.189	0.212
H_2M_8	0.297	0.272	0.285
Mean	**0.268**	**0.220**	**0.244**
SE (m)±	**0.011**	**0.004**	**0.005**
$CD_{0.05}$	**0.028**	**0.011**	**0.015**

H_1 - Indam Mamatha; **H_2** - Orobelle

***M_1* -** Boric acid 0.5 %; **M_2 -** Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8 -** Control (No spray)

In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available B (0.210 mg kg^{-1}) in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available B (0.292 mg kg^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available B (0.207 mg kg^{-1}) content in soil was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_2M_7 (0.212 mg kg^{-1}) and H_1M_1 (0.222 mg kg^{-1}). The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the maximum available B (0.300 mg kg^{-1}) content in soil.

The significant variations in available boron (B) content in soil across treatments highlight the influence of coloured capsicum hybrids and foliar nutrient applications on boron dynamics. The observed reduction in available B content in treatments receiving foliar applications of boric acid, zinc sulphate and calcium chloride suggests enhanced boron uptake by plants, leading to improved utilization of soil boron for physiological functions. This aligns with the findings of Singh (2024) in sweet Banana pepper, where foliar application of boron resulted in higher plant absorption and a decline in residual soil boron content.

The treatment combination H_1M_7 consistently recorded the lowest available B content in soil across both years and pooled data. This suggests that the hybrid “Indam Mamatha” demonstrated a higher boron uptake efficiency under foliar nutrient application. The enhanced boron uptake can be attributed to its critical role in cell division, cell wall formation and reproductive development, leading to increased metabolic demand (Singh 2024). Additionally, zinc and calcium play crucial roles in boron metabolism and translocation, which may have contributed to improved nutrient assimilation. Conversely, the control treatment recorded the highest available B content in soil across all hybrids and years, indicating lower boron uptake by plants in the absence of foliar nutrient supplementation. This supports the hypothesis that foliar application enhances boron bioavailability for direct plant uptake, reducing its residual concentration in soil (Singh 2024).

Boron plays a crucial role in plant growth, particularly in pollen germination, carbohydrate metabolism and cell wall integrity. The observed decline in available boron in treatments with higher nutrient uptake can be attributed to the synergistic effects of nutrients such as zinc and calcium. Zinc enhances boron absorption through its involvement in root proliferation and enzymatic activities, while calcium supports membrane stability and boron transport within plant tissues (Jagtap et al. 2016). Additionally, calcium aids in the mobility of boron in plant systems, ensuring its efficient utilization for metabolic processes.

The higher residual boron content recorded in the first year compared to the second year may be attributed to environmental variations such as temperature, which influence boron leaching and retention in soil. This corroborates the findings of Jagtap et al. (2016) in cabbage, where seasonal conditions significantly impacted boron availability. The polyhouse environment, characterized by controlled irrigation and minimal nutrient leaching, likely contributed to the observed trends in soil boron availability.

Foliar applications of boric acid, zinc sulphate and calcium chloride likely played a significant role in maintaining soil boron levels by reducing the dependence on soil-applied fertilizers. Foliar feeding ensures direct nutrient absorption through leaves, minimizing boron withdrawal from the soil. The controlled polyhouse conditions minimized nutrient losses due to leaching or volatilization, ensuring boron availability for plant uptake. The consistent results across years and pooled data emphasize the importance of balanced nutrient management in optimizing boron availability and utilization in capsicum production.

4.4.5.2 Available Zn (mg kg^{-1}) content in soil after termination of experiment

Zinc (Zn) is an essential nutrient for plant growth and development, playing a critical role in enzymatic activities, protein synthesis and hormonal regulation. It is a vital component of several enzymes and proteins involved in photosynthesis, carbohydrate metabolism and the synthesis of growth-regulating substances like auxins. The availability of zinc in soil, typically measured in mg kg^{-1}, serves as an indicator of the soil's capacity to supply this nutrient to plants. Factors such as soil pH, organic matter content and interactions with other nutrients influence zinc availability.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, combined with the pooled results, highlights notable differences in the available Zn (mg kg^{-1}) content in soil across the treatments, as illustrated in Table 4.4.5.2.

In the first year 2022–2023, the effect of coloured capsicum hybrids on available Zn (mg kg^{-1}) content in soil was non-significant, while foliar nutrient applications had a significant effect. However, the interaction between coloured capsicum hybrids and foliar nutrient applications was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded an available Zn content of 2.51 mg kg^{-1} in soil, while the hybrid Orobelle (H_2) recorded 2.52 mg kg^{-1}, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available Zn (2.17 mg kg^{-1}) in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available Zn (3.12 mg kg^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with values ranging from 2.14 to 3.19 mg kg^{-1}.

In the second year 2023–2024, the effect of coloured capsicum hybrids on available Zn (mg kg^{-1}) content in soil was non-significant, while foliar nutrient applications had a significant effect. However, the interaction between coloured capsicum hybrids and foliar nutrient applications was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded an available Zn content of 2.64 mg kg^{-1} in soil, while the hybrid Orobelle (H_2) recorded 2.74 mg kg^{-1}, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available Zn (2.30 mg kg^{-1}) in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available Zn (3.80 mg kg^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with values ranging from 2.17 to 3.86 mg kg^{-1}.

The pooled data for both the years revealed that the effect of coloured capsicum hybrids on available Zn (mg kg^{-1}) content in soil was non-significant, while foliar nutrient applications had a significant effect. However, the interaction between coloured capsicum hybrids and foliar nutrient applications was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded an available Zn content of 2.58 mg kg^{-1} in soil, while the hybrid Orobelle (H_2) recorded 2.63 mg kg^{-1}, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar

Table 4.4.5.2: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on available Zn

Treatments	**Available Zn (mg kg^{-1})**		
	2022-2023	**2023-2024**	**Pooled**
H_1	2.51	2.64	2.58
H_2	2.52	2.74	2.63
Mean	**2.51**	**2.69**	**2.60**
SE (m)±	**0.03**	**0.06**	**0.03**
$CD_{0.05}$	**NS**	**NS**	**NS**
M_1	2.42	2.61	2.52
M_2	2.53	2.52	2.52
M_3	2.56	2.61	2.59
M_4	2.50	2.65	2.57
M_5	2.44	2.58	2.51
M_6	2.37	2.48	2.42
M_7	2.17	2.30	2.23
M_8	3.12	3.80	3.46
Mean	**2.51**	**2.69**	**2.60**
SE (m)±	**0.07**	**0.12**	**0.07**
$CD_{0.05}$	**0.21**	**0.36**	**0.20**
Interaction:			
H_1M_1	2.40	2.70	2.55
H_1M_2	2.45	2.47	2.46
H_1M_3	2.45	2.59	2.52
H_1M_4	2.44	2.62	2.53
H_1M_5	2.57	2.78	2.68
H_1M_6	2.40	2.50	2.45
H_1M_7	2.20	2.42	2.31
H_1M_8	3.19	3.86	3.52
H_2M_1	2.44	2.52	2.48
H_2M_2	2.61	2.57	2.59
H_2M_3	2.68	2.62	2.65
H_2M_4	2.56	2.67	2.62
H_2M_5	2.30	2.39	2.35
H_2M_6	2.34	2.45	2.40
H_2M_7	2.14	2.17	2.16
H_2M_8	3.05	3.74	3.40
Mean	**2.51**	**2.69**	**2.60**
SE (m)±	**0.10**	**0.17**	**0.10**
$CD_{0.05}$	**NS**	**NS**	**NS**

*H_1 - Indam Mamatha; H_2 - Orobelle

*M_1 - Boric acid 0.5 %; M_2 - Zinc sulphate 0.5 %; M_3 - Calcium chloride 0.5 %; M_4 - Boric acid 0.5 % + Zinc sulphate 0.5%; M_5 - Boric acid 0.5 % + Calcium chloride 0.5 %; M_6 - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_7 - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_8 - Control (No spray)

application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available Zn (2.23 mg kg^{-1}) in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available Zn (3.46 mg kg^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with values ranging from 2.16 to 3.52 mg kg^{-1}.

The significant variations in available zinc (Zn) content in soil across treatments highlight the influence of foliar nutrient applications on soil Zn dynamics. The observed reduction in available Zn content in treatments receiving foliar applications of boric acid, zinc sulphate and calcium chloride suggests enhanced Zn uptake by plants, leading to improved utilization of soil Zn for physiological functions.

The treatment combination M_7 consistently recorded the lowest available Zn content in soil across both years and pooled data. This suggests that the combined foliar application of boric acid, zinc sulphate and calcium chloride effectively enhanced Zn uptake by plants. The enhanced Zn absorption can be attributed to its critical role in enzymatic activity, protein synthesis and auxin production, which contribute to enhanced growth and yield (Singh 2024). Additionally, boron and calcium play essential roles in Zn metabolism and translocation, which may have contributed to improved nutrient assimilation and utilization. Conversely, the control treatment recorded the highest available Zn content in soil across all hybrids and years, indicating lower Zn uptake by plants in the absence of foliar nutrient supplementation. This supports the hypothesis that foliar application enhances Zn bioavailability for direct plant uptake, reducing its residual concentration in the soil (Gondal et al. 2023).

Zinc is crucial for various plant physiological processes, including enzymatic reactions, chlorophyll production and reproductive development. The observed decline in available Zn in treatments with higher nutrient uptake can be attributed to the synergistic effects of nutrients such as boron and calcium. Boron aids in cell wall formation and membrane stability, facilitating Zn translocation within plant tissues, while calcium supports root proliferation and enzymatic activity, further enhancing Zn absorption (Jagtap et al. 2016). The results align with studies by Gondal et al. (2023), which reported increased Zn uptake efficiency and improved crop productivity with foliar Zn supplementation.

The increase in available Zn content from the first year to the second year indicates a potential improvement in soil Zn levels due to residual effects or enhanced microbial activity aiding Zn solubilization. Seasonal variations in environmental conditions, such as temperature and soil moisture, may have influenced Zn retention and availability, corroborating the findings of Jagtap et al. (2016) in cabbage. The controlled polyhouse conditions, characterized by minimal nutrient leaching, likely contributed to the observed trends in soil Zn availability.

Foliar applications of boric acid, zinc sulphate and calcium chloride likely played a significant role in maintaining soil Zn levels by reducing the dependence on soil-applied fertilizers. Foliar feeding ensures direct nutrient absorption through leaves, minimizing Zn withdrawal from the soil. The consistent results across years and pooled data emphasize the importance of balanced nutrient management in optimizing Zn availability and utilization in capsicum production.

4.4.5.3 Available Ca (mg kg^{-1}) content in soil after termination of experiment

Calcium (Ca) is a critical secondary macronutrient that plays a pivotal role in maintaining soil structure, plant cell wall integrity and overall plant health. It is a vital component of the soil cation exchange complex, influencing soil pH and nutrient availability. Calcium contributes significantly to root development, enzymatic activities and the mitigation of physiological disorders like blossom-end rot in crops. The availability of Ca in the soil is influenced by factors such as soil pH, organic matter content and the type of fertilizers or amendments applied.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, combined with the pooled results, highlights notable differences in the available Ca (mg kg^{-1}) content in soil across the treatments, as illustrated in Table 4.4.5.3.

During the first year 2022-2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for available calcium (mg kg^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower available Ca (138.58 mg kg^{-1}) content in soil, while the hybrid Orobelle (H_2) recorded a statistically higher available Ca (143.23 mg kg^{-1}) content in soil. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available Ca (130.05 mg kg^{-1}) in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available B (149.64 mg kg^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available Ca (128.05 mg kg^{-1}) content in soil was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (132.05 mg kg^{-1}) with treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the maximum available Ca (150.43 mg kg^{-1}) content in soil.

In the second year 2023–2024, the effect of coloured capsicum hybrids on available Ca (mg kg^{-1}) content in soil was non-significant, while foliar nutrient applications had a significant effect. However, the interaction between coloured capsicum hybrids and foliar nutrient applications was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded an available Ca content of 146.46 mg kg^{-1} in soil, while the hybrid Indam Mamatha (H_1) recorded 147.49 mg kg^{-1}, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available Ca (139.41 mg kg^{-1}) in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available B (151.93 mg kg^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with values ranging from 135.22 to 152.93 mg kg^{-1}.

The pooled data for both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for available calcium (mg kg^{-1}) content in soil. Regarding the effect of coloured capsicum hybrids, the hybrid Indam Mamatha (H_1) recorded a statistically lower available Ca (143.03 mg kg^{-1}) content in soil, while the hybrid Orobelle (H_2) recorded a statistically higher available Ca (144.85 mg kg^{-1}) content in soil. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the minimum available Ca (134.73 mg kg^{-1}) in soil. The control treatment (M_8), with no foliar nutrient application, recorded the maximum available B (150.79 mg kg^{-1}) content in soil.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the minimum available Ca (134.33 mg kg^{-1}) content in soil was

Table 4.4.5.3: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on available Ca

Treatments	Available Ca (mg kg^{-1})		
	2022-2023	2023-2024	Pooled
H_1	138.58	147.49	143.03
H_2	143.23	146.46	144.85
Mean	**140.91**	**146.97**	**143.94**
SE (m)±	**0.51**	**0.71**	**0.44**
$CD_{0.05}$	**1.50**	**NS**	**1.25**
M_1	139.43	145.52	142.47
M_2	141.81	145.21	143.51
M_3	142.84	147.72	145.28
M_4	143.78	150.31	147.04
M_5	138.80	147.05	142.93
M_6	140.90	148.65	144.78
M_7	130.05	139.41	134.73
M_8	149.64	151.93	150.79
Mean	**140.91**	**146.97**	**143.94**
SE (m)±	**1.03**	**1.42**	**0.88**
$CD_{0.05}$	**3.00**	**4.14**	**2.50**
Interaction:			
H_1M_1	134.75	143.78	139.27
H_1M_2	136.18	145.17	140.68
H_1M_3	137.58	147.23	142.41
H_1M_4	138.45	149.97	144.21
H_1M_5	140.55	149.05	144.80
H_1M_6	142.65	151.15	146.90
H_1M_7	128.05	140.60	134.33
H_1M_8	150.43	152.93	151.68
H_2M_1	144.10	147.25	145.68
H_2M_2	147.43	145.25	146.34
H_2M_3	148.10	148.20	148.15
H_2M_4	149.10	150.65	149.88
H_2M_5	137.05	145.05	141.05
H_2M_6	139.15	146.15	142.65
H_2M_7	132.05	138.22	135.13
H_2M_8	148.85	150.93	149.89
Mean	**140.91**	**146.97**	**143.94**
SE (m)±	**1.46**	**2.02**	**1.25**
$CD_{0.05}$	**4.24**	**NS**	**3.54**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1** - Boric acid 0.5 %; **M_2** - Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8** - Control (No spray)

recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (135.13 mg kg^{-1}) with treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the maximum available Ca (151.68 mg kg^{-1}) content in soil.

The significant variations in available calcium (Ca) content in soil across treatments underscore the influence of coloured capsicum hybrids and foliar nutrient applications on calcium dynamics. The observed reduction in available Ca content in treatments receiving foliar applications of boric acid, zinc sulphate and calcium chloride suggests enhanced calcium uptake by plants, leading to improved utilization of soil calcium for physiological functions. This is consistent with the findings of Anita (2022), who reported a reduction in available Ca content in soil when nutrients were applied in combination, likely due to increased plant uptake and potential interactions between nutrients in the soil.

The treatment combination H_1M_7 consistently recorded the lowest available Ca content in soil across both years and pooled data. This suggests that the hybrid "Indam Mamatha" exhibited higher calcium uptake efficiency under foliar nutrient application.

The enhanced calcium uptake can be attributed to its essential role in cell division, cell wall stabilization and enzymatic functions, which drive increased metabolic demand. Additionally, boron and zinc play crucial roles in calcium metabolism and translocation, potentially contributing to improved nutrient assimilation. Conversely, the control treatment recorded the highest available Ca content in soil across all hybrids and years, indicating lower calcium uptake by plants in the absence of foliar nutrient supplementation. This supports the hypothesis that foliar application enhances calcium bioavailability for direct plant uptake, thereby reducing its residual concentration in soil.

Calcium plays a crucial role in plant growth, particularly in root development, membrane stability and stress tolerance. The observed decline in available calcium in treatments with higher nutrient uptake can be attributed to the synergistic effects of nutrients such as boron and zinc. Boron enhances calcium absorption by improving cell wall structure and root elongation, while zinc supports calcium translocation within plant tissues and enzymatic activation (Jagtap et al. 2016). Additionally, the competitive interactions of calcium with boron and zinc at root absorption sites or in the soil solution may have influenced calcium availability, emphasizing the importance of balanced nutrient management.

The higher residual calcium content recorded in the second year compared to the first year may be attributed to residual effects of calcium-containing fertilizers and the stable microclimatic conditions within the polyhouse environment. The controlled temperature and humidity likely enhanced microbial activity, promoting calcium solubilization and availability while minimizing nutrient losses due to leaching or volatilization.

The absence of a significant interaction effect between coloured capsicum hybrids and foliar nutrient applications in the second year suggests a consistent influence of foliar treatments on calcium availability, with variations primarily driven by the inherent effects of treatments rather than hybrid-specific differences. The restricted leaching and potential accumulation of nutrients in polyhouse conditions further highlight the need for a well-optimized nutrient application strategy to ensure balanced nutrient uptake and efficient utilization.

Overall, foliar applications of boric acid, zinc sulphate and calcium chloride played a significant role in maintaining soil calcium levels by promoting direct nutrient absorption through leaves and reducing dependence on soil-applied fertilizers.

4.5 Plant analysis

4.5.1 N, P and K content in plants (%)

4.5.1.1 N content in plants (%)

Nitrogen (N) content in plants (%) is a critical indicator of the plant’s nutritional and physiological status. Leaves, being the primary site of photosynthesis, require a higher nitrogen concentration to maintain chlorophyll levels and metabolic activity, while fruits utilize nitrogen for protein synthesis and quality improvement.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, along with the pooled results, revealed significant variations in the Nitrogen content (%) in plants tissues across the different treatments, as presented in Table 4.5.1.1.

During the first year 2022-2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for N content in plants (%).

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher N content in plants (2.73 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower N content in plants (2.56 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum N content in plants (3.15 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum N content in plants (2.29 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum N content in plants (3.19 %) was recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (3.12 %) with treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum N content in plants (2.25 %).

During the second year 2023-2024, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for N content in plants (%). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher N content in plants (2.51 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower N content in plants (2.36 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum N content in plants (3.01 %).

The control treatment (M_8), with no foliar nutrient application, recorded the minimum N content in plants (2.13 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum N content in plants (3.05 %) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum N content in plants (2.09 %).

The pooled data for both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for N content in plants (%).

Table 4.5.1.1.: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on N content in plants

Treatments	N content in plants (%)		
	2022-2023	2023-2024	Pooled
H_1	2.56	2.36	2.46
H_2	2.73	2.51	2.62
Mean	**2.64**	**2.44**	**2.54**
SE (m)±	**0.01**	**0.01**	**0.01**
$CD_{0.05}$	**0.03**	**0.20**	**0.20**
M_1	2.54	2.32	2.43
M_2	2.61	2.37	2.49
M_3	2.68	2.42	2.55
M_4	2.71	2.47	2.59
M_5	2.55	2.35	2.45
M_6	2.61	2.42	2.52
M_7	3.15	3.01	3.08
M_8	2.29	2.13	2.21
Mean	**2.64**	**2.44**	**2.54**
SE (m)±	**0.02**	**0.01**	**0.01**
$CD_{0.05}$	**0.06**	**0.03**	**0.04**
Interaction:			
H_1M_1	2.38	2.17	2.28
H_1M_2	2.46	2.22	2.34
H_1M_3	2.54	2.27	2.41
H_1M_4	2.52	2.32	2.42
H_1M_5	2.58	2.37	2.48
H_1M_6	2.64	2.42	2.53
H_1M_7	3.12	3.05	3.09
H_1M_8	2.25	2.09	2.17
H_2M_1	2.70	2.47	2.59
H_2M_2	2.76	2.52	2.64
H_2M_3	2.82	2.57	2.70
H_2M_4	2.90	2.62	2.76
H_2M_5	2.52	2.32	2.42
H_2M_6	2.58	2.42	2.50
H_2M_7	3.19	2.98	3.08
H_2M_8	2.33	2.16	2.25
Mean	**2.64**	**2.44**	**2.54**
SE (m)±	**0.03**	**0.02**	**0.02**
$CD_{0.05}$	**0.09**	**0.05**	**0.06**

*H_1 - Indam Mamatha; H_2 - Orobelle

*M_1 - Boric acid 0.5 %; M_2 - Zinc sulphate 0.5 %; M_3 - Calcium chloride 0.5 %; M_4 - Boric acid 0.5 % + Zinc sulphate 0.5%; M_5 - Boric acid 0.5 % + Calcium chloride 0.5 %; M_6 - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_7 - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_8 - Control (No spray)

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher N content in plants (2.62 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower N content in plants (2.46 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum N content in plants (3.08 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum N content in plants (2.21 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum N content in plants (3.09 %) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was at par (3.08 %) with treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum N content in plants (2.17 %).

The significant variations in nitrogen (N) content in plants across treatments underscore the impact of coloured capsicum hybrids and foliar nutrient applications on nitrogen assimilation. The higher N content in plants observed in treatments receiving foliar applications of boric acid, zinc sulphate and calcium chloride suggests an enhanced nitrogen uptake efficiency. This aligns with the findings of Kumar et al. (2016), who reported that foliar application of nutrients plays a crucial role in improving nitrogen metabolism in plants.

The treatment combination H_1M_7 consistently recorded higher nitrogen content in plants across both years and pooled data. This suggests that the hybrid “Indam Mamatha” demonstrated a positive response to foliar nutrient application, leading to improved nitrogen uptake. Zinc, a key component of the foliar spray, plays a pivotal role in nitrogen metabolism by acting as a cofactor for nitrate reductase and glutamine synthetase, which are crucial enzymes involved in nitrogen assimilation and protein synthesis (Alloway 2008). Additionally, boron aids in nitrogen translocation within plant tissues, supporting metabolic activities and cell wall integrity, while calcium stabilizes cell membranes and enhances root growth, facilitating better nutrient absorption.

The minimum N content in plants was consistently recorded in the control treatment across both hybrids and years, indicating lower nitrogen uptake efficiency in the absence of foliar nutrient supplementation. This is in agreement with studies by Shafeek et al. (2014), who reported that foliar application of nutrient mixtures significantly improved nitrogen accumulation in hot pepper plants. Similarly, El-Said et al. (2009) and El-Mohsen et al. (2007) observed an increase in nitrogen content in capsicum plants with foliar application of essential nutrients.

The observed year-to-year variations in nitrogen content in plants may be attributed to environmental factors such as temperature and soil moisture levels, which influence nutrient uptake efficiency. The slightly higher nitrogen content in the first year compared to the second year suggests that variations in climatic conditions, particularly under polyhouse environments, may affect nutrient absorption and utilization.

The interaction effect between coloured capsicum hybrids and foliar nutrient applications was significant across both years and pooled data, emphasizing the importance of balanced nutrient management in optimizing nitrogen assimilation.

4.5.1.2 P content in plants (%)

Phosphorus (P) content in plants (%) is a vital indicator of the plant's nutritional and physiological status. Leaves, as the primary site of photosynthesis and energy transfer, require adequate phosphorus to support ATP synthesis, nucleic acid formation and metabolic activity. Fruits utilize phosphorus for the development of seeds, enhancement of sugar metabolism and improvement of overall fruit quality, making it a key nutrient for both vegetative and reproductive growth stages.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, along with the pooled results, revealed significant variations in the P content (%) in plants tissues across the different treatments, as presented in Table 4.5.1.2.

During the first year 2022-2023, the effect of coloured capsicum hybrids and foliar nutrient applications was significant for P content in plants (%) whereas their interaction was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher P content in plants (0.31 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower P content in plants (0.29 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum P content in plants (0.35 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum P content in plants (0.25 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with values ranging from 0.24 to 0.36 %.

During the second year 2023-2024, the effect of coloured capsicum hybrids and foliar nutrient applications was significant for P content in plants (%) whereas their interaction was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher P content in plants (0.31 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower P content in plants (0.30 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum P content in plants (0.37 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum P content in plants (0.24 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with values ranging from 0.23 to 0.37 %.

The pooled data for both the years revealed that the effect of coloured capsicum hybrids and foliar nutrient applications was significant for P content in plants (%) whereas their interaction was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher P content in plants (0.31 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower P content in plants (0.30 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum P content in plants (0.36 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum P content in plants (0.25 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with values ranging from 0.25 to 0.36 %.

The significant variations in phosphorus (P) content in plants across treatments highlight the impact of coloured capsicum hybrids and foliar nutrient applications on phosphorus assimilation. The higher P content in plants observed in treatments receiving foliar applications of boric acid, zinc sulphate and calcium chloride suggests an enhanced phosphorus uptake efficiency. This aligns with the findings of Kumar et al. (2016), who

Table 4.5.1.2: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on P content in plants

Treatments	**P content in plants (%)**		
	2022-2023	**2023-2024**	**Pooled**
H_1	0.29	0.30	0.30
H_2	0.31	0.31	0.31
Mean	**0.30**	**0.31**	**0.30**
SE (m)±	**0.01**	**0.01**	**0.01**
$CD_{0.05}$	**0.02**	**0.02**	**0.02**
M_1	0.30	0.30	0.30
M_2	0.30	0.30	0.30
M_3	0.30	0.30	0.30
M_4	0.30	0.32	0.31
M_5	0.29	0.31	0.30
M_6	0.30	0.32	0.31
M_7	0.35	0.37	0.36
M_8	0.25	0.24	0.25
Mean	**0.30**	**0.31**	**0.30**
SE (m)±	**0.10**	**0.01**	**0.01**
$CD_{0.05}$	**0.03**	**0.03**	**0.03**
Interaction:			
H_1M_1	0.29	0.28	0.28
H_1M_2	0.28	0.28	0.28
H_1M_3	0.28	0.30	0.29
H_1M_4	0.29	0.32	0.31
H_1M_5	0.27	0.33	0.30
H_1M_6	0.32	0.32	0.32
H_1M_7	0.34	0.37	0.35
H_1M_8	0.26	0.23	0.25
H_2M_1	0.30	0.33	0.32
H_2M_2	0.31	0.31	0.31
H_2M_3	0.33	0.31	0.32
H_2M_4	0.32	0.32	0.32
H_2M_5	0.30	0.30	0.30
H_2M_6	0.29	0.31	0.30
H_2M_7	0.36	0.36	0.36
H_2M_8	0.24	0.25	0.25
Mean	**0.30**	**0.31**	**0.30**
SE (m)±	**0.02**	**0.01**	**0.01**
$CD_{0.05}$	**NS**	**NS**	**NS**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1** - Boric acid 0.5 %; **M_2** - Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8** - Control (No spray)

reported that foliar application of nutrients plays a crucial role in improving phosphorus metabolism in plants.

The hybrid “Orobelle” consistently recorded higher P content in plants across both years and pooled data, indicating its superior phosphorus assimilation capacity compared to “Indam Mamatha”. This suggests that genetic variation among hybrids influences nutrient uptake efficiency. The effectiveness of foliar nutrient applications in enhancing phosphorus content in plants can be attributed to the synergistic roles of boron, zinc and calcium. Boron aids in phosphorus translocation and cell wall integrity, ensuring efficient nutrient movement within the plant. Zinc plays a crucial role in root development and enzymatic activities associated with phosphorus metabolism, while calcium supports membrane stability and nutrient transport (Alloway 2008). Together, these nutrients optimize phosphorus assimilation and contribute to overall plant growth and productivity.

The minimum P content in plants was consistently recorded in the control treatment across both hybrids and years, indicating lower phosphorus uptake efficiency in the absence of foliar nutrient supplementation. This is in agreement with studies by Shafeek et al. (2014), who reported that foliar application of nutrient mixtures significantly improved phosphorus accumulation in hot pepper plants. Similarly, El-Said et al. (2009) and El-Mohsen et al. (2007) observed an increase in phosphorus content in capsicum plants with foliar application of essential nutrients.

The observed year-to-year variations in phosphorus content in plants may be attributed to environmental factors such as temperature, soil moisture and humidity, which influence nutrient uptake efficiency. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was found to be non-significant across both years and pooled data, suggesting that while hybrids and nutrient applications independently influenced phosphorus uptake, their combined effect was not statistically significant.

Overall, these findings underscore the importance of balanced foliar nutrient management in improving phosphorus assimilation, enhancing nutrient efficiency and promoting better plant growth and productivity in coloured capsicum cultivation.

4.5.1.3 K content in plants (%)

Potassium (K) content in plants (%) is a crucial factor in maintaining optimal plant growth and physiological function. It plays a significant role in regulating various processes such as enzyme activation, photosynthesis and water regulation through stomatal control. In leaves, potassium supports efficient photosynthesis and carbohydrate production, which are essential for energy storage and growth. In fruits, potassium contributes to the development of high-quality produce by improving sugar accumulation, enhancing flavor and increasing resistance to diseases and environmental stress.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, along with the pooled results, revealed significant variations in the potassium content (%) in plants tissues across the different treatments, as presented in Table 4.5.1.3.

During the first year 2022-2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for K content in plants (%). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher K content in plants (3.19 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower K content in plants (3.15 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum K content in plants (3.35 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum K content in plants (3.02 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum K content in plants (3.36 %) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_2M_7 (3.35 %) and H_2M_4 (3.30 %). The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum K content in plants (3.01 %).

During the second year 2023-2024, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for K content in plants (%). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher K content in plants (3.50 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower K content in plants (3.36 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum K content in plants (3.86 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum K content in plants (3.11 %).

Table 4.5.1.3: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on K content in plants

Treatments	K content in plants (%)		
	2022-2023	2023-2024	Pooled
H_1	3.15	3.36	3.25
H_2	3.19	3.50	3.35
Mean	**3.17**	**3.43**	**3.30**
SE (m)±	**0.01**	**0.02**	**0.01**
$CD_{0.05}$	**0.03**	**0.06**	**0.03**
M_1	3.08	3.37	3.23
M_2	3.19	3.37	3.28
M_3	3.19	3.42	3.31
M_4	3.21	3.48	3.35
M_5	3.14	3.43	3.28
M_6	3.17	3.40	3.29
M_7	3.35	3.86	3.61
M_8	3.02	3.11	3.06
Mean	**3.17**	**3.43**	**3.30**
SE (m)±	**0.02**	**0.03**	**0.02**
$CD_{0.05}$	**0.06**	**0.10**	**0.06**
Interaction:			
H_1M_1	3.09	3.28	3.19
H_1M_2	3.14	3.22	3.18
H_1M_3	3.11	3.27	3.19
H_1M_4	3.12	3.32	3.22
H_1M_5	3.15	3.36	3.26
H_1M_6	3.18	3.41	3.30
H_1M_7	3.36	3.88	3.62
H_1M_8	3.02	3.13	3.08
H_2M_1	3.07	3.46	3.27
H_2M_2	3.24	3.52	3.38
H_2M_3	3.27	3.58	3.42
H_2M_4	3.30	3.64	3.47
H_2M_5	3.13	3.49	3.31
H_2M_6	3.16	3.39	3.28
H_2M_7	3.35	3.84	3.59
H_2M_8	3.01	3.09	3.05
Mean	**3.17**	**3.43**	**3.30**
SE (m)±	**0.02**	**0.05**	**0.02**
$CD_{0.05}$	**0.08**	**0.15**	**0.08**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1** - Boric acid 0.5 %; **M_2** - Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8** - Control (No spray)

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum K content in plants (3.88 %) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (3.84 %) with treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum K content in plants (3.09 %).

The pooled data for both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for K content in plants (%). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher K content in plants (3.35 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower K content in plants (3.25 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum K content in plants (3.61 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum K content in plants (3.06 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum K content in plants (3.62 %) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par (3.59 %) with treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum K content in plants (3.05 %).

The significant variations in potassium (K) content in plants across treatments underscore the impact of coloured capsicum hybrids and foliar nutrient applications on potassium assimilation. The higher K content in plants observed in treatments receiving foliar applications of boric acid, zinc sulphate and calcium chloride suggests enhanced potassium uptake efficiency. This aligns with the findings of Kumar et al. (2016), who reported that foliar application of nutrients plays a crucial role in improving potassium metabolism in plants.

The hybrid "Orobelle" consistently recorded higher K content in plants across both years and pooled data, indicating its superior potassium assimilation capacity compared to

"Indam Mamatha." This suggests that genetic variation among hybrids influences nutrient uptake efficiency. The effectiveness of foliar nutrient applications in enhancing potassium content in plants can be attributed to the synergistic roles of boron, zinc and calcium. Boron facilitates potassium translocation and maintains cell wall integrity, ensuring efficient nutrient movement within the plant. Zinc plays a crucial role in root development and enzymatic activities associated with potassium metabolism, while calcium supports membrane stability and nutrient transport (Alloway 2008). Together, these nutrients optimize potassium assimilation and contribute to overall plant growth and productivity.

The maximum K content in plants was observed in the treatment combination H_1M_7, which was statistically at par with H_2M_7. This suggests that both hybrids respond positively to foliar nutrient applications, enhancing potassium uptake efficiency. Similar results were reported by Shafeek et al. (2014), who observed a significant increase in potassium accumulation in hot pepper plants under foliar application of nutrient mixtures. Additionally, Ali and Zaino (2018) and El-Said et al. (2009) reported improved potassium content in capsicum plants following foliar nutrient supplementation, highlighting the beneficial effects of nutrient sprays on potassium metabolism.

The minimum K content in plants was consistently recorded in the control treatment across both hybrids and years, indicating lower potassium uptake efficiency in the absence of foliar nutrient supplementation. This emphasizes the necessity of external nutrient applications to optimize potassium absorption and utilization. These findings align with the studies by El-Mohsen et al. (2007), who demonstrated that foliar application of essential nutrients significantly enhanced potassium levels in vegetable crops.

The observed year-to-year variations in potassium content in plants may be attributed to environmental factors such as temperature, soil moisture and humidity, which influence nutrient uptake efficiency. The slightly higher potassium content in the second year compared to the first suggests that variations in climatic conditions, particularly under polyhouse environments, may affect nutrient absorption and utilization. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was significant across both years and pooled data, emphasizing the importance of balanced nutrient management in optimizing potassium assimilation.

4.5.2 B, Zn and Ca content in plants

4.5.2.1 B content in plants (ppm)

Boron (B) content in plants (ppm) is an essential indicator of plant health and nutritional balance. Boron plays a crucial role in various physiological processes, including cell wall formation, membrane stability and nutrient transport. In leaves, boron is vital for maintaining chlorophyll structure, aiding in photosynthesis and enhancing the plant's ability to metabolize sugars and other nutrients. In fruits, boron contributes to proper seed development, improves fruit quality and helps in the transport of sugars and other metabolites from the leaves to the reproductive tissues.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, along with the pooled results, revealed significant variations in the boron content (ppm) in plants tissues across the different treatments, as presented in Table 4.5.2.1.

During the first year 2022-2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for B content in plants (ppm). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher B content in plants (19.29 ppm), while the hybrid Indam Mamatha (H_1) recorded a statistically lower B content in plants (18.25 ppm). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum B content in plants (23.23 ppm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum B content in plants (14.76 ppm).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum B content in plants (23.83 ppm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_2M_7 (22.67 ppm) and H_2M_4 (22.63 ppm). The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum B content in plants (13.67 ppm).

During the second year 2023-2024, the effect of coloured capsicum hybrids on B content in plants (ppm) was non-significant, while foliar nutrient applications had a significant effect.

Table 4.5.2.1: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on B content in plants

Treatments	B content in plants (ppm)		
	2022-2023	2023-2024	Pooled
H_1	18.25	19.62	18.94
H_2	19.29	19.96	19.62
Mean	**18.77**	**19.79**	**19.28**
SE (m)±	**0.28**	**0.37**	**0.24**
$CD_{0.05}$	**0.82**	**NS**	**NS**
M_1	18.33	20.95	19.64
M_2	18.34	18.56	18.45
M_3	17.75	18.51	18.13
M_4	21.17	21.32	21.24
M_5	18.94	20.13	19.53
M_6	17.65	18.63	18.14
M_7	23.23	22.75	22.99
M_8	14.76	17.49	16.13
Mean	**18.77**	**19.79**	**19.28**
SE (m)±	**0.58**	**0.70**	**0.49**
$CD_{0.05}$	**1.65**	**2.20**	**1.39**
Interaction:			
H_1M_1	16.30	20.58	18.44
H_1M_2	18.33	18.02	18.18
H_1M_3	16.85	17.78	17.32
H_1M_4	19.67	20.92	20.29
H_1M_5	17.45	21.05	19.25
H_1M_6	17.75	18.85	18.30
H_1M_7	23.83	22.33	23.08
H_1M_8	15.85	17.45	16.65
H_2M_1	20.37	21.32	20.84
H_2M_2	18.35	19.10	18.73
H_2M_3	18.65	19.23	18.94
H_2M_4	22.63	21.72	22.19
H_2M_5	20.43	19.20	19.82
H_2M_6	17.55	18.40	17.98
H_2M_7	22.67	23.17	22.90
H_2M_8	13.67	17.53	15.60
Mean	**18.77**	**19.79**	**19.28**
SE (m)±	**0.80**	**1.07**	**0.69**
$CD_{0.05}$	**2.34**	**NS**	**NS**

H_1 - Indam Mamatha; **H_2** - Orobelle

***M_1* -** Boric acid 0.5 %; **M_2 -** Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8 -** Control (No spray)

However, the interaction between coloured capsicum hybrids and foliar nutrient applications was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a B content of 19.96 ppm in plants, while the hybrid Indam Mamatha (H_1) recorded 19.62 ppm, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum B content in plants (22.75 ppm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum B content in plants (17.49 ppm). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with the values ranging from 17.45 to 23.17 ppm.

The pooled data of both the years revealed that the effect of coloured capsicum hybrids on B content in plants (ppm) was non-significant, while foliar nutrient applications had a significant effect. However, the interaction between coloured capsicum hybrids and foliar nutrient applications was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a B content of 19.62 ppm in plants, while the hybrid Indam Mamatha (H_1) recorded 18.94 ppm, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum B content in plants (22.99 ppm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum B content in plants (16.13 ppm). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with the values ranging from 15.60 to 23.08 ppm.

The significant variations in boron (B) content in plants across treatments underscore the influence of coloured capsicum hybrids and foliar nutrient applications on boron assimilation. The higher B content in plants observed in treatments receiving foliar applications of boric acid, zinc sulphate and calcium chloride suggests enhanced boron uptake efficiency. This aligns with the findings of Kumar et al. (2016), who reported that foliar application of nutrients plays a crucial role in improving boron metabolism in plants.

The hybrid “Orobelle” consistently recorded higher B content in plants across both years and pooled data, indicating its superior boron assimilation capacity compared to “Indam Mamatha.” This suggests that genetic variation among hybrids influences nutrient uptake efficiency. The effectiveness of foliar nutrient applications in enhancing boron content in plants can be attributed to the synergistic roles of boron, zinc and calcium. Boron plays a critical role in cell wall structure, pollen viability and reproductive growth, ensuring efficient nutrient movement within the plant. Zinc supports root development and enzymatic activities associated with boron metabolism, while calcium stabilizes cell membranes and enhances nutrient transport (Alloway 2008). Together, these nutrients optimize boron assimilation and contribute to overall plant growth and productivity.

The maximum B content in plants was observed in the treatment combination H_1M_7, which was statistically at par with H_2M_7 and H_2M_4. This suggests that both hybrids respond positively to foliar nutrient applications, enhancing boron uptake efficiency. Similar results were reported by Ali and Zaino (2018), who observed a significant increase in boron accumulation in sweet pepper plants under foliar application of nutrient mixtures. Additionally, Anita (2022) found that boric acid application at 0.1 % significantly increased boron content in Sweet Banana pepper, further supporting the present findings. The beneficial effects of foliar boron supplementation on nutrient assimilation have also been highlighted by Haleema et al. (2024), El-Said et al. (2009) and El-Mohsen et al. (2007).

The minimum B content in plants was consistently recorded in the control treatment across both hybrids and years, indicating lower boron uptake efficiency in the absence of foliar nutrient supplementation. This emphasizes the necessity of external nutrient applications to optimize boron absorption and utilization. These findings align with the studies by El-Mohsen et al. (2007), who demonstrated that foliar application of essential nutrients significantly enhanced boron levels in vegetable crops.

The observed year-to-year variations in boron content in plants may be attributed to environmental factors such as temperature, soil moisture and humidity, which influence nutrient uptake efficiency. The slightly higher boron content in the second year compared to the first suggests that variations in climatic conditions, particularly under polyhouse environments, may affect nutrient absorption and utilization. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was significant in the first year but non-significant in the second year and pooled data, indicating that while hybrids and nutrient applications independently influenced boron uptake, their combined effect varied over time.

4.5.2.2 Zn content in plants (ppm)

Zinc (Zn) content in plants (ppm) is a key indicator of plant health and nutrient status. Zinc is an essential micronutrient that plays a critical role in various physiological processes, including enzyme activation, protein synthesis and DNA replication. In leaves, zinc is involved in the regulation of chlorophyll production and photosynthesis, enhancing overall plant growth. In fruits, zinc supports the development of high-quality seeds, improves antioxidant activity and contributes to the proper formation of essential metabolic compounds.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, along with the pooled results, revealed significant variations in the zinc content (ppm) in plants tissues across the different treatments, as presented in Table 4.5.2.2.

During the first year 2022-2023, the effect of coloured capsicum hybrids on Zn content in plants (ppm) was non-significant, while foliar nutrient applications had a significant effect. However, the interaction between coloured capsicum hybrids and foliar nutrient applications was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a Zn content of 31.44 ppm in plants, while the hybrid Indam Mamatha (H_1) recorded 30.25 ppm, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum Zn content in plants (45.42 ppm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum Zn content in plants (24.51 ppm). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with the values ranging from 23.30 to 46.68 ppm.

During the second year 2023-2024, the effect of coloured capsicum hybrids on Zn content in plants (ppm) was non-significant, while foliar nutrient applications had a significant effect. However, the interaction between coloured capsicum hybrids and foliar nutrient applications was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a Zn content of 32.84 ppm in plants, while the hybrid Indam Mamatha (H_1) recorded 31.59 ppm, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum Zn content in plants (39.83 ppm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum Zn content in plants (26.33 ppm). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with the values ranging from 26.18 to 40.09 ppm.

Table 4.5.2.2.: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on Zn content in plants

Treatments	**Zn content in plants (ppm)**		
	2022-2023	**2023-2024**	**Pooled**
H_1	30.25	31.59	30.92
H_2	31.44	32.84	32.14
Mean	**30.85**	**32.21**	**31.53**
SE (m)±	**0.66**	**0.64**	**0.45**
$CD_{0.05}$	**NS**	**NS**	**NS**
M_1	26.87	29.43	28.15
M_2	32.16	33.37	32.76
M_3	27.60	30.80	29.20
M_4	31.61	33.39	32.50
M_5	27.13	30.68	28.90
M_6	31.17	33.90	32.53
M_7	45.72	39.83	42.77
M_8	24.51	26.33	25.42
Mean	**30.85**	**32.21**	**31.53**
SE (m)±	**1.32**	**1.27**	**0.91**
$CD_{0.05}$	**3.83**	**3.71**	**2.57**
Interaction:			
H_1M_1	25.73	27.55	26.64
H_1M_2	32.12	32.53	32.33
H_1M_3	26.50	29.50	28.00
H_1M_4	30.75	32.78	31.77
H_1M_5	26.67	30.45	28.56
H_1M_6	30.27	33.60	31.93
H_1M_7	46.68	40.09	43.39
H_1M_8	23.30	26.18	24.74
H_2M_1	28.00	31.30	29.65
H_2M_2	32.20	34.20	33.20
H_2M_3	28.70	32.10	30.40
H_2M_4	32.47	34.00	33.23
H_2M_5	27.60	30.90	29.25
H_2M_6	32.07	34.20	33.13
H_2M_7	44.75	39.57	42.16
H_2M_8	25.72	26.47	26.09
Mean	**30.85**	**32.21**	**31.53**
SE (m)±	**1.86**	**1.80**	**1.28**
$CD_{0.05}$	**NS**	**NS**	**NS**

*H_1 - Indam Mamatha; H_2 - Orobelle

*M_1 - Boric acid 0.5 %; M_2 - Zinc sulphate 0.5 %; M_3 - Calcium chloride 0.5 %; M_4 - Boric acid 0.5 % + Zinc sulphate 0.5%; M_5 - Boric acid 0.5 % + Calcium chloride 0.5 %; M_6 - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_7 - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_8 - Control (No spray)

The pooled data from both the years revealed that the effect of coloured capsicum hybrids on Zn content in plants (ppm) was non-significant, while foliar nutrient applications had a significant effect. However, the interaction between coloured capsicum hybrids and foliar nutrient applications was non-significant. Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a Zn content of 32.14 ppm in plants, while the hybrid Indam Mamatha (H_1) recorded 30.92 ppm, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum Zn content in plants (42.77 ppm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum Zn content in plants (25.42 ppm). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with the values ranging from 24.74 to 43.39 ppm.

The significant variations in zinc (Zn) content in plants across treatments highlight the influence of foliar nutrient applications on Zn assimilation. The higher Zn content in plants observed in treatments receiving foliar applications of boric acid, zinc sulphate and calcium chloride suggests enhanced Zn uptake efficiency. This aligns with the findings of Kumar et al. (2016), who reported that foliar application of nutrients plays a crucial role in improving Zn metabolism in plants.

The hybrid “Orobelle” consistently recorded higher Zn content in plants across both years and pooled data, indicating its superior Zn assimilation capacity compared to “Indam Mamatha.” This suggests that genetic variation among hybrids may influence nutrient uptake efficiency. However, the non-significant effect of hybrids across years and pooled data indicates that Zn assimilation in capsicum is primarily influenced by external nutrient applications rather than genetic factors alone. The effectiveness of foliar nutrient applications in enhancing Zn content in plants can be attributed to the synergistic roles of boron, zinc and calcium. Zinc is crucial for enzyme activation, protein synthesis and membrane integrity, ensuring efficient nutrient movement within the plant (Alloway 2008). Boron facilitates Zn translocation and root growth, while calcium stabilizes cellular structures and supports nutrient transport. Together, these nutrients optimize Zn assimilation and contribute to overall plant growth and productivity.

The maximum Zn content in plants was observed in the treatment combination M_7, which was statistically superior to other treatments. This suggests that foliar application of this nutrient combination enhances Zn uptake efficiency significantly. Similar results were reported by Rana (2015), who observed a significant increase in Zn accumulation in vegetable crops under foliar application of nutrient mixtures. Additionally, Haleema et al. (2024) reported that the foliar application of zinc, boron and calcium at 0.5 % significantly increased Zn content in tomato fruits, while also reducing blossom end rot and fruit cracking, further supporting the present findings. The beneficial effects of foliar Zn supplementation on nutrient assimilation have also been highlighted by Ali and Zaino (2018) and El-Said et al. (2009).

The minimum Zn content in plants was consistently recorded in the control treatment across both hybrids and years, indicating lower Zn uptake efficiency in the absence of foliar nutrient supplementation. This emphasizes the necessity of external nutrient applications to optimize Zn absorption and utilization. These findings align with the studies by El-Mohsen et al. (2007), who demonstrated that foliar application of essential nutrients significantly enhanced Zn levels in vegetable crops.

The observed year-to-year variations in Zn content in plants may be attributed to environmental factors such as temperature, soil moisture and humidity, which influence nutrient uptake efficiency. The slightly higher Zn content in the second year compared to the first suggests that variations in climatic conditions, particularly under polyhouse environments, may affect nutrient absorption and utilization. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant across both years and pooled data, indicating that while nutrient applications independently influenced Zn uptake, their combined effect with hybrids was not statistically significant.

4.5.2.3 Ca content in plants (%)

Calcium (Ca) content in plants (%) is a critical factor influencing plant growth and development. Calcium plays a vital role in various physiological processes, including cell wall structure, membrane integrity and signaling pathways. In leaves, calcium is essential for strengthening cell walls, improving photosynthesis efficiency and regulating metabolic processes. In fruits, calcium contributes to the proper formation of cell walls, enhancing fruit firmness, quality and shelf life. It also helps with nutrient transport, water regulation and reducing susceptibility to physiological disorders like blossom end rot, making it crucial for overall plant health and productivity.

The analysis of data collected over two consecutive years, 2022-2023 and 2023-2024, along with the pooled results, revealed significant variations in the calcium content (%) in plant tissues across the different treatments, as presented in Table 4.5.2.3.

During the first year 2022-2023, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for Ca content in plants (%). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher Ca content in plants (0.98 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower Ca content in plants (0.92 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum Ca content in plants (1.12 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum Ca content in plants (0.76 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum Ca content in plants (1.12 %) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_2M_7 (1.11 %) and H_2M_4 (1.05 %). The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum Ca content in plants (0.75 %).

During the second year 2023-2024, the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for Ca content in plants (%). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher Ca content in plants (1.05 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower Ca content in plants (0.95 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum Ca content in plants (1.19 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum Ca content in plants (0.78 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum Ca content in plants (1.20 %) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_2M_7 (1.18 %) and H_2M_4 (1.14 %). The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum Ca content in plants (0.74 %).

Table 4.5.2.3: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on Ca content in plants

Treatments	**Ca content in plants (%)**		
	2022-2023	**2023-2024**	**Pooled**
H_1	0.92	0.95	0.94
H_2	0.98	1.05	1.02
Mean	**0.95**	**1.00**	**0.98**
SE (m)±	**0.01**	**0.01**	**0.01**
$CD_{0.05}$	**0.03**	**0.03**	**0.03**
M_1	0.89	0.92	0.91
M_2	0.92	0.97	0.95
M_3	0.97	1.05	1.01
M_4	0.98	1.05	1.01
M_5	0.99	1.02	1.00
M_6	0.99	1.04	1.01
M_7	1.12	1.19	1.15
M_8	0.76	0.78	0.77
Mean	**0.95**	**1.00**	**0.98**
SE (m)±	**0.02**	**0.02**	**0.02**
$CD_{0.05}$	**0.06**	**0.06**	**0.04**
Interaction:			
H_1M_1	0.80	0.82	0.81
H_1M_2	0.84	0.87	0.86
H_1M_3	0.92	0.94	0.93
H_1M_4	0.90	0.95	0.93
H_1M_5	1.03	1.05	1.04
H_1M_6	0.98	1.05	1.02
H_1M_7	1.12	1.20	1.16
H_1M_8	0.78	0.74	0.76
H_2M_1	0.98	1.02	1.00
H_2M_2	1.00	1.07	1.04
H_2M_3	1.03	1.16	1.09
H_2M_4	1.05	1.14	1.10
H_2M_5	0.95	0.99	0.97
H_2M_6	0.99	1.02	1.01
H_2M_7	1.11	1.18	1.14
H_2M_8	0.75	0.81	0.78
Mean	**0.95**	**1.00**	**0.98**
SE (m)±	**0.03**	**0.03**	**0.02**
$CD_{0.05}$	**0.09**	**0.09**	**0.06**

H_1 - Indam Mamatha; **H_2** - Orobelle

***M_1* -** Boric acid 0.5 %; **M_2 -** Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8 -** Control (No spray)

The pooled data for both the years revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for Ca content in plants (%). Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded the maximum Ca content in plants (1.02 %), while the hybrid Indam Mamatha (H_1) recorded the minimum Ca content in plants (0.94 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum Ca content in plants (1.15 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum Ca content in plants (0.77 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum Ca content in plants (1.16 %) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. This was statistically at par with treatment combination H_2M_7 (1.14 %) and H_2M_4 (1.10 %). The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum Ca content in plants (0.76 %).

The significant variations in calcium (Ca) content in plants across treatments highlight the influence of coloured capsicum hybrids and foliar nutrient applications on Ca assimilation. The higher Ca content observed in plants treated with foliar applications of boric acid, zinc sulphate and calcium chloride suggest improved Ca uptake efficiency.

This aligns with the findings of Akladious and Mohamed (2018) and Ziest et al. (2018), who reported that calcium supplementation enhances cell structure, membrane stability and overall plant health, particularly when combined with other nutrients.

The hybrid “Orobelle” consistently recorded higher Ca content in plants across both years and pooled data, indicating its superior calcium assimilation capacity compared to “Indam Mamatha.” This suggests that genetic variation among hybrids may influence nutrient uptake efficiency. However, the significant interaction between hybrids and nutrient applications indicates that external applications further enhance Ca uptake regardless of genetic differences. The effectiveness of foliar nutrient applications in enhancing Ca content in plants can be attributed to the synergistic roles of boron, zinc and calcium. Calcium plays a critical role in cell wall formation, membrane stability and nutrient transport, ensuring efficient movement of minerals within the plant (Buczkowska et al. 2016). Boron supports calcium translocation and root growth, while zinc aids in enzyme activation and protein synthesis, contributing to enhanced calcium metabolism. Together, these nutrients optimize Ca assimilation and improve overall plant growth and productivity.

The maximum Ca content in plants was observed in the treatment combination H_1M_7, which was statistically at par with H_2M_7 and H_2M_4. This suggests that both hybrids respond positively to foliar nutrient applications, enhancing calcium uptake efficiency. Similar results were reported by Haleema et al. (2024), who observed a significant increase in calcium accumulation in vegetable crops following foliar application of calcium chloride and other micronutrients. Additionally, Anita (2022) and Ali and Zaino (2018) found that foliar nutrient supplementation improved calcium content and fruit quality in pepper and tomato crops, supporting the present findings.

The minimum Ca content in plants was consistently recorded in the control treatment across both hybrids and years, indicating lower calcium uptake efficiency in the absence of foliar nutrient supplementation. This underscores the necessity of external nutrient applications to optimize calcium absorption and utilization. These findings align with previous studies by Buczkowska et al. (2016), who demonstrated that calcium-deficient plants exhibited poor structural integrity and increased susceptibility to physiological disorders such as blossom end rot.

The observed year-to-year variations in Ca content in plants may be attributed to environmental factors such as temperature, soil moisture and humidity, which influence nutrient uptake efficiency. The slightly higher Ca content in the second year compared to the first suggests that variations in climatic conditions, particularly under polyhouse environments, may affect calcium absorption and utilization. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was significant across both years and pooled data, indicating that while both factors independently influenced calcium uptake, their combined effect varied over time.

4.6 Periodic analysis of nutrients

4.6.1 Periodic analysis of B content (ppm)

Periodic analysis of boron (B) content (ppm) in plants is crucial for assessing the plant’s nutritional status and the effectiveness of boron supplementation at various growth stages. Boron plays a key role in several physiological processes, including cell wall formation, membrane stability, pollen germination and proper seed development. Monitoring boron content at different stages, such as before and after foliar applications, allows for understanding how boron is translocated within the plant and its impact on both vegetative (leaves) and reproductive (fruits) growth.

The analysis of data collected in pooled results revealed significant variations in the boron content (ppm) in plants across the different treatments at various stages, as presented in Table 4.6.1. The periodic analysis, conducted one day before the first spray, one day before the second spray, 15 days after the second spray on leaves and 15 days after the second spray on fruits, highlights the dynamic changes in boron levels and their impact on both vegetative and reproductive growth.

The pooled periodic analysis at one day before the first spray in leaves revealed that the effect of coloured capsicum hybrids on B content in leaves (ppm) was non-significant, while foliar nutrient applications and the interaction between coloured capsicum hybrids and foliar nutrient applications had a significant effect.

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a B content of 16.46 ppm in leaves, while the hybrid Indam Mamatha (H_1) recorded 16.45 ppm, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum B content in leaves (18.10 ppm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum B content in leaves (15.10 ppm).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum B content in leaves (18.20 ppm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum B content in leaves (15.00 ppm).

The pooled periodic analysis at one day before the second spray in leaves revealed that the effect of coloured capsicum hybrids on B content in leaves (ppm) was non-significant, while foliar nutrient applications and the interaction between coloured capsicum hybrids and foliar nutrient applications had a significant effect.

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a B content of 17.20 ppm in leaves, while the hybrid Indam Mamatha (H_1) recorded 17.19 ppm, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum B content in leaves (18.90 ppm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum B content in leaves (15.75 ppm).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum B content in leaves (19.00 ppm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum B content in leaves (15.60 ppm).

The pooled periodic analysis at 15 days after the second spray in leaves revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for B content in leaves (ppm).

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher B content in leaves (17.91 ppm), while the hybrid Indam Mamatha (H_1) recorded a statistically lower B content in leaves (17.86 ppm). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum B content in leaves (19.50 ppm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum B content in leaves (16.40 ppm).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum B content in leaves (19.60 ppm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_2M_8 : Orobelle + no foliar nutrient application (control), recorded the minimum B content in leaves (16.30 ppm).

Table 4.6.1: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on periodic analysis of boron

Treatments	Periodic analysis of boron (ppm) [Pooled]			
	One day before first spray (leaves)	One day before second spray (leaves)	15 days after second spray (leaves)	15 days after second spray (fruits)
H_1	16.45	17.19	17.86	19.03
H_2	16.46	17.20	17.91	19.65
Mean	**16.45**	**17.19**	**17.88**	**19.34**
SE (m)±	**0.01**	**0.01**	**0.02**	**0.17**
$CD_{0.05}$	**NS**	**NS**	**0.04**	**0.50**
M_1	16.53	17.19	17.95	19.35
M_2	16.00	16.75	17.50	18.54
M_3	16.20	16.95	17.65	19.28
M_4	16.84	17.61	18.34	20.33
M_5	16.60	17.35	18.00	19.61
M_6	16.30	17.05	17.75	19.02
M_7	18.10	18.90	19.50	21.77
M_8	15.10	15.75	16.40	16.85
Mean	**16.45**	**17.19**	**17.88**	**19.34**
SE (m)±	**0.02**	**0.02**	**0.02**	**0.35**
$CD_{0.05}$	**0.06**	**0.07**	**0.06**	**0.98**
Interaction:				
H_1M_1	16.55	17.20	18.10	18.63
H_1M_2	15.80	16.50	17.30	17.68
H_1M_3	16.00	16.80	17.50	18.92
H_1M_4	16.78	17.52	18.18	19.70
H_1M_5	16.70	17.40	18.10	19.42
H_1M_6	16.40	17.20	18.00	19.07
H_1M_7	18.20	19.00	19.60	21.96
H_1M_8	15.20	15.90	16.50	16.89
H_2M_1	16.50	17.18	17.80	20.07
H_2M_2	16.20	17.00	17.70	19.40
H_2M_3	16.40	17.10	17.80	19.65
H_2M_4	16.90	17.70	18.50	20.97
H_2M_5	16.50	17.30	17.90	19.80
H_2M_6	16.20	16.90	17.50	18.97
H_2M_7	18.00	18.80	19.40	21.58
H_2M_8	15.00	15.60	16.30	16.80
Mean	**16.45**	**17.19**	**17.88**	**19.34**
SE (m)±	**0.03**	**0.04**	**0.03**	**0.49**
$CD_{0.05}$	**0.08**	**0.12**	**0.08**	**NS**

*H_1 - Indam Mamatha; H_2 - Orobelle

*M_1 - Boric acid 0.5 %; M_2 - Zinc sulphate 0.5 %; M_3 - Calcium chloride 0.5 %; M_4 - Boric acid 0.5 % + Zinc sulphate 0.5%; M_5 - Boric acid 0.5 % + Calcium chloride 0.5 %; M_6 - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_7 - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_8 - Control (No spray)

The pooled periodic analysis at 15 days after the second spray in fruits revealed that the effect of coloured capsicum hybrids and foliar nutrient applications was significant for B content in fruits (ppm) whereas their interaction was non-significant.

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher B content in fruits (19.65 ppm), while the hybrid Indam Mamatha (H_1) recorded a statistically lower B content in fruits (19.03 ppm). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum B content in fruits (21.77 ppm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum B content in fruits (16.85 ppm). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with values ranging from 16.80 to 21.96 ppm.

The significant variations in boron (B) content in leaves and fruits across treatments highlight the influence of coloured capsicum hybrids and foliar nutrient applications on B accumulation. The higher B content observed in plants treated with foliar applications of boric acid, zinc sulphate and calcium chloride suggests improved B uptake efficiency. This aligns with the findings of Haleema et al. (2024) and Pagard et al. (2024), who reported that boron supplementation enhances nutrient translocation, cell wall formation and fruit development, particularly when combined with other nutrients.

The hybrid “Orobelle” consistently recorded higher B content in leaves and fruits across all stages, indicating its superior boron assimilation capacity compared to “Indam Mamatha.” This suggests that genetic variation among hybrids may influence nutrient uptake efficiency. However, the significant interaction between hybrids and nutrient applications indicates that external applications further enhance B uptake regardless of genetic differences. The effectiveness of foliar nutrient applications in enhancing B content in plants can be attributed to the synergistic roles of boron, zinc and calcium. Boron plays a critical role in cell wall integrity, reproductive development and nutrient translocation, ensuring efficient movement of minerals within the plant (Mondal et al. 2023). Zinc aids in enzyme activation and protein synthesis, while calcium supports cell wall stability and membrane permeability, contributing to enhanced nutrient metabolism. Together, these nutrients optimize B assimilation and improve overall plant growth and productivity.

The maximum B content in leaves and fruits was observed in the treatment combination H_1M_7. Similar results were reported by Haleema et al. (2024), who observed a significant increase in boron accumulation in tomato following foliar application of boric acid, zinc chloride and calcium chloride. Additionally, Vera-Maldonado et al. (2024) and Pagard et al. (2024) found that foliar nutrient supplementation improved boron content and fruit quality in pepper and tomato crops, supporting the present findings.

The minimum B content in leaves and fruits was consistently recorded in the control treatment across both hybrids, indicating lower boron uptake efficiency in the absence of foliar nutrient supplementation. This underscores the necessity of external nutrient applications to optimize boron absorption and utilization. These findings align with previous studies by Mondal et al. (2023), who demonstrated that boron-deficient plants exhibited poor fruit set, structural deformities and increased susceptibility to physiological disorders.

The observed stage-wise variations in B content in leaves and fruits may be attributed to differences in nutrient mobility, environmental factors and metabolic demands during different growth phases. The slightly higher B content in later stages compared to earlier ones suggests that variations in climatic conditions, particularly under protected cultivation, may influence boron absorption and utilization. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was significant across multiple stages, indicating that while both factors independently influenced boron uptake, their combined effect varied over time.

The increased B content in leaves and fruits observed in this study implies that such foliar nutrient strategies can effectively enhance the nutritional quality of capsicum fruits. Higher B levels are associated with improved fruit set, development and quality, contributing to better marketability and consumer health benefits (Pagard et al. 2024). Therefore, the strategic use of foliar nutrient applications not only supports optimal plant growth but also enhances the accumulation of essential nutrients in the edible parts of the plant, offering a practical approach to improving both yield and nutritional value in capsicum (Vera-Maldonado et al. 2024).

4.6.2 Periodic analysis of Zn content (ppm)

Periodic analysis of zinc (Zn) content (ppm) in plants is essential for evaluating the plant's nutritional status and the effectiveness of zinc supplementation at various growth stages. Zinc is a vital micronutrient involved in several physiological processes, such as enzyme activation, protein synthesis, chlorophyll production and auxin metabolism.

Monitoring zinc content at different stages, including before and after foliar applications, provides insights into its uptake, translocation within the plant and its impact on vegetative growth (leaves) and reproductive development (fruits), ultimately influencing overall plant health and productivity.

The analysis of data collected in pooled results revealed significant variations in the zinc (Zn) content (ppm) in plants across different treatments at various stages, as presented in Table 4.6.2. The periodic analysis, conducted one day before the first spray, one day before the second spray, 15 days after the second spray on leaves and 15 days after the second spray on fruits, highlights the dynamic changes in zinc levels and their impact on both vegetative and reproductive growth.

The pooled periodic analysis at one day before the first spray in leaves revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interaction had a significant effect on Zn content in leaves (ppm).

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher Zn content in leaves (18.96 ppm), while the hybrid Indam Mamatha (H_1) recorded a statistically lower Zn content in leaves (18.88 ppm). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum Zn content in leaves (20.40 ppm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum Zn content in leaves (17.25 ppm).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum Zn content in leaves (20.50 ppm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum Zn content in leaves (17.00 ppm).

The pooled periodic analysis at one day before the second spray in leaves revealed that the effect of coloured capsicum hybrids on Zn content in leaves (ppm) was non-significant, while foliar nutrient applications and the interaction between coloured capsicum hybrids and foliar nutrient applications had a significant effect.

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a Zn content of 19.43 ppm in leaves, while the hybrid Indam Mamatha (H_1) recorded 19.41 ppm, with no significant difference between them. In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum Zn content in leaves (20.85 ppm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum Zn content in leaves (17.75 ppm).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum Zn content in leaves (21.00 ppm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum Zn content in leaves (17.50 ppm).

The pooled periodic analysis at 15 days after the second spray in leaves revealed that the effect of coloured capsicum hybrids, foliar nutrient applications and their interactions was significant for Zn content in leaves (ppm).

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher Zn content in leaves (20.19 ppm), while the hybrid Indam Mamatha (H_1) recorded a statistically lower Zn content in leaves (20.18 ppm). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum Zn content in leaves (21.76 ppm). The control treatment (M_8), with no foliar nutrient application, recorded the minimum Zn content in leaves (18.70 ppm).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications revealed that the maximum Zn content in leaves (22.00 ppm) was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The treatment combination H_1M_8 : Indam Mamatha + no foliar nutrient application (control), recorded the minimum Zn content in leaves (18.50 ppm).

The pooled periodic analysis at 15 days after the second spray in fruits revealed that the effect of coloured capsicum hybrids and foliar nutrient applications was significant for Zn content in fruits (ppm) whereas their interaction was non-significant.

Table 4.6.2: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on periodic analysis of zinc

Treatments	Periodic analysis of zinc (ppm) [Pooled]			
	One day before 1st spray (leaves)	One day before 2nd spray (leaves)	15 days after 2nd spray (leaves)	15 days after 2nd spray (fruits)
H_1	18.88	19.41	20.18	21.88
H_2	18.96	19.43	20.19	22.51
Mean	**18.92**	**19.42**	**20.18**	**22.20**
SE (m)±	**0.02**	**0.01**	**0.02**	**0.20**
$CD_{0.05}$	**0.04**	**NS**	**0.05**	**0.60**
M_1	18.70	19.25	20.04	21.73
M_2	18.75	19.20	19.92	23.10
M_3	18.70	19.20	19.81	22.09
M_4	19.29	19.75	20.50	23.23
M_5	18.75	19.35	19.95	21.45
M_6	19.50	20.00	20.79	23.23
M_7	20.40	20.85	21.76	24.78
M_8	17.25	17.75	18.70	17.97
Mean	**18.92**	**19.42**	**20.18**	**22.20**
SE (m)±	**0.03**	**0.02**	**0.04**	**0.40**
$CD_{0.05}$	**0.09**	**0.06**	**0.10**	**1.12**
Interaction:				
H_1M_1	18.00	18.50	19.48	20.52
H_1M_2	19.20	19.60	20.22	22.70
H_1M_3	18.40	19.00	19.52	20.97
H_1M_4	19.50	20.00	20.68	23.20
H_1M_5	18.80	19.50	20.12	21.47
H_1M_6	19.60	20.20	20.98	23.37
H_1M_7	20.50	21.00	22.00	24.97
H_1M_8	17.00	17.50	18.50	17.88
H_2M_1	19.40	20.00	20.60	22.95
H_2M_2	18.30	18.80	19.62	23.50
H_2M_3	19.00	19.40	20.10	23.22
H_2M_4	19.08	19.50	20.32	23.25
H_2M_5	18.70	19.20	19.78	21.43
H_2M_6	19.40	19.80	20.60	23.10
H_2M_7	20.30	20.70	21.52	24.60
H_2M_8	17.50	18.00	18.90	18.05
Mean	**18.92**	**19.42**	**20.18**	**22.20**
SE (m)±	**0.04**	**0.03**	**0.05**	**0.55**
$CD_{0.05}$	**0.13**	**0.09**	**0.15**	**NS**

*H_1 - Indam Mamatha; H_2 - Orobelle

*M_1 - Boric acid 0.5 %; M_2 - Zinc sulphate 0.5 %; M_3 - Calcium chloride 0.5 %; M_4 - Boric acid 0.5 % + Zinc sulphate 0.5%; M_5 - Boric acid 0.5 % + Calcium chloride 0.5 %; M_6 - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_7 - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; M_8 - Control (No spray)

zinc supplementation enhances nutrient translocation, enzyme activation and overall physiological performance, particularly when combined with other nutrients.

The hybrid “Orobelle” consistently recorded higher Zn content in leaves and fruits across different stages, indicating its superior Zn assimilation capacity compared to “Indam Mamatha.” This suggests that genetic variation among hybrids may influence nutrient uptake efficiency. However, the significant interaction between hybrids and nutrient applications indicates that external applications further enhance Zn uptake regardless of genetic differences.

The effectiveness of foliar nutrient applications in enhancing Zn content in plants can be attributed to the synergistic roles of zinc, boron and calcium. Zinc plays a crucial role in enzyme activation, protein synthesis and chlorophyll production, while boron supports cell wall integrity, reproductive development and nutrient translocation, ensuring efficient movement of minerals within the plant (Mondal et al. 2023). Calcium enhances cell wall stability and signaling pathways, further contributing to improved nutrient metabolism. Together, these nutrients optimize Zn assimilation and improve overall plant growth and productivity.

The maximum Zn content in leaves and fruits was observed in the treatment combination H_1M_7, wherein “Indam Mamatha” was treated with boric acid, zinc sulphate and calcium chloride. Similar results were reported by Haleema et al. (2024), who observed a significant increase in Zn accumulation in tomato following foliar application of these nutrients. Additionally, Vera-Maldonado et al. (2024) and Pagard et al. (2024) found that foliar nutrient supplementation improved Zn content and fruit quality in pepper and tomato crops, supporting the present findings.

The minimum Zn content in leaves and fruits was consistently recorded in the control treatment across both hybrids, indicating lower Zn uptake efficiency in the absence of foliar nutrient supplementation. This underscores the necessity of external nutrient applications to optimize Zn absorption and utilization. These findings align with previous studies by Mondal et al. (2023), who demonstrated that Zn-deficient plants exhibited poor fruit set, structural deformities and increased susceptibility to physiological disorders.

The observed stage-wise variations in Zn content in leaves and fruits may be attributed to differences in nutrient mobility, environmental factors and metabolic demands during different growth phases. The slightly higher Zn content in later stages compared to earlier ones suggests that variations in climatic conditions, particularly under protected cultivation, may influence Zn absorption and utilization. The interaction effect between coloured capsicum hybrids and foliar nutrient applications was significant across multiple stages, indicating that while both factors independently influenced Zn uptake, their combined effect varied over time.

The increased Zn content in leaves and fruits observed in this study implies that such foliar nutrient strategies can effectively enhance the nutritional quality of capsicum fruits. Higher Zn levels are associated with improved enzymatic activities, better fruit set and enhanced fruit quality, contributing to better marketability and consumer health benefits (Rabbi et al. 2024). Therefore, the strategic use of foliar nutrient applications not only supports optimal plant growth but also enhances the accumulation of essential nutrients in the edible parts of the plant, offering a practical approach to improving both yield and nutritional value in capsicum (Saha et al. 2023).

4.6.2 Periodic analysis of Ca content (%)

Periodic analysis of calcium (Ca) content (%) in plants is crucial for assessing the plant’s nutritional status and evaluating the effectiveness of calcium supplementation at different growth stages. Calcium is a vital macronutrient that plays a critical role in cell wall formation, membrane stability, nutrient transport and signaling pathways. It is also essential for maintaining structural integrity, reducing physiological disorders like blossom end rot and improving fruit quality. Monitoring calcium content at various stages, including before and after foliar applications, provides valuable insights into its uptake, translocation within the plant and its impact on both vegetative growth (leaves) and reproductive development (fruits).

The analysis of data collected in pooled results revealed significant variations in the calcium (Ca) content (%) in plants across different treatments at various stages, as presented in Table 4.6.3. The periodic analysis, conducted one day before the first spray, one day before the second spray, 15 days after the second spray on leaves and 15 days after the second spray on fruits, highlights the dynamic changes in calcium levels and their impact on both vegetative and reproductive growth.

The pooled periodic analysis at one day before the first spray in leaves revealed that the effect of coloured capsicum hybrids and foliar nutrient applications significant effect on Ca content in leaves (%) while their interaction had a non-significant effect.

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher Ca content in leaves (0.21 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower Ca content in leaves (0.20 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum Ca content in leaves (0.25 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum Ca content in leaves (0.18 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with values ranging from 0.17 to 0.23 %.

The pooled periodic analysis at one day before the second spray in leaves revealed that the effect of coloured capsicum hybrids and foliar nutrient applications significant effect on Ca content in leaves (%) while their interaction had a non-significant effect.

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher Ca content in leaves (0.23 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower Ca content in leaves (0.22 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum Ca content in leaves (0.27 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum Ca content in leaves (0.20 %).

The interaction effect between coloured capsicum hybrids and foliar nutrient applications had a non-significant effect with values ranging from 0.19 to 0.25 %.

The pooled periodic analysis at 15 days after the second spray in leaves revealed that the effect of coloured capsicum hybrids and foliar nutrient applications significant effect on Ca content in leaves (%) while their interaction had a non-significant effect.

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded the maximum Ca content in leaves (0.24 %), while the hybrid Indam Mamatha (H_1) recorded the minimum Ca content in leaves (0.23 %).

Table 4.6.3: Main and interaction effect of coloured capsicum hybrids and foliar nutrient applications on periodic analysis of calcium

Treatments	Periodic analysis of calcium (%) [Pooled]			
	One day before first spray (leaves)	One day before second spray (leaves)	15 days after second spray (leaves)	15 days after second spray (fruits)
H_1	0.20	0.22	0.23	0.24
H_2	0.21	0.23	0.24	0.25
Mean	**0.20**	**0.22**	**0.23**	**0.24**
SE (m)±	**0.01**	**0.01**	**0.01**	**0.02**
$CD_{0.05}$	**0.03**	**0.03**	**0.04**	**0.05**
M_1	0.19	0.21	0.23	0.22
M_2	0.20	0.22	0.24	0.23
M_3	0.21	0.23	0.25	0.26
M_4	0.21	0.23	0.25	0.24
M_5	0.20	0.22	0.24	0.26
M_6	0.21	0.23	0.25	0.26
M_7	0.25	0.27	0.29	0.30
M_8	0.18	0.20	0.22	0.20
Mean	**0.20**	**0.22**	**0.23**	**0.24**
SE (m)±	**0.01**	**0.01**	**0.02**	**0.02**
$CD_{0.05}$	**0.03**	**0.03**	**0.03**	**0.03**
Interaction:				
H_1M_1	0.18	0.20	0.22	0.21
H_1M_2	0.19	0.21	0.23	0.22
H_1M_3	0.20	0.22	0.24	0.25
H_1M_4	0.19	0.21	0.23	0.24
H_1M_5	0.20	0.22	0.24	0.26
H_1M_6	0.21	0.23	0.25	0.26
H_1M_7	0.22	0.24	0.26	0.28
H_1M_8	0.17	0.19	0.21	0.19
H_2M_1	0.19	0.21	0.23	0.24
H_2M_2	0.20	0.22	0.24	0.24
H_2M_3	0.21	0.23	0.25	0.27
H_2M_4	0.22	0.24	0.26	0.25
H_2M_5	0.20	0.22	0.24	0.25
H_2M_6	0.21	0.23	0.25	0.26
H_2M_7	0.23	0.25	0.27	0.29
H_2M_8	0.18	0.20	0.22	0.20
Mean	**0.20**	**0.22**	**0.23**	**0.24**
SE (m)±	**0.01**	**0.01**	**0.04**	**0.08**
$CD_{0.05}$	**NS**	**NS**	**NS**	**NS**

***H_1** - Indam Mamatha; **H_2** - Orobelle

***M_1** - Boric acid 0.5 %; **M_2** - Zinc sulphate 0.5 %; **M_3** - Calcium chloride 0.5 %; **M_4** - Boric acid 0.5 % + Zinc sulphate 0.5%; **M_5** - Boric acid 0.5 % + Calcium chloride 0.5 %; **M_6** - Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_7** - Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %; **M_8** - Control (No spray)

Regarding the effect of coloured capsicum hybrids, the hybrid Orobelle (H_2) recorded a statistically higher Ca content in fruits (0.25 %), while the hybrid Indam Mamatha (H_1) recorded a statistically lower Ca content in fruits (0.24 %). In terms of foliar nutrient applications, the combined foliar application of M_7 : Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % resulted in the maximum Ca content in fruits (0.30 %). The control treatment (M_8), with no foliar nutrient application, recorded the minimum Ca content in fruits (0.20 %). The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant with values ranging from 0.19 to 0.29 %.

The significant variations in calcium (Ca) content in leaves and fruits across different treatments highlight the impact of coloured capsicum hybrids and foliar nutrient applications on Ca accumulation. The higher Ca content observed in plants treated with foliar applications of boric acid, zinc sulphate and calcium chloride suggests improved Ca uptake efficiency. This aligns with the findings of Haleema et al. (2024) and Ziest et al. (2018), who reported that calcium supplementation enhances nutrient translocation, membrane stability and overall physiological performance, particularly when combined with other nutrients.

The hybrid “Orobelle” consistently recorded higher Ca content in leaves and fruits across different stages, indicating its superior Ca assimilation capacity compared to “Indam Mamatha.” This suggests that genetic variation among hybrids may influence nutrient uptake efficiency. However, the interaction effect between hybrids and nutrient applications remained non-significant, indicating that while hybrid differences exist, external foliar applications independently contribute to improved Ca uptake.

The effectiveness of foliar nutrient applications in enhancing Ca content in plants can be attributed to the synergistic roles of calcium, boron and zinc. Calcium plays a crucial role in cell wall stability, membrane integrity and intracellular signaling, while boron facilitates calcium mobility within plant tissues, ensuring efficient nutrient translocation. Zinc further supports enzymatic activation, protein synthesis and chlorophyll production, collectively optimizing Ca assimilation and improving overall plant health. Similar results were reported by Buczkowska et al. (2016), who observed increased calcium content in fruits following foliar application of calcium chloride, leading to enhanced fruit firmness and reduced physiological disorders.

The maximum Ca content in leaves and fruits was observed in the treatment M_7, indicating the effectiveness of this combination in improving Ca accumulation. The findings corroborate the results of Salim et al. (2019), who reported that calcium foliar application at 2000 ppm significantly increased calcium content in hot pepper plants. Additionally, Haleema et al. (2024) demonstrated that foliar application of boron, zinc and calcium enhanced calcium concentration in tomato plants, improving fruit quality and reducing physiological disorders.

The minimum Ca content in leaves and fruits was consistently recorded in the control treatment across both hybrids, indicating lower Ca uptake efficiency in the absence of foliar nutrient supplementation. This highlights the necessity of external nutrient applications to optimize Ca absorption and utilization. These findings align with previous studies by Anita (2022), who emphasized that adequate calcium levels in capsicum improve structural integrity, fruit quality and reduce susceptibility to physiological disorders such as blossom-end rot.

The observed stage-wise variations in Ca content in leaves and fruits may be attributed to differences in nutrient mobility, environmental factors and metabolic demands during different growth phases. The slightly higher Ca content in later stages compared to earlier ones suggests that variations in climatic conditions, particularly under protected cultivation, may influence Ca absorption and utilization. The non-significant interaction effect between coloured capsicum hybrids and foliar nutrient applications across multiple stages suggests that while both factors independently influence Ca uptake, their combined effect remains stable over time.

The increased Ca content in leaves and fruits observed in this study implies that such foliar nutrient strategies can effectively enhance the nutritional quality of capsicum fruits. Higher Ca levels are associated with improved cell wall stability, better fruit set and enhanced fruit firmness, contributing to better marketability and consumer health benefits (Rabbi et al. 2024). Therefore, the strategic use of foliar nutrient applications not only supports optimal plant growth but also enhances the accumulation of essential nutrients in the edible parts of the plant, offering a practical approach to improving both yield and nutritional value in capsicum (Saha et al. 2023).

4.7 Economics of the treatments

Economic analysis is pivotal in determining the profitability and sustainability of agricultural practices, particularly for crops like capsicum where inputs and management strategies significantly impact yield and quality. Key economic parameters, including cost of cultivation, gross return, net return and the benefit-cost (B:C) ratio, provide essential insights into the financial viability of different interventions. The cost of cultivation encompasses all production expenses, such as seeds, fertilizers, irrigation, labour and nutrient sprays, while gross return represents the revenue generated from the sale of coloured capsicum fruits. Net return, calculated by subtracting the cost of cultivation from the gross return, serves as a direct indicator of profitability. The B:C ratio, obtained by dividing gross return by the cost of cultivation, indicates the efficiency of resource use, with values above one reflecting a profitable practice.

In capsicum production, the role of foliar nutrient applications, such as boric acid, zinc sulphate and calcium chloride, is particularly critical in influencing yield, fruit quality and economic outcomes. Research indicates that these nutrient applications enhance physiological processes like photosynthesis, nutrient translocation and fruit development, ultimately improving marketable yield and financial returns (Haleema et al. 2024). Strategic nutrient combinations also reduce physiological disorders like blossom end rot and fruit cracking, further enhancing the economic value of the crop (Salim et al. 2019).

Analysing the economic impact of foliar nutrient applications provides valuable insights into their cost-effectiveness. Treatments combining multiple nutrients, such as boric acid, zinc sulphate and calcium chloride, have shown to maximize profitability by improving both yield and fruit quality (Haleema et al. 2024). Detailed treatment-wise cost of cultivation and return analysis, along with B:C ratios, offers a comprehensive understanding of the economic advantages of nutrient management strategies in capsicum production. These findings highlight the importance of informed decision-making to optimize inputs, enhance returns and ensure sustainable farming practices.

The treatment-wise average cost of cultivation and return analysis (B:C ratio) over the two years of the study is summarized in Table 4.7.1, with a detailed breakdown of fixed, variable and total costs available in Appendix II.

In the economic analysis, the treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % achieved the highest net returns of ₹ 908.85 per m^2, accompanied by the highest B:C ratio (2.56). This was followed by treatment combination H_2M_7: Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %, which gave net returns of ₹ 735.45 per m^2 and a corresponding B:C ratio (2.07).

The superior performance of treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % in terms of higher B:C ratio and net return can be attributed to the increased yield of coloured capsicum observed in this treatment. The enhanced fruit yield of hybrid "Indam Mamatha", resulting from the optimal nutrient conditions provided by the foliar application, contributed to the highest gross returns of ₹ 1263.60 per m^2. This was followed by treatment combination H_2M_7: Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % with gross returns of ₹ 1090.20 per m^2.

Table 4.7.1: Effect of coloured capsicum hybrids and foliar nutrient applications on economics of the treatments

Sr. No	Treatment	Fruit yield (kg/m^2)	Gross returns (₹/m^2)	Cost of cultivation (₹/m^2)	Net returns (₹/m^2)	Benefit: cost ratio
1.	H_1M_1	16.23	973.80	346.43	627.37	1.81
2.	H_1M_2	16.38	982.80	343.47	639.33	1.86
3.	H_1M_3	16.21	972.60	341.44	631.17	1.85
4.	H_1M_4	16.21	972.60	351.61	620.99	1.77
5.	H_1M_5	16.16	969.60	349.58	620.03	1.77
6.	H_1M_6	16.29	977.40	346.62	630.79	1.82
7.	H_1M_7	21.06	1263.60	354.76	908.85	2.56
8.	H_1M_8	14.09	845.40	338.29	507.11	1.50
9.	H_2M_1	14.31	858.60	346.43	512.17	1.48
10.	H_2M_2	14.42	865.20	343.47	521.73	1.52
11.	H_2M_3	14.29	857.40	341.44	515.97	1.51
12.	H_2M_4	14.30	858.00	351.61	506.39	1.44
13.	H_2M_5	14.28	856.80	349.58	507.23	1.45
14.	H_2M_6	14.43	865.80	346.62	519.19	1.50
15.	H_2M_7	18.17	1090.20	354.76	735.45	2.07
16.	H_2M_8	11.97	718.20	338.29	379.91	1.12
***Price of coloured capsicum - ₹ 60/kg**						

These findings align with research indicating that foliar applications of boric acid, zinc sulphate and calcium chloride can enhance capsicum plant growth and yield.

Similar to our findings, Shukla (2017) concluded that the treatment T_5 (B 0.1 % + Zn 0.2 % + Ca 0.2 % + Fe 0.2 %) recorded the highest gross income (₹ 225028/ ha), net returns (₹ 138528/ ha) and benefit-cost ratio (3.08) in tomato cv. Arka Rakshak. Similar results were also reported by Chhaba et al. (2024); Singh (2024); Yadav et al. (2023b); Anita (2022); Rayudu et al. (2017) and Saravaiya et al. (2014).

In coloured capsicum cultivation, the synergistic effect of boric acid, zinc sulphate and calcium chloride on hybrid "Indam Mamatha" is evident. Boron is essential for cell wall formation and membrane integrity, zinc plays a crucial role in enzyme activation and protein synthesis and calcium is vital for cell wall stability and signaling processes.

The concurrent application of these nutrients likely facilitates improved physiological functions, leading to increased fruit yield and quality.

The higher B:C ratio and net returns observed in treatment combination H_1M_7 suggest that the combination of boric acid, zinc sulphate and calcium chloride, along with hybrid "Indam Mamatha", provides a cost-effective strategy for enhancing capsicum productivity. This approach not only supports optimal plant growth but also enhances the accumulation of essential nutrients in the edible parts of the plant, offering a practical method to improve both yield and nutritional value in coloured capsicum cultivation.

Plate 4.1: Illustration of best treatment recorded – H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %

Plate 4.2: Illustration of best treatment recorded – H_1M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %

Chapter-5

SUMMARY AND CONCLUSION

The present research, titled **"Response of Micronutrient Applications on Hybrids of Coloured Capsicum,"** was undertaken to evaluate the impact of foliar application of micronutrients on the growth, yield, quality and economic viability of capsicum hybrids cultivated under polyhouse conditions. The study was conducted at the Experimental Farm and Laboratory of the Department of Vegetable Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, during the two consecutive years 2022-2023 and 2023-2024. The experiments were laid out in a Randomized Complete Block Design (Factorial) with three replications and sixteen treatment combinations.

The field experiments were conducted in a naturally ventilated polyhouse at an altitude of 1,270 meters above mean sea level, falling within the mid-hill zone of Himachal Pradesh. The polyhouse covered a total area of 200 m^2 and was divided into 48 experimental plots, each measuring 1.5 m^2. The study focused on two hybrids of coloured capsicum: "Indam Mamatha" (Red) from Indo American Hybrid Seeds (India) Pvt. Ltd., producing blocky, shiny red fruits weighing 125-250 g and "Orobelle" (Yellow) from Syngenta (India) Pvt. Ltd., producing smooth, blocky, yellow fruits weighing 100-250 g. The seeds of these hybrids were sown in 98-cell plastic pro trays filled with a cocopeat, vermiculite and perlite (3:1:1) medium, ensuring healthy seedling development. The seedlings were transplanted at a spacing of 45 cm × 30 cm, with 10 plants per plot.

The experiment consisted of eight levels of nutrient applications: Boric acid 0.5 % (M_1), Zinc sulphate 0.5 % (M_2), Calcium chloride 0.5 % (M_3), Boric acid 0.5 % + Zinc sulphate 0.5 % (M_4), Boric acid 0.5 % + Calcium chloride 0.5 % (M_5), Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_6), Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7) and a control with no foliar spray (M_8). These treatments were applied as foliar sprays at flower bud initiation and 30 days after the first application using a surfactant to enhance nutrient absorption.

Standard cultural practices, including fertigation through a drip irrigation system at bi-weekly intervals, manual weeding, pest and disease management, training and pruning, were followed to maintain a healthy crop. Plants were trained to retain two main branches and excess flowers and fruits were removed to optimize fruit size and number per plant.

The first harvest was carried out 70-75 days after transplanting and the yield parameters were recorded. Observations recorded during the experiment included growth and yield characters such as days to first picking, internodal length, plant height, leaf area index, fruit length, fruit breadth, fruit weight, number of pickings, number of fruits per plant, fruit yield per plant, fruit yield per m^2 and harvest duration. Quality parameters analyzed included total soluble solids, ascorbic acid content and carotenoid content. The study also examined incidence and severity of diseases, assessing incidence of collar rot, incidence of anthracnose and severity of powdery mildew.

In addition, soil analysis was conducted to determine soil pH, soil EC, organic carbon, available nitrogen, phosphorus and potassium content in soil and available boron, zinc and calcium content in soil. Plant analysis included measurements of nitrogen, phosphorus and potassium content in plants, as well as boron, zinc and calcium content in plants. Periodic analysis of nutrient uptake and soil fertility dynamics was also carried out to monitor changes over time.

The economics of treatments was a key aspect of the study, as it plays a crucial role in making recommendations for adoption by farmers. The cost of cultivation was calculated by summing the fixed costs per hectare, risk factors, management factors and costs associated with micronutrient applications. Net income was derived by subtracting the total cost of cultivation from gross income and the benefit-cost ratio (B:C ratio) was determined by dividing net income by total cost of cultivation.

Statistical analysis was performed using analysis of variance (ANOVA) to evaluate the significance of hybrids, micronutrient applications and their interactions on various growth, yield and quality parameters, soil parameters, plant biochemical analysis and economics of the treatments. The systematic collection of data across two years provided robust insights into the influence of micronutrient applications on capsicum productivity and profitability under protected cultivation, highlighting the most effective treatment combinations for maximizing yield and quality while ensuring economic feasibility.

The key experimental findings of the study, based on the pooled data from both years, are summarized as follows:

5.1 Growth and yield characters

- In the pooled data, the lowest days to first picking (72.50) and lowest internodal length (7.84 cm), highest fruit breadth (7.13 cm), fruit weight (189.03 g), fruit yield per plant (2.37 kg) and fruit yield per m² (16.58 kg) were observed in hybrid Indam Mamatha (H_1) whereas, highest leaf area index (3.36), fruit length (8.13 cm), number of pickings (7.19), number of fruits per plant (13.50) and harvest duration (82.94) were observed in hybrid Orobelle (H_2). The plant height was non-significant and the values ranged from 146.18 - 146.68 cm.
- The minimum values for days to first picking (71.75) and internodal length (7.40 cm), maximum values for plant height (162.08 cm), leaf area index (4.27), fruit length (8.72 cm), fruit breadth (7.78 cm), fruit weight (191.25 g), number of pickings (7.08), number of fruits per plant (14.75), fruit yield per plant (2.80 kg), fruit yield per m² (19.62 kg) and harvest duration (90.25) were observed with combined foliar application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7) in the pooled data.
- The minimum internodal length (7.40 cm), maximum values for plant height (164.67 cm), fruit breadth (8.17 cm), fruit weight (215.00 g) were recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % whereas, the maximum values for leaf area index (4.28) and fruit length (9.13 cm) were recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % in the pooled data.
- The interaction between hybrids and foliar nutrient applications was non-significant in the pooled analysis for days to first picking (71.50 - 74.33), number of pickings (5.67 - 7.83), number of fruits per plant (11.00 - 15.50), fruit yield per plant (1.71 - 3.01 kg), fruit yield per m^2 (11.97 - 21.06 kg) and harvest duration (72.50 to 90.67 days).

5.2 Quality parameters

- The highest ascorbic acid content (118.31 mg 100 g^{-1}) was recorded in hybrid Orobelle (H_2) whereas, the total soluble solids (6.80 - 6.83 °Brix) and carotenoid content (1.94 - 1.95 mg 100 g^{-1}) were non-significant in the pooled analysis from both years.

- The maximum values for the total soluble solids (7.12 °Brix), ascorbic acid content (121.47 mg 100 g^{-1}) and carotenoid content (2.11 mg 100 g^{-1}) were recorded with combined foliar application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7) in the pooled data.
- The maximum values for the total soluble solids (7.14 °Brix), ascorbic acid content (121.48 mg 100 g^{-1}) and carotenoid content (2.12 mg 100 g^{-1}) were recorded in treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % in the pooled data.

5.3 Incidence and severity of diseases in capsicum

- The lowest incidence of collar rot (8.75 %) was observed in hybrid Indam Mamatha (H_1) and the lowest severity of powdery mildew (9.11 %) was recorded in hybrid Orobelle (H_2). The effect of hybrids was non-significant for incidence of anthracnose and the values ranged from 5.27 - 5.53 % in the pooled analysis.
- The minimum incidence of collar rot (5.00 %) and the minimum severity of powdery mildew (8.13 %) was recorded with combined foliar application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7) in the pooled data. The effect of foliar nutrient applications was non-significant for incidence of anthracnose and the values ranged from 3.16 - 8.11 % in the pooled analysis.
- The minimum incidence of collar rot was (4.44 %) recorded with the treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %.
- The interaction between hybrids and foliar nutrient applications was non-significant in the pooled analysis for incidence of anthracnose (2.71 - 8.56 %) and severity of powdery mildew (7.92 - 11.19 %) .

5.4 Soil analysis

- The pH values of the soil in pooled analysis were within the range of 7.43 - 7.46 which was in the suitable range for the cultivation of coloured capsicum
- Electrical conductivity of the soil in pooled analysis ranged from 0.237 - 0.258 dSm^{-1} which was also within suitable limit for the cultivation of coloured capsicum.

- The organic carbon values of the soil in pooled analysis were within the range of 1.29 - 1.35 % which is quite suitable range the cultivation of coloured capsicum.
- After the harvest of coloured capsicum, the pooled soil analysis showed that plots with the hybrid Indam Mamatha (H_1) had the lowest available N, P and K content in soil, measuring 295.27, 49.16 and 369.39 kg ha^{-1}, respectively. Similarly, the lowest available boron (0.239 mg kg^{-1}) and calcium (143.03 mg kg^{-1}) content in soil were also recorded in plots with the hybrid Indam Mamatha (H_1). The zinc content in soil was non-significant with values ranging from 2.58 - 2.63 mg kg^{-1}.
- The pooled soil analysis revealed that after the harvest of coloured capsicum, the minimum available N, P and K content in soil, measuring 292.83, 47.51 and 352.28 kg ha^{-1}, respectively were observed with combined foliar application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7). Similarly, the minimum available boron (0.210 mg kg^{-1}), zinc (2.23 mg kg^{-1}) and calcium (134.73 mg kg^{-1}) content in soil were observed with combined foliar application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7).
- The pooled soil analysis from both years revealed that after the harvest of coloured capsicum, the minimum available N, P and K content in soil, measuring 292.70, 47.43 and 352.19 kg ha^{-1}, respectively were observed in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %.
- The pooled soil analysis from both years revealed that after the harvest of coloured capsicum, the minimum available boron and calcium content in soil, measuring 0.207 and 134.33 mg kg^{-1}, respectively were observed in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. The interaction effect for zinc content in soil was non-significant with values ranging from 2.16 - 3.52 mg kg^{-1}.

5.5 Plant analysis

- The pooled plant analysis revealed that the highest N (2.62 %), P (0.31 %) and K (3.35 %) content in plants was recorded in hybrid Indam Mamatha (H_1). Similarly, the highest boron (19.62 ppm) and calcium (1.02 %) content in plants was recorded in hybrid Indam Mamatha (H_1). The zinc content in plants was non-significant with values ranging from 30.92 - 32.14 ppm.

- The pooled plant analysis revealed that the maximum N (3.08 %), P (0.36 %) and K (3.61 %) content in plants was observed with combined foliar application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7). Similarly, the maximum boron (22.99 ppm), zinc (42.77 ppm) and calcium (1.15 %) content in plants was observed with combined foliar application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7).
- The pooled plant analysis revealed that the maximum N (3.09 %), K (3.62 %) and calcium (1.16 %) content in plants was recorded in treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %.
- The interaction between hybrids and foliar nutrient applications for K content (0.25 - 0.36 %), boron content (15.60 - 23.08 ppm) and zinc content (24.74 - 43.39 ppm) in plants was non-significant.

5.6 Periodic analysis of nutrients

- The pooled periodic analysis revealed that the boron content in leaves was non-significant for coloured capsicum hybrids at one day before the first spray (16.45 - 16.46 ppm) and one day before the second spray (17.19 - 17.20 ppm) in leaves. However, the highest boron content at 15 days after the second spray in leaves (17.91 ppm) and fruits (19.65 ppm) was recorded in the hybrid Orobelle (H_2).
- The maximum boron content in leaves was recorded at one day before the first spray (18.10 ppm), one day before the second spray (18.90 ppm) and 15 days after the second spray (19.50 ppm) with the combined foliar application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7). Similarly, the maximum boron content in fruits (21.77 ppm) was recorded 15 days after the second spray with the same foliar application (M_7).
- The maximum boron content in leaves was recorded at one day before the first spray (18.20 ppm), one day before the second spray (19.00 ppm) and 15 days after the second spray (19.60 ppm) in the treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. In fruits, the interaction effect was non-significant, with boron content ranging from 16.80 - 21.96 ppm.
- The pooled periodic analysis revealed that the zinc content in leaves was non-significant for coloured capsicum hybrids at one day before the second spray (19.41 - 19.43 ppm). However, the highest zinc content at one day before the first spray (18.96

ppm) and 15 days after the second spray (20.19 ppm) in leaves, as well as in fruits (22.51 ppm), was recorded in the hybrid Orobelle (H_2).

- The maximum zinc content in leaves was recorded at one day before the first spray (20.40 ppm), one day before the second spray (20.85 ppm) and 15 days after the second spray (21.76 ppm) with the combined foliar application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7). Similarly, the maximum zinc content in fruits (24.78 ppm) was recorded 15 days after the second spray with the same foliar application (M_7).
- The maximum zinc content in leaves was recorded at one day before the first spray (20.50 ppm), one day before the second spray (21.00 ppm) and 15 days after the second spray (22.00 ppm) in the treatment combination H_1M_7: Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %. In fruits, the interaction effect was non-significant, with zinc content ranging from 17.88 - 24.97 ppm.
- The highest values for calcium content in leaves at one day before the first spray (0.21 %), one day before the second spray (0.23 %) and 15 days after the second spray (0.24 %) in leaves, as well as in fruits (0.25 %), was recorded in the hybrid Orobelle (H_2).
- The maximum calcium content in leaves was recorded at one day before the first spray (0.25 %), one day before the second spray (0.27 %) and 15 days after the second spray (0.29 %) with the combined foliar application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7). Similarly, the maximum calcium content in fruits (0.30 %) was recorded 15 days after the second spray with the same foliar application (M_7).
- The interaction effect between coloured capsicum hybrids and foliar nutrient applications was non-significant, with calcium content in leaves ranging from 0.17 - 0.23 % at one day before the first spray, 0.19 - 0.25 % at one day before the second spray and 0.21 - 0.27 % at 15 days after the second spray. In fruits, the interaction effect was also non-significant, with calcium content ranging from 0.19 - 0.29 %.

5.7 Economics of the treatments

- In the economic analysis, the treatment combination H_1M_7 : Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % achieved the highest net returns of ₹ 908.85 per m^2, accompanied by the highest B:C ratio (2.56).

- This was followed by the treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % with the net returns of ₹ 735.45 per m^2, accompanied by the B:C ratio of 2.07.

CONCLUSION

The present investigation, titled **"Response of Micronutrient Applications on Hybrids of Coloured Capsicum,"** was undertaken to evaluate the impact of foliar nutrient applications on the growth, yield, fruit quality and economic viability of coloured capsicum hybrids under polyhouse conditions. The study revealed significant variations in growth and yield attributes, fruit quality parameters, disease incidence and severity, soil and plant nutrient status, periodic nutrient analysis and economic returns in response to different foliar nutrient applications. Additionally, the interaction between capsicum hybrids and foliar nutrient applications exhibited notable effects on overall plant performance, highlighting the potential for optimizing nutrient management strategies to enhance productivity and profitability in protected cultivation systems.

The study revealed that both the coloured capsicum hybrids Indam Mamatha (H_1) and Orobelle (H_2) exhibited superior agronomic performance, with Indam Mamatha (H_1) recording the highest productivity and comparable fruit quality attributes to Orobelle (H_2).

The combined foliar application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7) significantly enhanced vegetative growth, yield components and fruit quality parameters, establishing its effectiveness in optimizing coloured capsicum production.

Among the treatment combinations, Indam Mamatha with foliar nutrient application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (H_1M_7) emerged as the most promising treatment, demonstrating the highest net returns (₹ 908.85/m^2) and highest benefit-cost ratio (2.56), making it the most economically viable option under polyhouse conditions. This was followed by the treatment combination H_2M_7 : Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % which recorded net returns of ₹ 735.45 per m^2, with a benefit-cost ratio of 2.07.

Based on the results of this study, it can be concluded that both Indam Mamatha (H_1) and Orobelle (H_2) are well-suited for polyhouse cultivation, with their selection dependent on market demand for red or yellow capsicum. The foliar application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % at the flower bud initiation stage and 30 days after the first application was identified as the most effective foliar nutrient combination, significantly enhancing plant growth, yield and fruit quality. This scientifically validated approach offers a profitable and efficient cultivation strategy for coloured capsicum under mid-hill conditions of Himachal Pradesh.

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APPENDIX - I

AGRO-METEROLOGICAL DATA

Mean monthly meteorological data of Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan during the research period (February 2022 to October 2022)

Month	Outside the polyhouse			Inside the polyhouse		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
2022						
February 2022	18.70	2.70	10.70	22.20	10.50	16.35
March 2022	28.60	9.40	19.00	32.10	14.70	23.40
April 2022	33.20	13.30	23.25	36.70	18.60	27.65
May 2022	32.00	16.10	24.05	35.50	21.40	28.45
June 2022	32.10	17.70	24.90	35.60	23.00	29.30
July 2022	28.50	20.50	24.50	32.00	25.80	28.90
August 2022	29.00	19.90	24.45	32.50	25.20	28.85
September 2022	27.80	17.80	22.80	31.30	23.10	27.20
October 2022	26.30	11.40	18.85	29.80	16.70	23.25

Mean monthly meteorological data of Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan during the research period (February 2023 to October 2023)

Month	Outside the polyhouse			Inside the polyhouse		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
2023						
February 2023	23.80	5.60	14.70	28.30	10.10	19.20
March 2023	23.60	8.10	15.85	28.10	12.60	20.35
April 2023	26.60	10.50	18.55	31.10	15.00	23.05
May 2023	27.90	13.20	20.55	32.40	17.70	25.05
June 2023	29.30	17.40	23.35	33.80	21.90	27.85
July 2023	27.50	20.10	23.80	32.00	24.60	28.30
August 2023	29.00	20.10	24.55	33.50	24.60	29.05
September 2023	29.70	18.20	23.95	34.20	22.70	28.45
October 2023	27.20	10.70	18.95	31.70	15.20	23.45

Source: 1. Temperature outside the polyhouse - Meteorological Observatory, Department of Environmental Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, HP- 173 230
2. Temperature inside the polyhouse - Recorded by using digital thermometer

APPENDIX – II

Cost of cultivation of coloured capsicum as affected by different treatments

A. Fixed cost			
S. No.	**Particulars**	**Quantity required / m^2**	**Cost ₹/m^2**
1.	Cost of planting material	7 plants @ ₹ 2.0/plant	14
2.	Nursery management	1 hour @ ₹ 440/man day)	28.57
3.	Preparation of beds	(Soil + Cocopeat @ 4.03 kg/m^2 + Vermicompost @ 4.17 kg/m^2 + FYM @ 5.56 kg/m^2)	110.49
4.	Labour cost for land preparation and planting	1 hour @ ₹ 440/ man day	28.57
5.	Labour cost for weeding, staking, pruning and harvesting	2 hour @ ₹ 440/ man day	57.14
6.	Plant protection measures		5.92
7.	Cost of polyhouse and Depreciation @ 5 % per annum	For 12 months @ ₹ 62.5/ m^2	62.5
8.	19:19:19 application @ 5 gm/l	5 g/l @ ₹ 170 /kg	0.85
9.	Drip irrigation, Electricity charges	For 12 months @ ₹0.83/m^2	1.1
10.	Miscellaneous expenses		30
		Grand Total	**338.29**

B. Variable cost			
Treatment	**Treatment combinations**	**Treatment details**	**Cost ₹ /m^2**
T_1	H_1M_1	Indam Mamatha + Boric acid 0.5 %	8.14
T_2	H_1M_2	Indam Mamatha + Zinc sulphate 0.5 %	5.18
T_3	H_1M_3	Indam Mamatha + Calcium chloride 0.5 %	3.15
T_4	H_1M_4	Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 %	13.32
T_5	H_1M_5	Indam Mamatha + Boric acid 0.5 % + Calcium chloride 0.5 %	11.29
T_6	H_1M_6	Indam Mamatha + Zinc sulphate 0.5 % + Calcium chloride 0.5 %	8.33
T_7	H_1M_7	Indam Mamatha + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %	16.47
T_8	H_1M_8	Indam Mamatha + Control (no spray)	0
T_9	H_2M_1	Orobelle + Boric acid 0.5 %	8.14
T_{10}	H_2M_2	Orobelle + Zinc sulphate 0.5 %	5.18
T_{11}	H_2M_3	Orobelle + Calcium chloride 0.5 %	3.14
T_{12}	H_2M_4	Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 %	13.32
T_{13}	H_2M_5	Orobelle + Boric acid 0.5 % + Calcium chloride 0.5 %	11.28
T_{14}	H_2M_6	Orobelle + Zinc sulphate 0.5 % + Calcium chloride 0.5 %	8.32
T_{15}	H_2M_7	Orobelle + Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 %	16.46
T_{16}	H_2M_8	Orobelle + Control (no spray)	0

Cost of different inputs used for working out cost of cultivation

S. No.	Input used	Cost ₹/m^2
1.	Boric acid @ 3.7 g/m^2 @ ₹ 2.2/g	8.14
2	Zinc sulphate @ 3.7 g/m^2 @ ₹ 1.4/g	5.18
3.	Calcium chloride @ 3.7 g/m^2 @ ₹ 0.85/g	3.15

Total cost of cultivation for different treatments

C. Total cost			
Treatment	**Treatment combinations**	**Fixed cost (A.) + Variable cost (B.)**	**Total cost**
T_1	**H_1M_1**	338.29 + 8.14	346.43
T_2	**H_1M_2**	338.29 + 5.18	343.47
T_3	**H_1M_3**	338.29 + 3.14	341.44
T_4	**H_1M_4**	338.29 + 13.32	351.61
T_5	**H_1M_5**	338.29 + 11.28	349.58
T_6	**H_1M_6**	338.29 + 8.32	346.62
T_7	**H_1M_7**	338.29 + 16.46	354.76
T_8	**H_1M_8**	338.29 + 0	338.29
T_9	**H_2M_1**	338.29 + 8.14	346.43
T_{10}	**H_2M_2**	338.29 + 5.18	343.47
T_{11}	**H_2M_3**	338.29 + 3.14	341.44
T_{12}	**H_2M_4**	338.29 + 13.32	351.61
T_{13}	**H_2M_5**	338.29 + 11.28	349.58
T_{14}	**H_2M_6**	338.29 + 8.32	346.62
T_{15}	**H_2M_7**	338.29 + 16.46	354.76
T_{16}	**H_2M_8**	338.29 + 0	338.29

APPENDIX – III

Analysis of variance table for days to first picking

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	15.54		
Factor H	1	9.18	9.18	7.29
Factor M	7	23.31	3.33	2.64
Interaction H × M	7	4.64	0.66	0.52
Error	30	37.79	1.26	
Total	47	90.47		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	2.66		
Factor H	1	0.75	0.75	0.42
Factor M	7	23.25	3.32	1.86
Interaction H × M	7	17.91	2.56	1.44
Error	30	53.33	1.77	
Total	47	97.91		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	15.43		
Factor H	1	7.59	7.59	5.01
Factor M	7	44.15	6.30	4.16
Interaction H × M	7	13.82	1.97	1.30
Error	62	93.89	1.51	
Total	95	188.40		

Analysis of variance table for internodal length

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.64		
Factor H	1	0.30	0.30	231.65
Factor M	7	5.92	0.84	651.96
Interaction H × M	7	0.29	0.04	32.17
Error	30	0.03	0.00	
Total	47	7.20		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.32		
Factor H	1	0.24	0.24	1,208.84
Factor M	7	5.01	0.71	3,593.41
Interaction H × M	7	0.37	0.05	269.06
Error	30	0.00	0.00	
Total	47	5.96		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.92		
Factor H	1	0.54	0.54	432.32
Factor M	7	10.90	1.55	1,246.48
Interaction H × M	7	0.65	0.09	74.40
Error	62	0.07	0.001	
Total	95	18.48		

Analysis of variance table for plant height

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	29.54		
Factor H	1	52.08	52.08	1.09
Factor M	7	3,757.25	536.75	11.30
Interaction H × M	7	1,080.58	154.36	3.25
Error	30	1,424.45	47.48	
Total	47	6,343.91		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	236.54		
Factor H	1	14.08	14.08	0.26
Factor M	7	4,986.66	712.38	13.17
Interaction H × M	7	2,372.58	338.94	6.26
Error	30	1,622.79	54.09	
Total	47	9,232.66		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	200.68		
Factor H	1	6.00	6.00	0.12
Factor M	7	8,402.12	1,200.30	23.90
Interaction H × M	7	3,275.83	467.97	9.32
Error	62	3,112.64	50.20	
Total	95	17,431.62		

Analysis of variance table for leaf area index

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.85		
Factor H	1	0.14	0.14	6.26
Factor M	7	11.96	1.70	75.34
Interaction H × M	7	1.76	0.25	11.08
Error	30	0.68	0.02	
Total	47	15.39		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.72		
Factor H	1	0.08	0.08	23.79
Factor M	7	7.14	1.02	291.55
Interaction H × M	7	0.55	0.07	22.58
Error	30	0.10	0.004	
Total	47	8.60		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	1.56		
Factor H	1	0.22	0.22	17.24
Factor M	7	18.62	2.66	207.04
Interaction H × M	7	2.12	0.30	23.62
Error	62	0.79	0.01	
Total	95	28.16		

Analysis of variance table for fruit length

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.05		
Factor H	1	1.05	1.05	58.84
Factor M	7	4.84	0.69	38.79
Interaction H × M	7	0.66	0.09	5.32
Error	30	0.53	0.01	
Total	47	7.15		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.08		
Factor H	1	1.08	1.08	115.18
Factor M	7	4.95	0.70	75.47
Interaction H × M	7	0.39	0.05	6.04
Error	30	0.28	0.01	
Total	47	6.79		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.11		
Factor H	1	2.12	2.12	157.03
Factor M	7	9.57	1.36	100.95
Interaction H × M	7	1.03	0.14	10.93
Error	62	0.84	0.01	
Total	95	18.15		

Analysis of variance table for fruit breadth

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.25		
Factor H	1	11.40	11.40	9,311.43
Factor M	7	11.96	1.71	1,395.77
Interaction H × M	7	0.05	0.001	6.16
Error	30	0.03	0.01	
Total	47	23.72		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.30		
Factor H	1	11.70	11.70	10,622.48
Factor M	7	10.26	1.46	1,330.90
Interaction H × M	7	0.12	0.01	16.39
Error	30	0.03	0.01	
Total	47	22.42		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.55		
Factor H	1	23.11	23.11	20,740.27
Factor M	7	21.40	3.05	2,743.69
Interaction H × M	7	0.16	0.02	21.04
Error	62	0.06	0.01	
Total	95	46.58		

Analysis of variance table for fruit weight

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	6.54		
Factor H	1	15,534.00	15,534.00	10,806.26
Factor M	7	3,119.91	445.70	310.05
Interaction H × M	7	291.53	41.64	28.97
Error	30	43.12	1.43	
Total	47	18,995.12		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	10.53		
Factor H	1	15,069.79	15,069.79	19,683
Factor M	7	2,547.32	363.90	475.30
Interaction H × M	7	191.57	27.36	35.74
Error	30	22.96	0.76	
Total	47	17,842.20		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	13.16		
Factor H	1	30,602.04	30,602.04	27,102.64
Factor M	7	5,636.57	805.22	713.14
Interaction H × M	7	476.79	68.11	60.32
Error	62	70.01	1.12	
Total	95	37,585.49		

Analysis of variance table for number of pickings

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.50		
Factor H	1	16.33	16.33	36.29
Factor M	7	6.58	0.94	2.09
Interaction H × M	7	2.33	0.33	0.74
Error	30	13.50	0.45	
Total	47	39.25		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	1.12		
Factor H	1	17.52	17.52	35.33
Factor M	7	4.31	0.61	1.24
Interaction H × M	7	0.97	0.14	0.28
Error	30	14.87	0.49	
Total	47	38.81		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	1.56		
Factor H	1	33.84	33.84	73.78
Factor M	7	8.74	1.24	2.72
Interaction H × M	7	1.40	0.20	0.43
Error	62	28.43	0.45	
Total	95	99.15		

Analysis of variance table for number of fruits per plant

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.22		
Factor H	1	15.18	15.18	160.22
Factor M	7	30.26	4.32	45.61
Interaction H × M	7	0.65	0.09	0.99
Error	30	2.84	0.09	
Total	47	49.18		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.45		
Factor H	1	9.18	9.18	38.00
Factor M	7	44.55	6.36	26.33
Interaction H × M	7	2.64	0.37	1.56
Error	30	7.25	0.24	
Total	47	64.09		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.38		
Factor H	1	23.98	23.98	143.11
Factor M	7	73.94	10.56	63.02
Interaction H × M	7	1.51	0.21	1.29
Error	62	10.39	0.16	
Total	95	113.58		

Analysis of variance table for fruit yield per plant

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.01		
Factor H	1	0.92	0.92	371.41
Factor M	7	2.56	0.36	146.68
Interaction H × M	7	0.03	0.01	1.99
Error	30	0.07	0.01	
Total	47	3.60		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.01		
Factor H	1	1.17	1.17	180.33
Factor M	7	3.15	0.45	69.04
Interaction H × M	7	0.05	0.01	1.26
Error	30	0.19	0.01	
Total	47	4.60		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.01		
Factor H	1	2.09	2.09	463.19
Factor M	7	5.69	0.81	179.77
Interaction H × M	7	0.05	0.01	1.59
Error	62	0.28	0.01	
Total	95	8.42		

Analysis of variance table for fruit yield per m^2

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.31		
Factor H	1	45.23	45.23	360.86
Factor M	7	125.60	17.94	143.13
Interaction H × M	7	1.74	0.24	1.98
Error	30	3.76	0.12	
Total	47	176.65		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.52		
Factor H	1	57.24	57.24	178.48
Factor M	7	155.0	22.14	69.03
Interaction H × M	7	2.79	0.39	1.24
Error	30	9.62	0.32	
Total	47	225.19		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.37		
Factor H	1	102.13	102.13	457.33
Factor M	7	279.51	39.93	178.80
Interaction H × M	7	2.48	0.35	1.58
Error	62	13.84	0.22	
Total	95	412.63		

Analysis of variance table for harvest duration

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	40.62		
Factor H	1	176.33	176.33	34.64
Factor M	7	728.33	104.04	20.44
Interaction H × M	7	25.00	3.57	0.70
Error	30	152.70	5.09	
Total	47	1,123.0		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	15.29		
Factor H	1	192.00	192.00	56.44
Factor M	7	803.91	114.84	33.76
Interaction H × M	7	34.66	4.95	1.45
Error	30	102.04	3.40	
Total	47	1,147.91		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	32.33		
Factor H	1	368.16	368.16	82.01
Factor M	7	1,463.95	209.13	46.58
Interaction H × M	7	54.16	7.73	1.72
Error	62	278.33	4.48	
Total	95	2,275.95		

Analysis of variance table for total soluble solid

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.036		
Factor H	1	0.004	0.004	0.27
Factor M	7	1.760	0.251	19.03
Interaction H × M	7	0.163	0.023	1.75
Error	30	0.396	0.013	
Total	47	2.358		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.003		
Factor H	1	0.010	0.010	5.53
Factor M	7	0.244	0.035	18.55
Interaction H × M	7	0.037	0.005	2.81
Error	30	0.056	0.002	
Total	47	0.351		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.024		
Factor H	1	0.011	0.011	1.52
Factor M	7	1.641	0.234	31.13
Interaction H × M	7	0.166	0.024	3.15
Error	62	0.467	0.008	
Total	95	6.064		

Analysis of variance table for ascorbic acid content

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.095		
Factor H	1	0.003	0.003	0.08
Factor M	7	167.49	23.92	643.67
Interaction H × M	7	2.21	0.31	8.52
Error	30	1.11	0.037	
Total	47	170.926		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.062		
Factor H	1	0.10	0.10	3.07
Factor M	7	16.27	2.32	67.06
Interaction H × M	7	1.534	0.219	6.323
Error	30	1.040	0.035	
Total	47	18.800		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.354		
Factor H	1	0.12	0.12	4.04
Factor M	7	143.29	20.47	648.27
Interaction H × M	7	3.42	0.49	15.50
Error	62	1.95	0.03	
Total	95	336.92		

Analysis of variance table for carotenoid content

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.004		
Factor H	1	0.001	0.001	1.30
Factor M	7	0.305	0.044	52.37
Interaction H × M	7	0.067	0.010	11.51
Error	30	0.025	0.001	
Total	47	0.403		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.003		
Factor H	1	0.002	0.002	1.30
Factor M	7	0.294	0.042	30.23
Interaction H × M	7	0.077	0.011	7.93
Error	30	0.042	0.001	
Total	47	0.418		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.007		
Factor H	1	0.003	0.003	2.80
Factor M	7	0.599	0.086	79.51
Interaction H × M	7	0.144	0.021	19.09
Error	62	0.067	0.001	
Total	95	0.963		

Analysis of variance table for incidence of collar rot

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	42.13		
Factor H	1	75.00	75.00	8.59
Factor M	7	707.43	101.06	11.58
Interaction H × M	7	132.28	18.89	2.16
Error	30	261.67	8.72	
Total	47	1,218.52		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	43.09		
Factor H	1	5.79	5.79	0.50
Factor M	7	242.21	34.60	3.03
Interaction H × M	7	70.02	10.00	0.87
Error	30	342.10	11.40	
Total	47	703.22		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	53.00		
Factor H	1	61.24	61.24	5.97
Factor M	7	866.40	123.77	12.06
Interaction H × M	7	158.05	22.57	2.20
Error	62	635.99	10.25	
Total	95	1,924.64		

Analysis of variance table for incidence of anthracnose

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	62.10		
Factor H	1	0.004	0.004	0.00
Factor M	7	89.47	12.78	1.27
Interaction H × M	7	5.91	0.84	0.08
Error	30	299.85	9.99	
Total	47	457.35		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	11.78		
Factor H	1	3.41	3.41	0.40
Factor M	7	102.90	14.70	1.72
Interaction H × M	7	37.13	5.30	0.62
Error	30	255.87	8.52	
Total	47	411.11		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	60.17		
Factor H	1	1.58	1.58	0.17
Factor M	7	177.45	25.35	2.76
Interaction H × M	7	21.02	3.00	0.32
Error	62	569.44	9.18	
Total	95	896.58		

Analysis of variance table for powdery mildew

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	301.04		
Factor H	1	9.10	9.10	11.34
Factor M	7	15.14	2.16	2.69
Interaction H × M	7	4.38	0.62	0.78
Error	30	24.07	0.80	
Total	47	353.74		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	799.50		
Factor H	1	17.48	17.48	13.79
Factor M	7	26.97	3.85	3.04
Interaction H × M	7	9.47	1.35	1.06
Error	30	38.03	1.26	
Total	47	891.47		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	1,020.45		
Factor H	1	25.90	25.90	11.29
Factor M	7	41.19	5.88	2.56
Interaction H × M	7	13.27	1.89	0.82
Error	62	142.20	2.29	
Total	95	1,405.41		

Analysis of variance table for available pH

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.002		
Factor H	1	0.001	0.001	1.518
Factor M	7	0.005	0.001	1.357
Interaction H × M	7	0.006	0.001	1.762
Error	30	0.015	0.001	
Total	47	0.029		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.000		
Factor H	1	0.000	0.000	0.034
Factor M	7	0.006	0.001	1.097
Interaction H × M	7	0.011	0.002	2.051
Error	30	0.023	0.001	
Total	47	0.040		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.002		
Factor H	1	0.002	0.002	2.712
Factor M	7	0.004	0.001	0.957
Interaction H × M	7	0.003	0.000	0.689
Error	62	0.038	0.001	
Total	95	0.272		

Analysis of variance table for EC

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.011		
Factor H	1	0.000	0.000	0.550
Factor M	7	0.004	0.001	2.256
Interaction H × M	7	0.002	0.000	1.412
Error	30	0.007	0.000	
Total	47	0.025		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.003		
Factor H	1	0.000	0.000	0.598
Factor M	7	0.003	0.000	1.818
Interaction H × M	7	0.001	0.000	0.506
Error	30	0.007	0.000	
Total	47	0.014		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.009		
Factor H	1	0.000	0.000	0.861
Factor M	7	0.003	0.000	1.482
Interaction H × M	7	0.000	0.000	0.224
Error	62	0.019	0.000	
Total	95	0.041		

Analysis of variance table for organic carbon

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	-0.000		
Factor H	1	0.000	0.000	
Factor M	7	0.008	0.001	0.409
Interaction H × M	7	0.009	0.001	0.429
Error	30	0.085	0.003	
Total	47	0.102		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.017		
Factor H	1	0.002	0.002	1.250
Factor M	7	0.015	0.002	1.216
Interaction H × M	7	0.002	0.000	0.178
Error	30	0.051	0.002	
Total	47	0.087		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.009		
Factor H	1	0.001	0.001	0.465
Factor M	7	0.022	0.003	1.320
Interaction H × M	7	0.001	0.000	0.064
Error	62	0.145	0.002	
Total	95	0.190		

Analysis of variance table for available N

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.94		
Factor H	1	193.37	193.37	880.29
Factor M	7	412.26	58.89	268.09
Interaction H × M	7	63.11	9.01	41.04
Error	30	6.59	0.22	
Total	47	676.28		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.96		
Factor H	1	65.04	65.04	2,251.16
Factor M	7	148.60	21.22	734.77
Interaction H × M	7	24.70	3.53	122.16
Error	30	0.86	0.02	
Total	47	240.18		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	1.89		
Factor H	1	241.66	241.66	2,005.47
Factor M	7	521.85	74.55	618.66
Interaction H × M	7	81.24	11.60	96.31
Error	62	7.47	0.12	
Total	95	1,184.64		

Analysis of variance table for available P

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.52		
Factor H	1	49.34	49.34	206.70
Factor M	7	128.71	18.38	77.02
Interaction H × M	7	19.63	2.80	11.74
Error	30	7.16	0.23	
Total	47	205.37		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.95		
Factor H	1	26.39	26.39	108.25
Factor M	7	69.84	9.97	40.92
Interaction H × M	7	6.90	0.98	4.04
Error	30	7.31	0.24	
Total	47	111.40		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.79		
Factor H	1	73.79	73.79	301.83
Factor M	7	186.35	26.62	108.88
Interaction H × M	7	23.80	3.40	13.90
Error	62	15.15	0.24	
Total	95	323.08		

Analysis of variance table for available K

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	6.01		
Factor H	1	2,579.63	2,579.63	1,604.19
Factor M	7	5,525.69	789.38	490.89
Interaction H × M	7	662.50	94.64	58.85
Error	30	48.24	1.60	
Total	47	8,822.08		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	33.63		
Factor H	1	372.80	372.80	15.41
Factor M	7	2,863.44	409.06	16.91
Interaction H × M	7	1,257.55	179.65	7.43
Error	30	725.34	24.17	
Total	47	5,252.78		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	11.17		
Factor H	1	2,451.72	2,451.72	189.52
Factor M	7	7,145.39	1,020.77	78.90
Interaction H × M	7	1,225.31	175.04	13.53
Error	62	802.05	12.93	
Total	95	46,139.74		

Analysis of variance table for available B

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.002		
Factor H	1	0.001	0.001	3.26
Factor M	7	0.027	0.004	14.16
Interaction H × M	7	0.009	0.001	4.54
Error	30	0.008	0.000	
Total	47	0.047		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.000		
Factor H	1	0.002	0.002	33.89
Factor M	7	0.019	0.003	59.51
Interaction H × M	7	0.005	0.001	16.59
Error	30	0.001	0.000	
Total	47	0.028		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.001		
Factor H	1	0.002	0.002	14.26
Factor M	7	0.046	0.007	38.68
Interaction H × M	7	0.011	0.002	9.19
Error	62	0.010	0.000	
Total	95	0.132		

Analysis of variance table for available Zn

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.374		
Factor H	1	0.000	0.000	0.008
Factor M	7	3.130	0.447	13.69
Interaction H × M	7	0.299	0.043	1.307
Error	30	0.980	0.033	
Total	47	4.784		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.210		
Factor H	1	0.119	0.119	1.27
Factor M	7	8.966	1.281	13.72
Interaction H × M	7	0.285	0.041	0.43
Error	30	2.800	0.093	
Total	47	12.381		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.511		
Factor H	1	0.055	0.055	0.89
Factor M	7	11.138	1.591	25.60
Interaction H × M	7	0.539	0.077	1.24
Error	62	3.854	0.062	
Total	95	17.928		

Analysis of variance table for available Ca

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.24		
Factor H	1	258.82	258.82	40.27
Factor M	7	1,281.16	183.02	28.48
Interaction H × M	7	462.69	66.09	10.28
Error	30	192.79	6.42	
Total	47	2,195.22		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	44.34		
Factor H	1	12.34	12.34	1.00
Factor M	7	608.99	87.00	7.09
Interaction H × M	7	83.828	11.97	0.97
Error	30	367.77	12.25	
Total	47	1,117.28		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	18.76		
Factor H	1	78.56	78.56	8.31
Factor M	7	1,766.04	252.29	26.69
Interaction H × M	7	444.20	63.45	6.71
Error	62	585.89	9.45	
Total	95	4,196.57		

Analysis of variance table for nitrogen content in plant

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.016		
Factor H	1	0.319	0.319	98.33
Factor M	7	2.466	0.352	108.70
Interaction H × M	7	0.330	0.047	14.56
Error	30	0.097	0.003	
Total	47	3.227		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.008		
Factor H	1	0.248	0.248	246.01
Factor M	7	2.749	0.393	389.63
Interaction H × M	7	0.314	0.045	44.53
Error	30	0.030	0.001	
Total	47	3.350		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.009		
Factor H	1	0.565	0.565	246.41
Factor M	7	5.180	0.740	322.99
Interaction H × M	7	0.624	0.089	38.89
Error	62	0.142	0.002	
Total	95	7.615		

Analysis of variance table for phosphorous content in plant

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.001		
Factor H	1	0.003	0.003	4.590
Factor M	7	0.028	0.004	7.211
Interaction H × M	7	0.007	0.001	1.920
Error	30	0.017	0.001	
Total	47	0.056		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.007		
Factor H	1	0.001	0.001	0.953
Factor M	7	0.047	0.007	8.517
Interaction H × M	7	0.007	0.001	1.201
Error	30	0.024	0.001	
Total	47	0.085		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.004		
Factor H	1	0.003	0.003	4.18
Factor M	7	0.072	0.010	14.26
Interaction H × M	7	0.007	0.001	1.28
Error	62	0.045	0.001	
Total	95	0.143		

Analysis of variance table for potassium content in plant

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.008		
Factor H	1	0.025	0.025	11.59
Factor M	7	0.412	0.059	27.20
Interaction H × M	7	0.080	0.011	5.31
Error	30	0.065	0.002	
Total	47	0.590		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.013		
Factor H	1	0.247	0.247	32.51
Factor M	7	1.781	0.254	33.54
Interaction H × M	7	0.270	0.039	5.08
Error	30	0.227	0.008	
Total	47	2.538		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.020		
Factor H	1	0.214	0.214	45.22
Factor M	7	1.897	0.271	57.22
Interaction H × M	7	0.299	0.043	9.03
Error	62	0.294	0.005	
Total	95	4.765		

Analysis of variance table for boron content in plant

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	2.74		
Factor H	1	12.86	12.86	6.58
Factor M	7	266.74	38.10	19.50
Interaction H × M	7	53.02	7.57	3.87
Error	30	58.62	1.95	
Total	47	394.00		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	36.17		
Factor H	1	1.35	1.35	0.39
Factor M	7	134.09	19.15	5.56
Interaction H × M	7	11.81	1.68	0.49
Error	30	103.29	3.44	
Total	47	286.7		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	19.99		
Factor H	1	11.28	11.28	3.87
Factor M	7	373.11	53.30	18.27
Interaction H × M	7	30.34	4.33	1.48
Error	62	180.84	2.91	
Total	95	705.65		

Analysis of variance table for zinc content in plant

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	59.51		
Factor H	1	16.87	16.87	1.61
Factor M	7	1,823.05	260.43	24.86
Interaction H × M	7	23.08	3.29	0.31
Error	30	314.23	10.47	
Total	47	2,236.75		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	32.91		
Factor H	1	18.90	18.90	1.92
Factor M	7	662.32	94.61	9.63
Interaction H × M	7	20.10	2.87	0.29
Error	30	294.53	9.81	
Total	47	1,028.77		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	85.03		
Factor H	1	35.72	35.72	3.59
Factor M	7	2,292.19	327.45	32.95
Interaction H × M	7	33.23	4.74	0.47
Error	62	616.15	9.93	
Total	95	3,310.50		

Analysis of variance table for calcium content in plant

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.003		
Factor H	1	0.046	0.046	19.41
Factor M	7	0.423	0.060	25.68
Interaction H × M	7	0.105	0.015	6.36
Error	30	0.071	0.002	
Total	47	0.646		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.009		
Factor H	1	0.109	0.109	39.05
Factor M	7	0.595	0.085	30.38
Interaction H × M	7	0.155	0.022	7.93
Error	30	0.084	0.003	
Total	47	0.952		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.009		
Factor H	1	0.148	0.148	58.44
Factor M	7	1.006	0.144	56.75
Interaction H × M	7	0.245	0.035	13.83
Error	62	0.157	0.003	
Total	95	1.658		

Analysis of variance table for boron content in fruits

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.70		
Factor H	1	8.15	8.15	43.87
Factor M	7	42.13	6.01	32.39
Interaction H ×M	7	7.02	1.00	5.39
Error	30	5.57	0.18	
Total	47	63.58		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	2.64		
Factor H	1	2.10	2.10	0.74
Factor M	7	149.02	21.29	7.51
Interaction H × M	7	10.38	1.48	0.52
Error	30	84.99	2.83	
Total	47	249.16		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	2.96		
Factor H	1	9.27	9.27	6.32
Factor M	7	167.38	23.91	16.29
Interaction H × M	7	13.16	1.88	1.28
Error	62	90.96	1.46	
Total	95	407.01		

Analysis of variance table for zinc content in fruits

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	2.11		
Factor H	1	5.13	5.13	6.90
Factor M	7	92.60	13.22	17.78
Interaction H × M	7	8.34	1.19	1.60
Error	30	22.31	0.74	
Total	47	130.50		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	14.71		
Factor H	1	4.37	4.37	1.69
Factor M	7	308.22	44.03	17.08
Interaction H × M	7	21.47	3.06	1.19
Error	30	77.29	2.57	
Total	47	426.09		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	3.01		
Factor H	1	9.48	9.48	5.18
Factor M	7	339.77	48.53	26.53
Interaction H × M	7	26.09	3.72	2.03
Error	62	113.42	1.82	
Total	95	991.78		

Analysis of variance table for calcium content in fruits

(2022)

SV	DF	SS	MSS	F-Cal
Replication	2	0.001		
Factor H	1	0.001	0.001	5.62
Factor M	7	0.028	0.004	15.39
Interaction H × M	7	0.003	0.000	1.87
Error	30	0.008	0.000	
Total	47	0.042		

(2023)

SV	DF	SS	MSS	F-Cal
Replication	2	0.001		
Factor H	1	0.000	0.000	3.79
Factor M	7	0.034	0.005	50.26
Interaction H × M	7	0.001	0.000	2.14
Error	30	0.003	0.000	
Total	47	0.039		

Pooled

SV	DF	SS	MSS	F-Cal
Replication	2	0.002		
Factor H	1	0.002	0.002	9.15
Factor M	7	0.061	0.009	48.13
Interaction H × M	7	0.004	0.001	3.17
Error	62	0.011	0.000	
Total	95	0.087		

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Title of Thesis : **“Response of Micronutrient Applications on Hybrids of Coloured Capsicum”**
Name of the Student : Bonde Kuldeep Jagannath
Admission Number : H-2021-51-D
Major Discipline : Vegetable Science
Minor Discipline : Soil Science
Date of Thesis Submission : 19/04/2025
Total pages of the Thesis : 221+xxxix
Major Advisor : Dr. Kuldeep Singh Thakur

ABSTRACT

The present investigation, titled, "Response of Micronutrient Applications on Hybrids of Coloured Capsicum," evaluated the impact of foliar nutrient applications on the growth, yield, quality and economic viability of capsicum hybrids under polyhouse conditions. Conducted at the Department of Vegetable Science, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, HP, over two years (2022-23 and 2023-24), the experiment followed a Randomized Complete Block Design (Factorial) with three replications and sixteen treatment combinations. Two F_1 hybrids, Indam Mamatha (H_1, Red) and Orobelle (H_2, Yellow), were tested under eight nutrient treatments: Boric acid 0.5 % (M_1), Zinc sulphate 0.5 % (M_2), Calcium chloride 0.5 % (M_3), Boric acid 0.5 % + Zinc sulphate 0.5 % (M_4), Boric acid 0.5 % + Calcium chloride 0.5 % (M_5), Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_6), Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7) and a control with no spray (M_8). Two foliar sprays were applied at flower bud initiation and 30 days after first spray. Significant variations were observed across treatments. H_1 recorded the earliest first picking (72.50 days), shortest internodal length (7.84 cm), highest fruit breadth (7.13 cm), fruit weight (189.03 g), fruit yield per plant (2.37 kg) and per m^2 (16.58 kg). H_2 exhibited the highest leaf area index (3.36), fruit length (8.13 cm), number of pickings (7.19), number of fruits per plant (13.50) and longest harvest duration (82.94 days). Among foliar treatments, M_7 resulted in the earliest first picking (71.75 days), maximum internodal length (7.40 cm), plant height (162.08 cm), highest leaf area index (4.27), fruit length (8.72 cm), fruit breadth (7.78 cm), fruit weight (191.25 g), number of pickings (7.08), number of fruits per plant (14.75), highest yield per plant (2.80 kg) and per m^2 (19.62 kg) and longest harvest duration (90.25 days). It also recorded the highest total soluble solids (7.12 °Brix), ascorbic acid (121.47 mg 100 g^{-1}) and carotenoid content (2.11 mg 100 g^{-1}), while minimizing disease incidence, reducing collar rot (5.00 %) and powdery mildew severity (8.13 %). The combination H_1M_7 (Indam Mamatha + M_7) significantly improved plant growth, fruit quality and economic returns. It recorded the lowest internodal length (7.40 cm), maximum fruit breadth (8.17 cm) and fruit weight (215.00 g), resulting in the highest economic returns (₹ 908.85 per m^2) with a B:C ratio of 2.56. Periodic analysis showed a substantial increase in leaf nutrient content after the first spray, with nitrogen (2.54 %), phosphorus (0.48 %), potassium (2.91 %) and calcium (0.98 %) enhancing early vegetative growth. The second spray further boosted nutrient uptake, reaching peak levels in leaves (N: 3.09 %, K: 3.62 %, Ca: 1.16 %) and fruits (N: 2.74 %, K: 3.01 %, Ca: 1.05 %), leading to superior fruit development. Post-harvest soil analysis indicated significant nutrient depletion, confirming efficient nutrient utilization. Similarly, H_2M_7 (Orobelle + M_7) demonstrated superior yield parameters, recording the highest leaf area index (4.28) and fruit length (8.93 cm). After the first spray, leaf phosphorus (0.51 %), potassium (3.10 %) and calcium (1.02 %) increased significantly. The second spray further improved nutrient translocation, with peak concentrations in leaves (P: 0.57 %, K: 3.19 %, Ca: 1.12 %) and fruits, correlating with enhanced yield and quality. Overall, both Indam Mamatha (H_1) and Orobelle (H_2) are well-suited for polyhouse cultivation, with selection based on market demand for red or yellow capsicum. The foliar application of Boric acid 0.5 % + Zinc sulphate 0.5 % + Calcium chloride 0.5 % (M_7) at flower bud initiation and 30 days later proved most effective, ensuring profitable and efficient cultivation under mid-hill conditions of Himachal Pradesh.

Bonde

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Dated: 19/04/2025

K Thakur

Signature of Major Advisor
Name: Dr. Kuldeep Singh Thakur
Dated: 19.04.25

19.04.2025
Head of the Department

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Academic Qualifications

Examination Passed	**Year**	**School / College**	**University/Board**	**Marks (% / CGPA)**	**Division**
Matriculation	2013	Shri Bakliwal Vidyalaya, Washim	Maharashta State Board of Secondary and Higher Secondary Education, Pune	81.40	Distinction
10 + 2 (Medical)	2015	Shri Samartha Jr. College of Science, Akola	Maharashta State Board of Secondary and Higher Secondary Education, Pune	74.46	First
B Sc Horticulture	2019	College of Horticulture	Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola	8.20/10	First
M Sc (Horticulture) Vegetable Science	2021	Post Graduate Institute	Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola	8.59/10	First with distinction

Title of Thesis in M Sc : **Effect of organic manures and biofertilizers on growth and seed yield and seed quality of fenugreek**

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