EFFECT OF NANO Zn AND Cu ON GROWTH, PRODUCTIVITY AND QUALITY OF WINTER SEASON GUAVA (*Psidium guajava* L.) VARIETY ALLAHABAD SAFEDA.

Thesis Submitted for the Award of the Degree

of

DOCTOR OF PHILOSOPHY

in

Horticulture - Fruit Science

By

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2024

DECLARATION

I, hereby declared that the presented work in the thesis entitled "**Effect of nano Zn and Cu on growth, productivity and quality of winter season guava (*Psidium guajava* L.) variety Allahabad Safeda.**" in fulfilment of degree of **Doctor of Philosophy (Ph.D.)** is outcome of research work carried out by me under the supervision of Dr. Manish Bakshi, working as Associate Professor, in the Horticulture Department of Lovely Professional University, Punjab, India. In keeping with general practice of reporting scientific observations, due acknowledgements have been made whenever work described here has been based on findings of other investigator. This work has not been submitted in part or full to any other University or Institute for the award of any degree.

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CERTIFICATE

This is to certify that the work reported in the Ph.D. thesis entitled "**Effect of nano Zn and Cu on growth, productivity and quality of winter season guava (*Psidium guajava* L.) variety Allahabad Safeda.**" submitted in fulfillment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in the Department of Horticulture, is a research work carried out by Lakshya, (12014239), is bonafide record of his original work carried out under my supervision and that no part of thesis has been submitted for any other degree, diploma or equivalent course.

(Signature of Supervisor)

Dr. Manish Bakshi

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Abstract

Response of nano zinc and nano copper was evaluated on guava plants for various growth and reproductive parameters in the years 2022 and 2023 at horticulture farms of Department of Horticulture, Lovely Professional University, Punjab. A total of 10 treatment combinations were undertaken in the experiment with 3 replications. Among the vegetative parameters, maximal growth in plant height (0.53m), increase in plant spread E-W (0.86m), N-S (0.71m), increase in no. of leaves (18.64), maximum chlorophyll index (43.04), maximum leaf area (70.43 cm^2), and maximum fruit set percent (55.29%) was recorded under treatment T_8 [nano-Zn_2(60ppm) + Cu_1 (20ppm)]. Maximum no. of flowers per shoot at 30th day (6.03), maximum number of flowers per shoot at 45th day (14.10) maximum no. of flowers per shoot at 60th day (5.92) maximum no. of fruits per shoot at 45th day (3.15), maximum no. of fruits per shoot at 75th day (3.48), maximum no. of fruits per shoot at 90th day (1.73), maximum total no. of flowers per shoot (34.03), maximum total no. of fruits per shoot (18.58), maximum no. of fruits harvested per shoot (10.32), maximum fruit retention percent (55.57%), lowest fruit drop percent (44.43%) highest no. of fruits per plant (174.86), maximum fruit weight (174.92g), maximum fruit volume (171.37cc), yield/plant (32.29 kg/plant), and fruit yield/hectare (8,943.37q/ha) was recorded under treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)]. Among the quality parameters during the storage condition of Guava, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] showed increasing trend for biochemical traits as the storage period progressed excluding lowest titratable acidity percent, maximum TSS: acid ratio, maximum ascorbic acid (g/mol), antioxidant percent, pectin content percent and lowest spoilage percent were also observed under the same treatment. Leaf nutrient status of Guava leaves was also estimated for the various treatments undertaken in the experimentation. Treatment T_9 recorded the maximum levels of nitrogen, copper and zinc. Economics of Guava cultivation for different treatments was worked out and highest B:C ratio 1:2.88 in 2022 and 1:3.16 in 2023 respectively was recorded under treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)]. From the present investigation, vegetative parameters were found to be better with application of treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] as compared to other treatments. It was discovered that treatments T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] were successful in enhanced the growth and quality of guava fruit. Also, the Benefit: Cost ratio was recorded maximum in T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] during 2022 and 2023. In summary, it is recommended to apply foliar spray of nano zinc and nano copper (60 and 30 ppm, respectively) along with RDF for profitable production of guava.

Key words: Guava, zinc, copper, and nano-micronutrients.

ACKNOWLEDGEMENT

The work presented in this thesis would not have been possible without my close association with many peoples who were always there when I needed them the most. I take this opportunity to acknowledge them and extend my sincere gratitude for helping me make this thesis a possibility. First and foremost, I express my heartfelt gratitude to my supervisor, Dr. Manish Bakshi, for providing invaluable guidance and support throughout my research journey, starting from the selection of the research topic to the discovery of the results. Dr. Bakshi's extensive knowledge, unwavering motivation, and exceptional patience have greatly empowered and inspired me to excel in my research writing endeavours. Undertaking an academic study on such a challenging subject would not have been as manageable without his guidance. He has been more than a mentor to me, serving as an extraordinary advisor for my doctoral studies, exceeding all expectations.

I am acutely aware of the profound assistance and harmonious collaboration extended to me by the venerable faculty members of the Department of Agriculture, alongside the assiduous laboratory personnel. I will always remember my fellow lab mates and the good times we had together. They not only brought joy and happiness to our shared experiences, but they also supported me during late nights when we had to work hard to finish tasks before deadlines. Their presence sparked interesting discussions that made our research journey more exciting and created a strong bond between us.

Moreover, I want to express my sincere gratitude to all my dear friends and dedicated supporters, especially Pallvi verma, Amandeep, Sangam, Sehbaz, Vishal, and Rupinder singh. Their constant support has been crucial in transforming this research project into a successful and significant achievement.

When it comes to expressing heartfelt gratitude, words alone are insufficient to convey the immense appreciation I have for my dear parents, Ms. Ram sawroop and Bimla devi, my respected Brother, Ms. Sharvan kumar, Sister-in-law, Promila devi, and my beloved sisters, Hansa devi, Chandermukhi, and Renu. Their unwavering support, wise guidance, and unwavering belief in my abilities have been the driving force behind my educational journey, filling me with unwavering determination. Without their constant encouragement, reaching this height of achievement would have been a distant dream.

I am truly indebted to them as they have been my pillars of strength. Their moral support, encouragement, and motivation have propelled me forward in achieving my personal goals. My family, my lifeline have always provided financial support, allowing me to focus solely on my studies and pursue my objectives without any hindrances along the way.

I am forever grateful to Aman for his constant support, dedication, and belief in my abilities. His presence throughout this research journey has not only helped me grow personally and professionally but has also made this achievement meaningful and fulfilling. He has always had faith in my abilities and has supported me unconditionally, even when I encountered difficulties and setbacks. HIs unwavering belief in my potential has been a constant source of strength, motivating me during times when I felt tired or uncertain. Without his, this journey would have felt incomplete and devoid of rewards. His unwavering support has been like a strong pillar of strength, and I will always be thankful for that.

Throughout this journey, I am deeply grateful and sincerely appreciate my beloved wife, Priyanka. Her unwavering dedication and constant encouragement have played a crucial role in the successful completion of my research. I cannot fully express the extent of her steadfast commitment, which has guided me through moments of doubt and uncertainty. Priyanka's contributions to my research have been extremely valuable. Her thoughtful insights, helpful feedback, and deep understanding of the subject have not only improved the quality of my work but also broadened my knowledge.

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LIST OF ABBREVIATIONS

Abbreviations	Description	Abbreviations	Description
%	Percentage	°C	Degree Celcius
P	Phosphorous	N	Nitrogen
K	Potassium	Cu	Copper
nano-Cu	Nano Copper	RH	Relative Humidity
B	Boron	nano-Zn	Nano Zinc
Zn	Zinc	TSS	Total soluble solids
SE(d)	Standard error deviation	SE(m)	Standard error mean
NS	Non-significant	ppm	Parts per million
No.	Number	mg/g	milligram per gram
m	Meter	mg	Milligram
L.	Linneous	L^{-1}	per liter
i.e;	That is	kg	Kilogram
g or gm	Gram	ha	Hectare
RBD	Randomized Block Design	Fig.	Figure
et al.	et alii (Co-workers)	DPPH	2,2-diphenylpicrylhydrazyl
cm^2	centimetre square	cm	Centimetre
C.D.	Critical difference	CV	Co-efficient of Variation
@	at the rate		

Chapter- I

INTRODUCTION

Guava belongs to the Myrtaceae family, is believed to have originated in southern Mexico and Central America (Dakappa *et al*., 2013). It is known for its delicious and nutritious fruits, as well as its adaptability to various climatic conditions. India is largest producer of guava in India (Mitra *et al*.,2016). Guava plants can vary in size from small shrubs to medium-sized trees, depending on the variety and growing conditions. They have a dense canopy of evergreen leaves that provide good shade. The leaves are elliptical, glossy, and have a strong aroma when crushed. They are often used in traditional medicine due to their potential health benefits (Naseer *et al*.,2018). Guava plants produce white flowers with numerous stamens. The flowers are usually fragrant and attract pollinators like bees, butterflies, and birds (Rajagopal *et al*.,2005). Guava fruits come in various shapes, sizes, and colors, depending on the variety. They can be round, oval, or pear-shaped. The skin can be green, yellow, or maroon when ripe. The flesh of the fruit is usually creamy white or pink, and it contains numerous small edible seeds (Das *et al*.,2011).

Guava fruits have a unique flavor that is often described as a mix of sweet and slightly tangy, with a tropical aroma. Guava good in vitamin A and C, as well as fibre besides being a rich source of pectin, a type of fibre that helps to lower cholesterol levels (Kadam *et al*.,2012). Its leaves can be used to make a tea that has anti-inflammatory and antioxidant properties (Deguchi *et al*.,2010). Guavas are a popular ingredient in traditional medicine in many parts of the world. They also contain some potassium, magnesium, and calcium. They are considered a healthy snack option (Xing *et al*.,2021). Guava fruits can be eaten fresh, either by themselves or added to fruit salads, smoothies, and desserts. They are also used to make juices, jams, jellies, and sauces. In some cultures, guava leaves are used to brew tea with potential health benefits (Meena *et al*.,2022). Guava fruits and leaves are believed to have various medicinal properties (Nwodo *et al*.,2008). They are sometimes used in traditional medicine for treating digestive issues, coughs, and other ailments.

Due to abundance of vitamin C, which is an antioxidant, regular consumption of guava helps to protect the body against damage from free radicals which are often attributed to chronic diseases such as cancer and heart disease (Vijaya Anand *et al*.,2016). The fibre present in the fruit helps to keep the digestive system regular and can help to prevent constipation. Potassium present in guava, which is a mineral that helps to regulate blood pressure. High blood pressure is a risk factor for heart disease. It has a low glycemic index, which means that they do not cause a sudden spike in blood sugar levels. This makes them a good choice for people with diabetes or prediabetes (Rai *et al*.,2016).

In addition to these health benefits, guavas are also a delicious and versatile fruit. They can be eaten fresh, cooked, or juiced. They can also be used in pies, jams, and jellies. Guavas are a great addition to any diet and can be enjoyed by people of all ages.

Essential oil of guava also has activity against the *Salmonella* and *S. aureus* (Goncalves *et al*.,2008). Various compounds like Gallic acid, galangin, kaempferol, homogentisic acid and cyanidin 3-glucoside are found in peel, seeds and pulp of guava. But it is surprising that the amount of these compounds is high in seeds and peel as compared to the pulp. Due to the presence of these compounds, guava holds an important place in human food chain (Chen *et al*.,2015).

Guava cultivation is widespread across India, with substantial production in states such as Maharashtra, Uttar Pradesh, Bihar, Odisha, Punjab, Gujarat, Madhya Pradesh, Uttarakhand and West Bengal. However, Uttar Pradesh holds particular importance as the leading guava-producing state. Within Uttar Pradesh, the Allahabad (Prayagraj) region is renowned for its superior quality guavas, garnering acclaim both domestically and internationally. Covering approximately 3.7% of the total area under fruit crops, Uttar Pradesh's guava cultivation extends over 2.7 lakh hectares. This substantial cultivation translates to a noteworthy contribution of 3.3% to the country's total fruit production, as indicated by data from the National Horticulture Board (NHB) for the year 2017-18. The success of guava cultivation in Uttar Pradesh, especially in the Allahabad region, can be attributed to favorable agro-climatic conditions and effective agricultural practices. This region's reputation for producing premium quality guavas underscores its significance in the global guava market, solidifying Uttar Pradesh's status as a key player in India's fruit production sector.

Guava trees are known for their prolific fruit-bearing capacity, but to sustain their vigor and productivity over the long term, proper nourishment is essential. Without adequate management, continuous fruit production can deplete soil nutrient reserves, leading to adverse effects on crop growth and productivity. It's crucial to replenish lost nutrients to maintain soil fertility and ensure optimal crop yields in subsequent years. As highlighted by Gaund *et al*. (2022), the replenishment of these nutrients is imperative to preserve the fertility status of the soil. This involves implementing appropriate soil management practices such as fertilization, mulching, and organic matter incorporation to enhance nutrient availability and soil structure. Additionally, soil testing can help in identifying specific nutrient deficiencies, enabling targeted fertilization strategies. By prioritizing soil fertility maintenance, farmers can sustainably manage guava orchards, promoting healthy tree growth, consistent yields, and long-term profitability. Proper nourishment not only supports current crop production but also lays the foundation for future success, ensuring the sustainability of guava cultivation practices.

Effective management practices are crucial for ensuring profitable guava cultivation, encompassing cultural practices alongside fertilization and nutrition strategies. As emphasized by Miao *et al*. (2006), nutrition stands out as a paramount factor influencing the growth, yield, and quality of crops, including guavas. Maintaining optimal nutrition levels is imperative for sustaining higher yields and superior fruit quality. However, the escalating costs of conventional fertilizers coupled with their detrimental effects on soil health worldwide necessitate a re-evaluation of soil supplementation approaches. It's essential to explore alternative sources that enhance soil productivity while promoting higher yields and better fruit quality. This shift towards sustainable soil management involves the utilization of organic amendments, such as compost, manure, and biofertilizers, which not only provide essential nutrients but also improve soil structure and microbial activity. Additionally, employing precision fertilization techniques based on soil testing and nutrient management plans helps optimize nutrient utilization while minimizing environmental impacts.

By integrating these alternative sources of soil nutrition and adopting precision fertilization practices, farmers can mitigate the adverse effects of conventional fertilizers, improve soil health, and enhance guava orchard productivity sustainably. This holistic approach to orchard management ensures long-term profitability while safeguarding environmental sustainability. Micronutrients are essential nutrients that plants need in small amounts to grow and develop properly. They are involved in a variety of plant functions, including photosynthesis, nitrogen fixation, and defence against pests and diseases (Rawat *et al*.,2010). The micronutrients, although needed in smaller quantities play an essential role in different physiological processes within the plant (Sachin *et al*., 2019; Shivpoojan *et al*.,2018; Bhoyar *et al*.,2016). Micronutrient deficiencies can lead to a variety of problems in plants, including stunted growth, yellowing leaves, and reduced yields. In severe cases, micronutrient deficiencies can even kill plants.

Zinc, a micronutrient is required for the growth and development of fruits, vegetables, and cereals. It plays multifaceted roles in plant physiology. Its significance lies in various metabolic processes vital for plant functioning. Firstly, zinc is indispensable for chlorophyll formation, facilitating photosynthesis, the process by which plants convert light energy into chemical energy. This pivotal role ensures optimal energy production essential for plant growth (Mapodzeke *et al.*,2021).

Moreover, zinc acts as a cofactor for numerous enzymes involved in various biochemical pathways. These enzymes play pivotal roles in protein synthesis, carbohydrate metabolism, and the conversion of starches to sugars. Additionally, zinc's presence in plant tissues contributes to their resilience against cold temperatures, aiding in cold stress tolerance. Furthermore, zinc participates in the synthesis of auxins, plant hormones crucial for growth regulation and stem elongation. By promoting the formation of auxins, zinc facilitates proper plant development and morphology (Hamzah Saleem *et al.,*2022). Zinc is basically a multifunctional pigment that plays a variety of roles in the formation of chlorophyll, enzyme activation, carbohydrate metabolism, tolerance to cold stress, and hormone regulation. All of these functions work together to support the general growth, development, and health of plants. Adequate zinc levels are essential for efficient photosynthesis. It is essential for cell division and elongation, which are fundamental processes in plant growth and development. It is particularly important for root development and the formation of lateral roots. This is a component of ribosomes, the cellular structures responsible for protein synthesis. Proper protein synthesis is crucial for the production of enzymes, hormones, and structural proteins that are necessary for plant functioning (Seregin *et al.*,2011).

In addition, zinc also involved in pollen formation and pollen tube elongation, which are critical for successful pollination and fertilization in flowering plants. Adequate zinc levels contribute to healthy reproduction and seed production. This also plays a role in activating plant defence mechanisms against various stresses, including pathogens and oxidative stress. It helps in the synthesis of antioxidants and enzymes that protect plants against damage caused by reactive oxygen species. The process involved in the regulation of ion channels and transporters that allow plants to take up essential nutrients from the soil is affected by zinc. Adequate zinc levels help maintain nutrient balance and uptake. Instead, the zinc deficiency and toxicity can have negative effects on plants. Zinc deficiency can lead to stunted growth, chlorosis (yellowing of leaves), reduced fruit and seed production, and overall poor plant health. Instead, excessive zinc can be toxic, causing symptoms such as root damage, reduced nutrient uptake, and imbalances with other nutrients (Dumanović *et al.*,2021).

Copper is a participatory nutrient in a variety of plant functions like photosynthesis, nitrogen fixation, and the production of enzymes. It is also important for plant defence system (Suman *et al*.,2017; Jat *et al*.,2020). Copper plays a crucial role in various plant processes, including photosynthesis, enzyme activation, lignin synthesis, and electron transport within cells. It is a cofactor for many enzymes involved in these processes, making it essential for overall plant health. At appropriate concentrations, copper promotes healthy plant growth, root development, and overall vigor. It aids in the formation of chlorophyll, which is necessary for photosynthesis, and helps in the metabolism of carbohydrates and proteins. Copper is a critical component of enzymes involved in redox reactions, such as cytochrome oxidase and superoxide dismutase. These enzymes help protect plant cells from oxidative stress caused by reactive oxygen species.

While copper is necessary for plants, excessive concentrations can be toxic. Copper toxicity can disrupt cellular processes and lead to various negative effects, including chlorosis (yellowing of leaves), reduced root growth, inhibited photosynthesis, and damage to cell membranes. An elevated copper level can undermine with the uptake of other essential nutrients, such as iron and zinc leading to nutrient imbalances and deficiencies, even if those nutrients are present in the soil. Copper is essential for plant growth and health, but its effects can range from beneficial to detrimental depending on its concentration. Maintaining proper copper levels in soil and understanding the specific needs of different plant species are key factors in managing its impact on plants (Krasilnikov *et al*.,2022).

In this era demand of food supplies is more as population is increasing continually (King *et. al*., 2017). Farmers are following the practice of applying more chemical fertilizers in soil for increasing the production from field. These chemical fertilizers retarded the soil health. And it creates an imbalance in soil fertility level (Krasilnikov *et al*.,2022). Soil organic carbon is affected by the use of chemical fertilizers that is correlated with the availability of nutrients to plants (Rasool *et al*.,2008). The major concern is that if we continually follow the same practice the soil will stop to germinate the seeds in it and it will make totally imbalance on the earth (Penuelas and Sardans, 2022). The situation at this time can be handled by using the limited number of chemical fertilizers in the soil and for maintaining the quantity and quality of crop yield foliar fertilization can be used in a limited amount of chemicals can be used (Niu *et al*.,2021).

Foliar fertilization targets the nutrients where they are needed most, minimizing nutrient losses through leaching or fixation in the soil. It allows for precise nutrient targeting, particularly useful in cases of localized nutrient deficiencies or during critical growth stages. Nano micronutrients can often be formulated to remain in suspension and not clog spray equipment (Solanki *et al*.,2015). This makes them compatible with various foliar application techniques. Some nutrients' availability to plants can be influenced by soil pH. Foliar fertilization bypasses this limitation, as the pH of the leaf surface is generally neutral (Patil *et al*.,2018).

Nanotechnology involves use of materials at the nanoscale, which is about 1-100 nanometres in size. Nanoparticles are much smaller than traditional fertilizers, which makes them easier for plants to absorb. They can also be targeted to specific areas of the plant, which can improve efficiency and reduce waste (Pérez-Labrada, 2019). Nano-fertilizers can be engineered to target specific plant tissues or cells. This enables precise delivery of nutrients to areas where they are most needed, such as the roots or leaves, resulting in optimized nutrient utilization. Nano-fertilizer technology is very innovative, and there is only a small amount of reported literature in scientific journals. However, some reports and patented products strongly suggest that nano-fertilizer formulation has a lot of room for improvement. Foliar application of nano-particles as fertilizer has resulted in increased production (Tarafdar, 2015). Conventional fertilizers often lead to nutrient runoff, which can cause water pollution. Nano-fertilizers can reduce this environmental impact by releasing nutrients gradually and improving nutrient uptake, minimizing excess nutrient runoff. The enhanced efficiency of nano-fertilizers means that they can be applied less frequently compared to conventional fertilizers while achieving similar or even better results. This can reduce labor, costs, and potential environmental impacts. Nano-fertilizers can be designed to alter the pH of the soil microenvironment, making nutrients more available for plant uptake. This can be particularly beneficial in soils with pH imbalances (Iqbal and M.A.,2019). Nanotechnology is still a relatively new field, but it has the potential to revolutionize the way fertilizers are used. Nano-fertilizers can help to improve crop yields, reduce environmental impact, and make agriculture more sustainable.

Another application of nanotechnology mediated foliar fertilization involves applying finely engineered nanoparticles of essential elements directly to the leaves of plants. This method aims to deliver nutrients directly to the plant's foliage, where they can be rapidly absorbed and utilized. Nanoparticles have a high surface area-to-volume ratio, which allows for efficient nutrient absorption through the stomata (tiny pores on leaves) and the leaf cuticle. This can lead to quicker correction of nutrient deficiencies compared to traditional soil application (Elshamy *et al*.,2019). Foliar fertilization with nano-micronutrients has the potential to address nutrient deficiencies rapidly and precisely. However, the technology is still advancing, and a cautious approach is necessary.

Nano zinc and copper particles have gained attention in recent years due to their potential applications in agriculture, particularly in enhancing plant growth, development, and nutrient uptake. Nano zinc and copper particles can be engineered to be more bioavailable and easily absorbable by plants (Hong *et al*., 2021). When applied to soil or as foliar sprays, these nanoparticles can enhance the uptake of essential nutrients like zinc and copper, which are vital for plant growth, photosynthesis, and overall health. Nano zinc and copper can stimulate plant growth by improving root development and increasing nutrient absorption (Al-Janabi *et al*., 2021). This can result in enhanced biomass production, higher crop yields, and improved overall plant vigour.

Nano zinc and copper particles have been studied for their potential to alleviate environmental stresses in plants by promoting antioxidant activity, improving water uptake, and mitigating the toxic effects of heavy metals (Faizan *et al*., 2023). Nano-sized particles can be incorporated into fertilizers to provide a controlled release of nutrients. This can improve nutrient use efficiency and reduce nutrient leaching, minimizing environmental pollution. Nano zinc and copper can influence chlorophyll content and photosynthesis rates in plants, leading to improved carbon assimilation and energy production (Zuo *et al*., 2017).

Research gap

1. **Proper formulation:** Nanoparticle formulations for agricultural use not yet well-designed to ensure stability, uniform dispersion, and compatibility with the target plants.
2. **Application timing:** Foliar fertilization is often most effective during periods of active growth and when nutrient demand is high. The actual time for application of the nano formulated nutrients not yet decided for the guava crop. Also not found in the scientific journals.

3. **Concentration control:** Effective concentration of nano zinc and copper for guava crop not yet recommended by any horticulture universities or any scientific journal for different yield contributing parameters. So, there is a lot of room for the Carefully follow recommended application rates to prevent nutrient excess, which can lead to phytotoxicity.

4. **Crop sensitivity:** Some crops are more sensitive to nano fertilizers than others. It's important to conduct small-scale trials before large-scale application.

Finding out following objectives of nano zinc and copper effect on the growth, yield, and quality of the winter-season Guava (*Psidium guajava* L.) cultivar Allahabad Safeda.

1. To study the effect of nano Zn and Cu on the growth, flowering and yield of guava plants.
2. To evaluate the effect of nano Zn and Cu on plant nutrient status.
3. To study the effect of nano Zn and Cu on the shelf life of guava fruits.
4. To work out the economics of the different treatments.

Chapter-II

REVIEW OF LITERATURE

A comprehensive review has been done about the work carried out in various aspects related to the topic of the study in guava crop. The salient findings reported by different researchers have been mentioned under suitable headings below in this section.

A. EFFECT ON GROWTH

Francis *et al.* (2022) used CuO and ZnO nanoparticles for evaluation of seed germination and plant growth of *Amaranthus hybridus* using hydroponics and foliar application methods with varying concentrations of CuO and ZnO nanoparticles. Treated plants exhibited enhanced agronomic characteristics, SPAD value, total reducing sugars, antioxidant activity, as well as increased levels of copper and zinc ions in both roots and shoots following nanoparticle application. Notable outcomes were utilization of remarkably low concentrations of CuO and ZnO nanoparticles yet yielding substantial improvements in plant development.

El-Gioushy *et al.* (2021) conducted a study on washington navel orange trees to assess the effects of foliar spraying with $ZnSO_4$ and $CuSO_4$. Among the various combinations tested, $ZnSO_4$ at a concentration of 600 mg/L, coupled with $CuSO_4$ at concentrations of 200 mgL^{-1} and 400 mgL^{-1}, demonstrated the maximum favorable outcomes across most of the parameters evaluated. The interaction between $ZnSO_4$ and $CuSO_4$ concentrations substantially influenced the observed effects. Combining $ZnSO_4$ and $CuSO_4$ at their greatest levels resulted in the most favorable vegetative development metrics, such as shoot length, leaf/shoot and total assimilation area/shoot. The highest values for fruiting features and quality of fruits were obtained from the application of 600 mg^{-1} $ZnSO_4$ + 400 mg^{-1} $CuSO_4$ to leaves exhibiting the highest nutritional status, as shown by higher total leaf chlorophyll and leaf mineral contents. Based on these findings, it is reasonable to recommend foliar spraying with 600 mg^{-1} $ZnSO_4$ alongside 400 mg^{-1} $CuSO_4$ from March to July annually, provided similar environmental conditions and horticultural practices to those employed in the study are maintained.

Morab *et al.* (2021) examined the effects of foliar feeding with nano-fertilizers (nano-zinc) on savoury plants, including growth indices like plant height, leaf count, and an increase in fresh and dry weight. The greatest nitrogen percentages per leaf were 1.95 percent and 1.97

percent, respectively, when pomegranate transplants were treated with nano-zinc at dosages of 2 and 3 g. This might be the case due to zinc's effects on natural auxin (IAA) production and its ability to activate several enzymes involved in biochemical processes, including protein synthesis and glucose metabolism.

Al-Janabi *et al.* (2021) conducted research on pomegranates during the 2018–2019 growth season in order to determine the effects of twice-spraying nano-K, nano-Zn, and Cu levels of 0,1,2 gL^{-1}, 0,2,3 gL^{-1}, and 0,0.5,1 gL^{-1} respectively. The diameter increased, the number of leaves increased/transplant, the area of leaves, the total chlorophyll, P%, and K% were all affected by the nano-potassium. The total chlorophyll for both concentrations reached 69.833 and 73.211 mg/g fresh weight when the pomegranates were transplanted and treated with nano-zinc at two and three-gram concentrations. Furthermore, nitrogen was highly substantial attained 1.97% and 1.95%. After applying nano-zinc to pomegranates at two different concentrations (2 and 3 gL^{-1}), the percentage of zinc increased substantially to 22.3 and 22.7 $mgKg^{-1}$, respectively. After applying nano-copper (0.5 and 1 gL^{-1}) to the pomegranate transplant, copper percentage increased to 8.9 and 9.1 $mgKg^{-1}$, respectively. When potassium was applied to the pomegranate transplant at both concentrations, as opposed to the control, the best outcome was seen.

Rossi *et al.* (2019) examined the physiological reactions and absorption of zinc sulfate ($ZnSO_4$) and zinc nano-fertilizer (ZnO NPs) applied foliarly to coffee (*Coffea arabica* L.) plants in greenhouse research to better understand the impacts on plant physiology. Grown in a greenhouse, one-year-old coffee plants were given two foliar sprays (10 mg/L Zn) as zinc oxide nanoparticles (20 w/t) or zinc sulfate monohydrate ($ZnSO_4 \cdot H_2O$). After 45 days, the treated plants were compared to the untreated ones. Comparing treated to untreated roots, stem, and leaves, ZnO NPs improved the fresh weight by 37% (root) and 95% (leaves), and the dry weight by 28%, 85%, and 20%, respectively. The rise in DW for the roots, stems, and leaves was 28%, 85%, and 20%, respectively. According to these findings, coffee systems may benefit from the use of ZnO NPs to increase fruit set and quality, particularly in regions with high levels of zinc shortage.

El-Hak El *et al.* (2019), worked on foliar application of nano-zinc on five-year-old flame-seedless grapevines to determine its effect growth and development, productivity and fruit biochemical characteristics. Treated plants exhibited notable increases in growth, productivity, and fruit quality. Spraying grape vines with 0.4 ppm nano-zinc increased leaf area and fresh weight considerably, while 1.2 ppm dose of nano-Zn enhanced substantially total carbohydrate, iron concentration in leaf, clusters number, weight of clusters, and average yield. Additionally, as compared to traditional fertilizer, the yield increased substantially at 0.4, 0.8, and 1.2 parts per million with nano-zinc. Zinc fertilizer amounts used in production practices were conserved as the rate of consumption of nano-zinc fertilizer was reduced. To increase various vegetative characteristics, it was determined that the optimal treatment was to spray vines with 0.4 ppm of nano-zinc.

Bhardwaj *et al.* (2019) Studied the impact of foliar applied urea and Zn on the plant spread and reproductive traits of guava cv. Allahabad Safeda planted in HDP, the experiment comprised sixteen treatments, each replicated three times in a randomized block design. The treatment combination of urea at 2% concentration and zinc at 0.6% concentration (T_{12}), resulted in increased number of branches (23.00), flowering days (74.33 days), fruits/plant (42), fruit set% (54.44%), weight of fruit (155.61g), total fruit yield/plant (6.57 kg), titratable acidity% (0.55%), Vit-C content (267.30 mg/100g), TSS (12.25 ^{0}B), and Total sugar content% (8.15%). Following closely, treatment T11 (Urea 2% + zinc 0.4%) also exhibited favorable results. Conversely, the control group demonstrated the lowest values across all parameters.

Faizan *et al.* (2018) studied the impact of zinc oxide nanoparticles (ZnO-NPs) on the growth, photosynthetic efficiency, and antioxidant system of tomato. Roots of 20-day old tomato plants were exposed to varying concentrations of ZnO-NPs for durations of 15, 30, or 45 minutes. The results showed that ZnO-NPs treatments during the 45-day growth stage substantially enhanced growth, photosynthetic efficiency, and the activities of carbonic anhydrase and antioxidant systems. Application of 8 mg L^{-1} ZnO-NPs for 30 minutes was the most effective treatment, leading to elevated levels of proline accumulation, antioxidant enzyme activity, and photosynthetic rate. The research concluded that the presence of ZnO-NPs promoted proline synthesis and antioxidant defence systems, potentially contributing to plant stability and improved photosynthetic efficiency.

Harris *et al.* (2017) Investigated the effects of application with H_3BO_3 and $CuSO_4$ on tomato growth and yield. The treatments included various concentrations of H_3BO_3 and $CuSO_4$, both individually and in combination, along with a control group. Foliar sprays were administered at 10-day intervals starting 40 days after transplanting. Results indicated that foliar application of $CuSO_4$ at concentrations of 150 and 250 ppm led to increased plant height, while application of H_3BO_3 at 250 ppm had its effect on leaves. Regarding fruit yield, application of H_3BO_3 at concentrations of 150 and 250 ppm on a dry basis resulted in the highest yields, with H_3BO_3 at 350 ppm yielding more fruits than the control. Conversely, the control treatment exhibited poor performance across all measured parameters.

Wassel *et al.* (2017) investigated the effects of six nano fertilizers (Amino-minerals: Orgland Active-Fe, Boron-10, Amino-Zn, and Super-Fe) at concentrations ranging from 0.1% to 0.2% on vegetative growth, vine yield, berry coloration, and fruit quality in Flame Seedless grapevines. The study was conducted in a private vineyard located in El-Tawfekya village, Samalout district, Minia Governorate, during the 2015 and 2016 growing seasons. Compared to the control group, grapevines treated with nano-fertilizers at concentrations of 0.1% or 0.2% exhibited substantial improvements in growth parameters, vine nutritional status, berry set, yield, coloration, and overall fruit quality. The most pronounced benefits were observed with the use of amino minerals, specifically Orgland, active-Fe, Boron-10, Amino-Zn, and Super-Fe, in descending order of concentration.

Juarez-Maldonado *et al.* (2016) noted in their study that nanoparticles containing nano copper (nCu) have potential use in agriculture. Two phases of the investigation were carried out. The goal of the initial step was to find the ideal nCu concentration using tomato seedlings. A chitosan hydrogel was used to absorb nCu at a rate of 100 mg nCu kg^{-1}. The substrate was treated with hydrogel in five different ways before uprooting: $0.3gL^{-1}$, $0.15gL^{-1}$, $0.06gL^{-1}$, $0.03gL^{-1}$, and $0.015gL^{-1}$, these treatments are added on to the control. In the subplots assessed a chitosan treatment without nCu and a control, as well as the best treatment outcomes from the first stage. Along with fruit quality, the effects of the treatments were assessed on the antioxidant levels in the fruit and leaves. 0.06 gL^{-1} nCu-chitosan hydrogel treatments gave best results, according to the first stage's results. With variations in lycopene content in the fruit and catalase activity in the leaves, the subplots results showed that plants treated with nCu gave the best outcomes for the maximum parameters of plant growth. Tomato growth and quality were positively impacted by the application of chitosan hydrogels containing nCu.

Sau *et al.* (2016) studied on the "Allahabad Safeda" variety of guava (*Psidium guajava* L.) during the rainy season from February to August 2013–2015. In the experiment, eight different combinations and individual treatments of micronutrients containing copper, zinc, and boron were applied to the experimental trees. Treatment T8 (0.2g/L Borax + 0.5g/L Zinc sulphate + 0.5g/L Copper sulphate) resulted in the highest leaf area (53.51 cm2), number of shoots per meter branch (14.95), and emergence of leaves per shoot (14.54) among all treatments. Additionally, it yielded the highest fruit production, with 12.64 kg per tree and 7.92 t per hectare. Except for the number of shoots per meter branch, all independent factors and the dependent variable, fruit production, exhibited a positive and significant correlation. Fruit retention percentage showed the strongest association, followed by the number of fruits per tree.

Kumar *et al.* (2015) concluded on guava trees were treated with foliar sprays that contained potassium, zinc, calcium, and boron at two distinct times: right before fruit set and two weeks later. Several improvements were obtained from the foliar fertilization: 0.01 percent zinc applied two weeks after fruit set increased yield by 52.50 kg/tree, 0.03% B applied after two weeks enhanced weight by 150g, and 0.03g/L Zn applied 15 days after fruit set, increased plant height by 12.17%. Furthermore, at 11.50 percent ripeness with 0.5 percent potassium at the fruit set, foliar fertilization improved the pulp's seed ratio, total sugars, acidity content, and total soluble solids (TSS). At the same time, fruit drop% was reduced to 5.90% with 0.03% Zn applied 15 days after set of fruits. On fruit treated with 0.01 percent boron, seed hardness was assessed at 11.48 kg, indicating a non-uniform pattern. The developmental stage has a major impact on the growth, production, and quality of guava fruit. Two weeks following fruit set, foliar fertilization has a notable impact on plant growth and fruit quality.

Ojeda-Barrios *et al.* (2014) aimed to assess the zinc (Zn) nutritional status of pecan tree leaves, as well as their physiological and vegetative characteristics, and yield quality, following the application of various zinc compounds via spray. Eight-year-old "Western Schley" pecan trees, grafted to native seedlings, were subjected to treatments with ZnNO3 (100 mgL^{-1} Zn), Zn-EDTA (50, 100, and 150 mgL^{-1} Zn), and Zn-DTPA (100 mgL^{-1} Zn), compared to a Zn-untreated control. After a 3-year evaluation period, the trees displaying the most favorable outcomes were those treated with ZnNO3 (100 mgL^{-1} Zn) and Zn-DTPA (100 mgL^{-1} Zn). These treatments led to a substantial increase in leaf Zn content, by 73% and 69%, respectively, compared to the control group. The Zn-treated trees exhibited 46 SPAD units, equivalent to 43 $mgkg^{-1}$ dry weight (DW) of chlorophyll, in contrast to the 22 $mgkg^{-1}$ DW of Zn-deficient leaves. Under Zn-deficient conditions, chlorophyll levels were 37% lower on a leaf area basis compared to Zn-treated plants. However, Zn treatments did not impact nut quality. Based on the findings, Zn-DTPA and Zn-NO3 are deemed effective options for zinc fertilization of pecan trees through foliar application.

Bisen *et al*. (2020) evaluated the effect of zinc sulphate at concentrations of 0, 0.2, 0.4, and 0.6 percent, sprayed on two-year-old Pant Prabhat guava trees. These foliar sprays were administered to only 50% of the trees, with the first application in June and the second in September. However, the height, canopy size, trunk diameter, and volume of the trees were unaffected by the quantity and frequency of zinc sulphate foliar treatments. Notably, the concentration of 0.6 percent zinc sulfate showed the biggest increase in shoot length. Moreover, a twofold application of zinc sulfate led to the least amount of blossom and fruit drop, along with the highest effect on reproductive traits per hectare (especially evident at the 0.6 percent concentration). Leaf content analysis revealed that the highest levels were observed when 0.6 percent zinc sulphate was utilized, particularly for leaf zinc (139.29 ppm), leaf nitrogen (1.091%), and leaf potassium (0.434%). While the levels of calcium and magnesium in the leaves remained unchanged, the quantity of leaf phosphorus varied with increasing zinc concentration.

B. EFFECT ON FLOWERING

Bisen *et al*. (2020) tried with application of zinc sulfate at concentrations of 0, 0.2, 0.4, and 0.6 percent on two-year-old guava trees of the Pant Prabhat cultivar. These foliar sprays were administered to only 50% of the trees, with the first application in June and the second in September. However, neither the concentration nor the frequency of zinc sulfate foliar sprays influenced the height, canopy size, trunk diameter, or volume of the trees. Interestingly, the highest increase in length of shoot was recorded at the 0.6% Zn-sulfate concentration. Leaf content analysis revealed that the highest levels were observed when 0.6 percent zinc sulfate was utilized, particularly for leaf zinc (139.29 ppm), leaf nitrogen (1.091%), and leaf potassium (0.434%). While the levels of calcium and magnesium in the leaves remained constant, the quantity of leaf phosphorus varied with increasing zinc concentration.

Sachin *et al*. (2019) carried out a study in order to determine how foliar micronutrient treatment affected guava (*Psidium guajava* L.) reproductive parameters, The maximum fruit set % and no. of flowers/shoot were observed with 1.0 percent of zinc sulphate, 1.0 percent of borax, and 1.0 percent of copper sulphate, while control had the lowest values for these traits. Instead, foliar treatment of 1.0 percent of ZnSO4 resulted the lowest fruit drop % and the less time taken in towards fruit maturity.

Bhoyar *et al.* (2016) evaluated the impact of spraying of zinc, iron, and boron, either individually or in various combinations, shows on plant spread and reproductive traits as well as on biochemical traits of guava cv. Sardar L-49. Growth parameters remained unaffected by the different micronutrient combinations. However, the mixture of 0.5g/L Zinc sulphate, 0.5g/L Ferrous sulphate, and 0.30g/L borax effects on total yield (57.10 kg/tree) as well as sensory attributes such as aroma (7.70), sense of taste (8.10), flavour (8.20), and overall suitability (7.90). Fruit/shoot also experienced an increase (3.60). Moreover, the foliar application of 0.3% borax impacted the flower numbers/shoot (5.30). The application of 0.50g/L $FeSO_4$ with 0.3% borax impact in the lowest drop of fruit, while the lowest fruit drop/shoot was seen in the application of 0.50g/L Zinc sulphate and 0.30g/L borax. The mixture of micronutrients improved the set of fruits, reduced fruit drops, and enhanced yield, consequently improving the sensory qualities of guava fruits.

In the study by **Ojeda-Barrios *et al.* (2014),** the focus was on assessing the yield quality, vegetative and physiological characteristics, leaf nutritional status, and zinc (Zn) levels in pecan trees treated with different zinc compounds through foliar spraying. Eight-year-old "Western Schley" pecan trees, grafted onto native seedlings, were subjected to treatments with ZnNO3 (100 mgL−1 Zn), Zn-EDTA (50, 100, and 150 mgL−1 Zn), and Zn-DTPA (100 mgL−1 Zn), alongside a Zn-untreated control. Following a 3-year evaluation period, the most promising outcomes were observed in trees treated with $ZnNO^3$ (100 mgl^{-1} Zn) and Zn-DTPA (100 mgl^{-1} Zn). These treatments resulted in significant increases in leaf Zn content, by 73% and 69%, respectively, compared to the control group. The Zn-treated trees exhibited chlorophyll levels of 46 SPAD units and 43 $mgkg^{-1}$ dry weight (DW), whereas zinc-deficient leaves showed chlorophyll levels of 22.00 $mgkg^{-1}$ dry weight (DW). Chlorophyll levels under zinc-deficient conditions were 37% lower on a leaf area basis compared to Zn-treated plants. Notably, the Zn treatments did not affect nut quality. Based on the findings, Zn-DTPA and Zn-NO_3 are considered effective options for zinc fertilization of pecan trees via foliar application.

C. EFFECT ON YIELD

Shukla *et al.* (2022) investigated the impact of micronutrient spraying on the physical characteristics of guava cv. Allahabad Safeda. Foliar application with 0.4% zinc sulfate and 0.4% borax resulted in the most substantial outcomes for 10-year-old guava plants. This treatment demonstrated maximum fruit set (68.80%), fruit retention (65.89%), fruit length (7.59 cm), specific gravity (0.92), fruit yield per plant (42.20 kg/plant), and overall yield (q/ha).

According to **Sajid *et al.* (2022),** foliar application of potassium nitrate and copper sulphate to pear (*Pyrus communis* L.) trees at 2% and 0.6% produced the highest fruit weight, fruit volume, fruit yield, minimum fruit drop and disease incidence. Ascorbic acid content, total soluble solids, fruit juice pH and minimum titratable acidity were among the quality parameters that showed comparable outcomes.

Patel *et al.* (2022) conducted an experiment and revealed substantial variations with a high analysis of variance, suggesting that guava growth, yield, and quality are adequately varied. The plant height of T_9 ($ZnSO_4$ and Boric acid) was the highest, along with the branch number (8.24), leaves/shoot (26.40), fruits/plant (194.30), weight/fruit (226.13g), yield of fruits/plant (49.80 kg/tree), titratable acidity (0.42%), Vit-C (192.82 mg/100g), and TSS (12.60 ^{0}B). The lowest values were noted in the control group. This study's findings demonstrated that mixture of micronutrients boosted fruit set%, decreased fruit drop%, and raised total production. This treatment also leads with guava qualities.

Morab *et al.* (2021) Found the effectiveness of nano formulated fertilizers. They found that foliar application on grape vines with 0.4 ppm nano-Zn enhanced area of leaf, fresh weight of leaf, and dry weight considerably over control. However, total carbohydrate, Fe leaf content, cluster number, cluster weight, and yield were all considerably elevated by 1.2 ppm nano-zinc. Additionally, nano zinc at 0.4, 0.8, and 1.2 ppm greatly boosted yield in comparison to traditional fertilizers.

The foliar nutrition of nano-fertilizers was studied by **Morab *et al.* (2021).** Growth characteristics of savory plants, such as plant spread, increase upon application of nano-zinc. This might be the case since zinc is known to activate several enzymes involved in metabolic processes, including protein synthesis and glucose metabolism, as well as to alter the generation of natural auxin (IAA). The maximum percentage of nitrogen was noted in pomegranate transplants treated with nano-zinc at dosages of 2 and 3 g. L^{-1} stood for 1.95

percent and 1.97 percent, in that order.

El-Gioushy *et al.* (2021) carried out study on *Citrus sinensis* L. to check out the results of $ZnSO_4$ and $CuSO_4$. The research found that mixture of $ZnSO_4$ and $CuSO_4$ yielded the effective outcomes across various treatments. Notably, a substantial correlation was observed between the treatments 400ppm $CuSO_4$ and 600ppm $ZnSO_4$ and improved nutritional status, characterized by maximum total leaf chlorophyll and leaf mineral contents. Moreover, the highest concentrations of $ZnSO_4$ (600ppm) and $CuSO_4$ (400ppm) resulted in superior fruiting characteristics and fruit quality. Therefore, it is suggested to apply a foliar spray containing 600ppm, $ZnSO_4$ and 400ppm $CuSO_4$ once a month from March to July, provided that the environmental conditions and horticultural practices align with those of the study.

Meena *et. al.* (2020) discovered a notable positive relationship between the concentrations of zinc (Zn) and iron (Fe) in guava leaves and various parameters linked to fruit yield and quality. These encompassed factors such as the quantity of fruits and other characters of fruits, yield per plant, biochemical characters, seed cavity size, ascorbic acid content, pulp weight, and total phenols. Conversely, the levels of Zn and Fe displayed a substantial inverse correlation with specific gravity, acidity percentage, the total no. of seeds/fruit, and seed weight in the fruits of guava cv. L-49.

In research by **Bisen *et al.* (2020)**, guava trees of the Pant Prabhat cultivar, aged two years, were subjected to foliar spraying of zinc sulphate at concentrations of 0, 0.2%, 0.4%, and 0.6%. The spray started in first week of June, followed by a 2nd in first week of September, applied to 50 percent of the trees. Interestingly, neither the concentration nor the frequency of zinc sulphate foliar sprays affected the height, canopy size, trunk diameter, or overall volume of the trees. However, a substantial enhancement in length of shoot was seen, particularly at the 0.6% $ZnSO_4$ concentration. In lowest levels of flower and fruit drop, accompanied by the highest fruit weight/tree and yield/hectare, were recorded with the application of a double spray of zinc sulphate at 0.6 percent concentration. Moreover, the foliage exhibited the highest nutrient content when treated with 0.6 percent zinc sulphate, with the highest levels observed in leaf zinc (139.29 ppm), leaf nitrogen (1.091%), and leaf potassium (0.434%). Although calcium and magnesium levels remained unchanged, phosphorus levels varied with increasing zinc concentrations.

In **Sachin *et al.* (2019)** study, the impact of foliar micronutrient application on reproductive parameters in guava (Psidium guajava L.) was investigated. Treatment T_8, consisting of $ZnSO_4$ (1.00%), borax (1.00%), and $CuSO_4$ (1.00%), resulted best amongst the control treatment (T_1). Notably, treatment T_8 resulted the enhanced no. of flowers/shoot (29.90), fruit set% (79.30%), and fruit retention% (63.22%). Conversely, T_1 displayed the shortest time to fruit maturity (130.33 days), with a fruit set percentage of 50.53%. The application of 1.0% $ZnSO_4$, borax, and $CuSO_4$ collectively (T8) resulted in the less fruit drop% (36.84%) and the less time taken to fruit mature (116.30 days).

El-Hak El *et al.* (2019) studied on grapevines to conclude the results of the nano-Zn foliar application in terms of growth and production point of view. Over two consecutive growing seasons in 2014 and 2015, the study assessed the effects of nano-zinc on five-year-old grapevines in a private orchard located in the Gharbia Governorate of Egypt. Six treatments were utilized, including a control with water, zinc sulfate, zinc EDTA, and three different concentrations of nano-zinc (0.4 ppm, 0.8 ppm, and 1.2 ppm). Nano-zinc spray enhanced several parameters compared to the control. Specifically, $1.2 mgL^{-1}$ nano-Zn improved total sugar%, leaf Fe content, number of clusters, cluster weight, and yield, while 0.4 ppm nano-zinc increased leaf area and fresh weight. Furthermore, nano-zinc treatments demonstrated higher yields compared to conventional fertilizers, leading to reduced zinc fertilizer usage. The optimal application for enhancing vegetative traits was determined to be 0.4 ppm nano-zinc.

Bhardwaj *et al.* (2019) in their study conducted on guava fruit crop by applying Zn and urea in HDP (high density plantation). The experiment featured 16 treatments, each replicated three times, and was arranged in a randomized block design. The results revealed that treatment T12 (Urea 2% + zinc 0.6%) exhibited the highest values across various parameters, including plant height (246.47 cm), number of branches (23.00), flowering duration (74.33 days), fruit per plant (42), fruit set percentage (54.44%), fruit weight (155.61g), fruit yield/plant (6.60 kg), Titratable acidity (0.56%), Vit-C content (267.33 mg/100g), total soluble solids (12.26 °B), and sugar content (8.15%). Treatment T11 (Urea 2% + zinc 0.4%) also demonstrated notable results. In contrast, the control group exhibited the lowest values for these parameters.

A study by **López-Vargas *et al.* (2018)** involved applying four treatments—50, 125, 250, and 500ppm, with Cu. Antioxidant component levels and fruit quality were shown to be impacted. Fruits that were produced had more firmness as a result of the Cu nanoparticle treatment. Ascorbic acid, lycopene and antioxidant activity are less in the control. Enzymatic activity of the enzymes catalase (CAT) and superoxide dismutase (SOD) substantially increased, whereas that of the ascorbate peroxidase (APX) and glutathione peroxidase (GPX) decreased. More bioactive chemicals accumulated in tomato fruits as a result of applying Cu NPs.

Suman *et. al.* (2017) the study focusses on investigating various traits related to quality and quantity of fruits, and growth of plants. Among the treatments evaluated, treatment T_{11}, comprising 0.3percent BH_3O_3, 0.4% $FeSO_4$, 0.7% $MgSO_4$, 0.5% $MnSO_4$, 0.5% $ZnSO_4$, and 0.4% $CuSO_4$, exhibited the highest levels of fruit set and retention. Conversely, treatment T_{10}, which included 0.3% BH_3O_3, 0.4% $FeSO_4$, 0.7% $MgSO_4$, 0.5% $MnSO_4$, and 0.5% $ZnSO_4$, demonstrated the least fruit drop. Additionally, T10 displayed the shortest time to initial harvesting (88.08 days) and the longest overall harvesting duration (123.61 days). In contrast, the control group required the most time for both initial harvesting (103.33 days) and overall harvesting (158.6 days).

Harris and colleagues (2017) investigated the effect of H_3BO_3 and $CuSO_4$ spray on the growth and reproductive characters of tomatoes in an experiment conducted at the Crop Farm, Eastern University, Sri Lanka, spanning from December 2013 to April 2014. The experiment, employing a completely randomized design (CRD) with eight replications, comprised ten treatments: T1) H_3BO_3 = 150 ppm; T2) H_3BO_3 = 250 ppm; T3) H_3BO_3 = 350 ppm; T4) $CuSO_4$ = 150 ppm; T5) $CuSO_4$ = 250 ppm; T6) $CuSO_4$ = 350 ppm; T7) H_3BO_3 (150 ppm) + $CuSO_4$ (150 ppm); T8) H_3BO_3 (250 ppm) + $CuSO_4$ (250 ppm); T9) H_3BO_3 (350 ppm) + $CuSO_4$ (350 ppm); T10) Control. Three foliar sprays were administered at 10-day intervals, starting 40 days post-transplantation. Seedlings were grown in a nursery for 30 days before being transplanted into polybags following Sri Lanka's Department of Agriculture guidelines. The potting media comprised sand: topsoil: decomposed cow dung in a 1:1:1 ratio. Plant height increased with $CuSO_4$ at 150 and 250 ppm, whereas the number of leaves per plant increased with H_3BO_3 at 250 ppm and H_3BO_3 (250 ppm) + $CuSO_4$ (250 ppm) in comparison to the control. Longer roots were encouraged by $CuSO_4$ at 250 and 350 ppm as well as by H_3BO_3 (250 ppm) + $CuSO_4$ (250 ppm). H_3BO_3 at 150 and 250 ppm yielded the highest fruit yield on a dry basis, whereas H_3BO_3 at 350 ppm increased fruit quantity. The control treatment exhibited inferior performance across all evaluated parameters.

Zakzouk and UAI conducted a study in the 2015 and 2016 season on mango to evaluate the fruit quality and disease resistance (Zebda and Ewasy malformation). In control, they sprayed HMO (horticulture mineral oil) 1.5percent and 0.05 and 0.1% nano-Zn before flower initiation. When juxtaposed with Zebda Cv., Ewasy Cv. showed better values in terms of panicle length, sex ratio, yield, fruit retention at harvest, leaf physical properties, and pigment and mineral contents of the leaf. Zebda Cv., in contrast to Ewasy Cv., had a much higher leaf carotene concentration and a higher proportion of resistance to deformity. Fruit resistance to malformation %, weight/tree ratio, and other research features were all improved by nano-Zn treatments, particularly the 0.1% one. The greatest values in fruit weight and yield/tree were obtained with nano-Zn treatments at 0.05% and 0.1%. Comparing treated vs untreated trees, the increase percentages were 41.45, 44.97, 33.74, and 57.36, respectively. Based on the research findings, it is recommended that mango trees in the Belbeis area, Sharkia Governorate, and similar environments be sprayed with 0.1% of nano-zinc before to blooming in order to boost fruit quality and productivity while also strengthening their resistance to malformation.

Davarpanah *et al*. (2016) examined the influence of nano-fertilizer treatments on pomegranates during pre-blossom stages. They administered a single dose of nano-B chelate (0, 3.25, and 6.5 mg B/L) and nano-Zn chelate (0, 60, and 120 mg Zn/L) @ of 5.3 L/tree. Following treatment in August, there was a notable rise in micronutrient concentrations in the leaves, indicating improved nutritional status. The increase in fruit yield was predominantly attributed to a solitary foliar application of relatively less amount of nano-B and nano-Zn (34ppm B/tree and 636ppm Zn/tree, respectively), resulted in enhanced no. of fruits/tree. By augmenting the fruit quantity/tree before full blossom, a single foliar treatment with nano-B and nano-Zn chelate fertilizers substantially enhanced overall pomegranate fruit production.

Arshad *et al*. (2016) conducted a thorough investigation in Gharo, Sindh, Pakistan during the 2014–15 season to assess the influence of varying Zinc (Zn) fertilization rates on enhancing the quality and yield of Guava fruit. The study revealed that in the absence of foliar Zn fertilizers, there was no noticeable impact on both production and quality. However, both fruit quality and quantity substantially improved following the application of foliar fertilizers.

Plants treated with Zn5 (0.5 percent) exhibited maximum plant height (3.111 m), fruit width (6.070 cm), fruit length (6.989 cm), fruit weight (111.555 gm), no. of fruits for each plant (379.70), and yield (41.930 kg/plant). Additionally, higher TSS (9.373%), Vitamin C content (45.147 mg per 100 ml of juice), firmness (5.969 kg/cm2), and reduced acidity (0.485 percent) were observed in fruits treated with the same concentration. While some metrics showed substantially lower outcomes, treatments Zn6 (0.6%) and Zn7 (0.7%) yielded nearly comparable results.

Kumar *et al.* (2015), foliar sprays containing zinc, calcium, potassium, and boron were applied to guava plants at two distinct times, first at the time of flower to fruit set and second after 15 days of fruit set. The spray resulted in various improvements, including a 12.17% increase in plant height by 0.030percent Zn applied 15days after fruit set, 150g higher weight of the fruit with 0.030percent Zn application, and a 147.70% increase in fruit volume with 0.03percent boron applied 15day after fruit set. Moreover, foliar fertilization led to enhancements in parameters such as pulp: seed ratio, total sugars, total soluble solids (TSS), and a decrease in fruit drop percentage and acidity content. The study demonstrated that foliar fertilizer treatment influenced both plant growth and fruit quality, particularly when applied two weeks after fruit set.

The potential of copper nanoparticles (Cu-NPs) to boost the development and yield of the wheat cultivar Millat-2011 was investigated for the first time in Pakistan by **Hafeez *et al.* (2015)**. To achieve this, a number of tests were carried out. At 0.2 to 0.8 ppm of CuNPs, seed germination was unaffected; however, at 1.0 ppm, it dramatically declined. Wheat plants were negatively impacted by Cu-NP concentrations more than 2 ppm in solution culture. Conversely, as compared to control plants, MS media mixed with modest doses of Cu-NPs (0.2, 0.4, 0.6, and 0.8 and 1.0 ppm) greatly enhanced leaf area, chlorophyll content, fresh and dry weight, and root dry weight. In comparison to the control, Cu-NPs (10, 20, 30, 40, and 50 ppm) greatly effected the plant height and reproductive traits of wheat when added to the soil in pots. But 30 ppm Cu-NPs resulted in noticeably greater leaf area, 100 grain weight, and chlorophyll content. According to the study's findings, concentration determines whether or not Cu-NPs may improve wheat growth and output.

Chandra *et al.* (2015), spray of $ZnSO_4$, $MgSO_4$, and $CuSO_4$ at 0.5 percent concentrations resulted in larger fruit with increased pulp-to-stone ratio, weight, and volume.

Combining these sulfates at the same concentration led to highest TSS, Total sugar content, Vit-C levels, and a lowest titratable acidity%, indicating improved fruit quality. The most effective method for increasing fruit yield was found to be simultaneous spraying of copper, magnesium, and zinc sulfates at 0.5 percent each. The study concluded that the optimal approach for enhancing fruit yield, production, and improving fruit quality in aonla involved joint application of zinc sulfate, magnesium sulfate, and copper sulfate, all at a concentration of 0.5 percent.

In their trial conducted at the Horticultural Research Farm of Babasaheb Bhimrao Ambedkar University during the Rabi season of 2012–2013, **Yadav *et al.* (2014)** aimed to evaluate the effects on the growth, physical attributes, and quality characteristics of guava. The observations indicated that foliar applications of $ZnSO_4$ + borax at 0.6% and $ZnSO_4$ + $CuSO_4$ + borax at 0.5% resulted in the highest fruit set percentage (67.40%) and fruit drop percentage (58.71%).

Jat *et al.* (2014) conducted trial on the use of 1.5% urea resulted in notable enhancements in retention of fruits (63.20percentage), weight of fruits (155.50g), and fruits/ha (22095 kg/ha). Similarly, treatment Z3 (0.6% ZnSO4) demonstrated substantial improvements in fruit retention (62.90percent), weight of fruit (153.90g), maximum no. of fruits/plant (489.70), and yield (20984 kg/ha) in relation to the influence of zinc sulfate.

Ali *et. al.* (2014) investigated the impact of foliar micronutrient spray on peach fruit quality. The soil type, characterized by pre-treatment soil analysis, was identified as silt loam, containing adequate organic matter and being calcareous and alkaline. The soil shows deficiency in phosphorus, zinc, iron, and boron, but had sufficient levels of manganese (Mn) and copper (Cu). T_6 (Zinc + Copper + iron + Manganese + Boron), by the spray of micronutrients fruits was increased in length and production also enhanced. Following micronutrient foliar application, there was a linear decrease in the juice's pH and acidity. Therefore, foliar micronutrient spraying had a substantial ($P < 0.05$) impact on peach fruit quality.

Devi *et. al.* (2013) concluded spray twice: once at the bud's commencement and once after 20 days. In terms of several criteria, including fruit number per plant (194.7), and yield per hectare (192.53q/ha), treatment T_6 (0.6% boric acid) showed the best results. T_9 (0.4% copper sulphate) substantially impacted variables like ascorbic acid content, dry weight of 10 fruits, and stem diameter. Treatment T_3 (0.75% zinc sulphate) showed the best results for plant height, stem diameter, fruit length, and seeds per fruit. Treatments T_4 (0.25% boric acid) and T_1 (0.25% zinc sulphate) flowered earlier than T_{10}. The optimal treatments for improving chili characteristics were boric acid (0.6%), with respective increases in fruit output of 30.79%, 23.55%, and 15.03% related to the control.

In the years 2006 and 2007, **Sajid *et al.* (2010)** conducted a study in Dargai, Malakand Agency, Pakistan, focusing on the effects of zinc and boron spray on the growth and reproductive traits of Blood red sweet orange trees. They applied H_3BO_3) at 0.02percent and 0.04percent, and ZnSO4.7H2O at 0.50percent and 1.0percent, supplemented with 0.80percent urea and 0.10percent surfactant, at three growth stages. The experiment employed a randomized complete block design. Zinc and boron spray substantially influenced days to flower, reproductive characters, dieback%, chlorosis %, and rosette %/plant. The combination of 1.0% zinc and 0.02% boron resulted in the highest fruit yield per plant. Concurrent foliar spraying of Zn and B reduced dieback, chlorosis, and rosette percentages. The study concludes that combining zinc and boron foliar applications effectively manages physiological disorders and enhances citrus orchard productivity in the Dargai region of Pakistan.

Patil *et. al*. (2010) conducted research at the All India Co-Ordinated Vegetable Improvement Project (AICVIP), University of Agricultural Sciences, Dharwad, found the foliar micronutrient application on tomato (Megha) plant spread and reproductive traits from 2005–06 to 2006–07. Across two years, boric acid at 100 ppm exhibited the highest number of primary branches (18.30). A micronutrient combination (Boron, Zinc, Manganese, and Iron at 100 ppm, Molybdenum @ 50 ppm) followed closely with 27.98 t/ha. Boron application demonstrated the highest benefit ratio of 1.80, yielding net returns of Rs 97,850/ha, while the micronutrient combination yielded Rs 88,900/ha. The control group had the lowest net returns (Rs 53,250/ha). Treatment TSS was highest in the combination of 1.0% boron, copper sulfate, and magnesium sulfate, while treatment T4 (boron 1.0%) exhibited the highest ascorbic acid (171.53 mg/100g) and lowest acidity (0.42%).

D. EFFECT ON PLANT NUTRIENT STATUS

Al-Janabi *et al.* (2021) investigated zinc foliar spraying. Plant components may be developed as novel nanomaterials by utilizing the properties of nano-particulate Zn, such as reactivity, uncommon surface area that promotes Zn solubility, diffusion, and accessibility to plants. The results demonstrate that pomegranate parameters increased somewhat with a low dosage of foliar spray or Zn nano-fertilizers (2 and 3 $g.L^{-1}$). It's noteworthy that zinc deficiencies are widespread in many crops, and zinc is one of the most crucial minerals for plants. In addition, a number of enzymes depend on the concentration of Zn in cells for their proper operation, including aldolases, trans phosphorylases, dehydrogenases, and isomerases. Additionally, the effects of copper on pomegranate transplants revealed a rise in parameters, which may be the result of heightened enzymatic activity and a reflection of an effective rate of photosynthesis. This process might lead to an improvement in plant characteristics and development via the substances generated by leaves. Applying these nutrients may also raise the amount of chlorophyll in the leaves, encouraging physiological plant functions that favor the creation of proteins and carbohydrates.

Sau *et al.* (2016) determined that the plants treated with a combination of B1 = (H_3BO_3 @ 0.2%), Zn1 = ($ZnSO_4$ @ 0.5%), and Cu1 = (CuSO4 @ 0.5%) had the greatest N content (66.67% greater than the control), which was statistically equivalent to B1Zn1 = (H_3BO_3@ 0.2% + ZnSO4 @ 0.5 %). Guava leaves with the highest K content (1.62%) were found in plants treated with B1 = (H_3BO_3@ 0.2%) and Zn1 = (ZnSO4 @ 0.5%). No appreciable increases in the P content of leaves were seen after micronutrient fertilization, either in isolation or in combination. The guava leaves with the greatest B content (19.01 ppm) were found on trees treated with B1 = (H_3BO_3@ 0.2%) and Zn1 = (ZnSO4 @ 0.5%), which was 32.20 times higher than the no treatment (control). Foliar treatment of Zn_1 = $ZnSO_4$ @ 0.50%+Cu_1 = CuSO4 @ 0.50%, had the highest Zn content (39.36 ppm), which was statistically comparable to the outcomes of applying B1Zn1Cu1 and Zn1. In contrast to the concentration of zinc, the plants that benefited from foliar fertilization with Cu1 had the greatest concentration of Cu in their guava leaves—65.70 percent greater than the trees that did not get any micronutrient fertilizers. Increased leaf nutrient content in guava due to micronutrient fertilization. Among the micronutrients evaluated, Cu contributes less to the rise in leaf N, P, and K contents. This may be because the experimental soil contains a high concentration of accessible Cu.

A study by **Soliemanzadeh *et. al*. (2013)** evaluated the impact of Zn, Cu, and Fe foliar spraying on pistachio tree fruit set, along with specific quality and quantity attributes. The combination of Fe and Cu resulted in the highest final fruit set percentage, while the control group exhibited the lowest splitting rate, with the Cu and Fe combination showing the greatest. However, the spraying of Zn, Cu, and Fe had no effect on blankness compared to the control group. The Cu treatment induced the most vegetative growth, whereas the two different doses of Zn produced the highest yield. Additionally, foliar application of Zn, Cu, and Fe led to an increase in their concentrations in the leaves, with Zn showing the least increase, followed by Cu and then Fe.

E. EFFECT ON SHELF LIFE

Sushmitha *et al* (2019) conducted a trial on guava by applying a spray of micronutrients to check out the results on biochemical changes in guava fruit. The treatment soil application of fertilizers + spray of zinc + magnesium + manganese with a dose of 0.75g/L + copper +iron at the dose of 0.5g/L +MAP 0.5g/L resulted in the increased reducing and non-reducing sugars (3.60percent and 5.93percent).

According to **Pérez-Labrada *et al*. (2019)** research, tomatoes are a crop with substantial nutritional and economic value, but salt stress can have a negative impact on them. The aim of this study is to measure the agronomic and biochemical reactions of tomato plants grown under salt stress by applying copper nanoparticles topically. The following four treatments were assessed: an absolute control, salt stress, and the foliar application of copper nanoparticles (250 mg L^{-1}) with or without salt stress (50 mM NaCl). Tomato plants underwent substantial development damage due to saline stress; however, the damage was lessened by the foliar spray of copper nanoparticles, which enhanced performance and raised the Na^+/K^+ ratio. Using Cu nanoparticles raised the amount of copper in tomato plant tissues under salinity, which in turn raised the number of phenols (16%) in the leaves and the amounts of vitamin C (80%), glutathione (GSH) (81%), and phenols (7.8%) in the fruit when compared to the control. In a similar vein, leaf tissue showed increases in the activities of the enzymes catalase (CAT), ascorbate peroxidase (APX), glutathione peroxidase (GPX), superoxide dismutase (SOD), and phenylalanine ammonia lyase (PAL) by 104%, 140%, 26%, 8%, and 93%, respectively. Applying copper nanoparticles foliar to tomatoes in salinity seems to increase the plants' ability to withstand stress by boosting their antioxidant defenses.

In a study of **Munde *et al.* 2018** investigated the effects of foliar micronutrient treatment on guava fruit quality features. They found that foliar zinc sulphate at 1% resulted in the highest TSS value of 11.80 ^{0}B, and other biochemical traits. The application of 1 percent ferrous sulphate resulted in the lowest acidity (0.35%), whereas the application of Cuso4@1%+Feso4@1%+Znso4@1% + Borax @ 0.50% led to the lowest physiological weight loss (3.10, 7.60, 8.00, 13.14, respectively) on the second, fourth, sixth, and eight days of storage. 7.10 days of satisfactory fruit preservation were documented with this treatment. The control group saw the greatest physiological weight reduction and the lowest level of maintaining quality.

Hernández *et al.* (2017) conducted an experiment to look into how using nanoparticles affected agricultural productivity. There's proof that the growth and development of several crops are substantially impacted by copper nanoparticles. dietary that has been biofortified, particularly with (NPs Cu), has been shown to have higher nutritional value, and human health benefits from dietary intake. The study was conducted for evaluation the results of Cu on weight of the fruit and nutritional quality. Cu NPs were applied topically at five different doses: 0, 1.8, 3.6, 5.4, 7.2, and 9.0 mg L^{-1}. Fruit weight, hardness, total soluble solids, polar and equatorial diameter, bioactive chemicals, and copper concentration in melon pulp were the factors assessed. The outcomes showed that applying NPs Cu topically enhanced the concentration of Cu as well as the melon fruits' physical and nutraceutical quality. The fruits of watermelon showed results at the dose of Cu @7.2ppm and 9.0ppm.

Thirupathaiah *et al.* (2017) studied the effect of nutrients on the biochemicals and postharvest shelf life of sapota cv. Kalipatti. Zinc and iron sulphates were applied topically and topically in soil; sodium tetraborate (Jai bore) was applied topically; and soluble was applied topically in foliage. The results indicated that applying T10-RDF + 0.5 percent ZnSO4 + 0.5 percent FeSO4 + 0.3 percent B topically to each tree (i.e., twice as topically, once at 50% flowering and the other at pea-sized fruits) caused a physiological loss in fruit weight of 7.05 percent at three days after harvest and 1.35 percent at six days after harvest without affecting quality attributes and increased shelf life (12 days) with a maximum percentage.

El-Baz *et al.* (2011) studied common seedy guava trees grown in a private orchard at EL Kefah village, Badr center, Behera governorate to examine the effects of various defoliation treatments on tree yield and fruit quality at harvest time. They also looked at weight loss, decay, and total loss during storage at room temperature as representative conditions for the marketing of guava trees. When compared to the control in both research seasons, every tested treatment substantially enhanced fruit quality (fruit weight, firmness, total sugar content, vitamin C, acidity, SSC, and SSC/ acid ratio). Fruits of the other treatments were stored at 12–14 ºC and RH 82 percent throughout the winter harvest season, whereas both control fruits were kept at 20–22 °C and RH 75 percent during the typical summer harvest time. In comparison to other treatments, the results demonstrated a considerable improvement in winter crop production with 10% urea. Moreover, $ZnSO_4$ 2 percent + NH4NO3 4 percent substantially improved the quality of the fruit in comparison to other treatments. The fruit quality (fruit weight, firmness, total sugars, vitamin C, acidity, SSC, and SSC/acid ratio) improved the most and the least after 9 days of room storage when $ZnSO_4$ 2% + NH4NO3 4% was added. Fruits harvested early in the summer resulted in a considerable increase in output, whereas the control fruits (summer yield) exhibited an increase in fruit weight loss and decay and a drop in quality. It took three days for the degradation to reach 100% because of the higher summer temperatures. The excellent quality of the winter crop produced by these treatments more than made up for the production decrease in guava fruit plants.

Bhatt *et al* (2006), The impact of foliar applying multimodal, copper, iron, manganese, zinc, boron, zinc, molybdenum, zinc, and manganese combination on the nutritional content of tomato shoots and fruits was investigated. Fruit concentrations of N, P, K, sulfur, zinc, Fe, copper, Mn, and boron were found to be considerably higher when most micronutrients were sprayed on the foliage. Apart from potassium and nitrogen, the treatment of micronutrients had a substantial impact on the accumulation of other minerals in shoots. To increase the nutritional content, it was discovered that applying a combination of micronutrients worked best.

F. ECONOMICS

Mekawy (2021) conducted a study on seven-year-old Flame Seedless grapevines to found the result of ZnONPs at concentrations of 60, 120, 240, and 480 mg/L, as well as chelated zinc at 1.5 g/L, compared to a control with no zinc application. The research spanned the 2018 and 2019 seasons. The grapevines, which were spur-pruned in the third week of December, were planted in clay loam soil, spaced 2 by 3 meters apart, and trained using a Spanish Parron support system. Results indicated that both chelated zinc and ZnONPs applied foliarly improved berry quality and vegetative growth characteristics. However, increasing ZnONP concentrations up to 480 mg/L resulted in a decrease in these characteristics compared to the control or conventional zinc supply. This study suggests that foliar application of ZnONPs may enhance both the quantity and quality of Flame Seedless grape production, leading to increased financial returns.

Zagade *et al.* (2020) assessed the economics of guava farming in relation to several foliar micronutrient spray regimens. The lowest cost of interculture and fertilizer application (Rs. 80600/ha) resulted in the control, according to the research. The treatment that needed the greatest cost, Rs. 92,800/ha, was in the treatment application with copper sulfate at the dose of 1g/L + iron sulfate at the dose of 1 g/L + zinc sulfate at a dose of 1g/L + Borax at a dose of 0.5g/L. Because there are no costs associated with inputs or applications, in-control therapy may have the lowest cost. Chemical and labor expenditures for foliar application might be the source of the greatest cost in the treatment of copper sulfate at the dose of 1g/L + iron sulfate at the dose of 1 g/L + zinc sulfate at a dose of 1g/L + Borax at a dose of 0.5g/L. The maximum gross returns (Rs.1400/tree) was found in the the tree that was treated with zinc sulfate at 1g/L, according to the economic returns analysis. It was at most Rs. 976/tree in the control treatment. The best fruit production was obtained by applying zinc sulfate, which may be the cause of this.

Kate *et al.* (2020) studied the effect of spray Zn, Fe, and B in the soil on guava quality and the most economical amount of these nutrients. The experiment was conducted during Mrig Bahar 2019 in a fifteen-year-old Sardar guava orchard with trees of uniform growth and vigor spaced at six*six meters. According to the study's findings, guava's growth, yield, and quality characteristics were all strongly influenced by the micronutrient treatments that were applied. The aforementioned process also resulted in the highest levels of physical and chemical quality features. The best gross return (Rs. 5,66,200/ha), net return (Rs. 3,36,600/ha), and B:C ratio (2.47) was recorded under treatment T_9 (zinc sulfate(100g) + ferrous sulfate (100g) + Borax (25g).

Patil *et al.* (2010) investigated the effects of spray applications on the height and reproductive traits of tomatoes (variety: Megha) over the years 2005–06 and 2006–07. Among the nine experimental treatments, the application of H3BO3 at a concentration of 100 ppm resulted in the highest growth rate, as observed from the average data across both years.

Following closely, a micronutrient combination consisting of boron, zinc, manganese, ferrous at 100 ppm, and molybdenum at 50 ppm, yielded a production of 27.98 tons per hectare, surpassing other treatments. While the combined micronutrients generated net returns of Rs 88,900 per hectare, the application of boron alone achieved the highest Benefit-to-Cost ratio of 1.80, resulting in net returns of Rs 97,850 per hectare. In contrast, the control group exhibited the lowest net returns at Rs 53,250 per hectare.

Chapter-III

MATERIALS AND METHODOLOGY

The research is entitled **"Effect of nano Zn and Cu on growth, productivity and quality of winter season guava (*Psidium guajava* L.) variety Allahabad Safeda".** The study was conducted during the years 2022 and 2023 at Horticulture Farms, Department of Horticulture, Lovely Professional University, Punjab. Winter season crop of guava was selected for the studies and the age of the plants was 4-5 years. The analysis of chemical properties was conducted in the laboratories of the Department of Horticulture at Lovely Professional University, Punjab. The experimental design followed in the research work was Randomized Block Design (RBD). The materials utilized and the procedures followed are outlined in detail below.

3.1 Experimental site and Description

3.1.1 Location of the experiment

The study was evaluated on guava plants at Lovely Professional University in Phagwara, Punjab, India. The experimental site stands at an altitude of 232 meters above mean sea level, marked by coordinates of 31.244604 N latitude and 75.701022 longitude. Punjab lies in the central plain zones and adores a subtropical type of climate. In summers, temperatures may reach as high as 43 degrees centigrade and in winters may drop as low as 0 degree centigrade.

3.1.2 Climatic and weather conditions:

The location of the experimental site is located in the sub-tropical region, the site exhibits distinct climatic features with mild winters and scorching summers. The majority of rainfall occurs in July, August, and September, primarily associated with the South-West monsoon. December and January are characterized by extremely cold conditions.

Conversely, the summer months from April to June experience high temperatures, with the highest recorded temperature nearing 43°C. Monsoon showers typically start in the latter part of July, continuing until the end of September, unless delayed by the South-West monsoon. Notably, frequent rainfall is observed during July and August.

3.1.3 Soil condition at the experiment site

Before initiating the investigation, a set of soil samples was obtained randomly from the orchard site. This ensures a representative sample that reflects the overall soil variability in the orchard. For soil samples collection from an orchard, depths should be 6 to 12 inches, collection of samples by using the auger and clean plastic buckets, and plastic bags for sample storage. Use the soil auger or sampling tube to collect soil samples at each designated point. Insert the auger into the soil and extract a core. Collect multiple cores from each sampling point to create a composite sample. Combine the individual soil cores from each sampling point in a clean plastic bucket. Mix the soil thoroughly to create a homogeneous composite sample for each zone.

This composite sample served as the basis for assessing the chemical characteristics of the soil. The initial fertility status of the trial land is represented in Table 3.1, Furthermore, after the harvest, additional soil samples were obtained and subjected to analysis to gauge any changes.

Table no. 3.1 Chemical properties of soil at experimental site

S. No.	Particulars	Result	Method Followed
1.	pH	8.10	pH meter
2.	EC	0.20 hos/cm	EC meter
3.	OC	0.45 %	Walkley and black`s method
4.	Available Nitrogen	52.03 ppm	Alkaline potassium permanganate
5.	Available phosphorus	22.72 ppm	Olsen method
6.	Available potassium	55.06 ppm	Flame photometer method
7.	Zinc	0.45 ppm	
8.	Copper	0.52 ppm	

3.1.4 Nutrient and manure application

NPK and Farm yard manure are provided to the respective treatments as per the recommendation in the Package of Practice of PAU Summer, 2021. That is Urea @ 300-600 /tree, super phosphate @ 1500-2000 g/tree, and muriate of potash @ 600-1000 g/tree in split doses i.e.; Half of the inorganic fertilizers should be applied in May-June and the remaining half in September-October. And the FYM applied @ 25-40 kg/tree. Farmyard manure applied in May.

3.2 Treatment details

- Source of Nano Zn; - Nano Zn is available in 50,000ppm.
- Source of Nano Cu; - Nano Cu is available in 50,000ppm.

Nano-Zn	nano-Zn_1= 40 ppm
	nano-Zn_2= 60 ppm
Nano-Cu	nano-Cu_1= 20 ppm
	nano-Cu_2= 30 ppm

- $ZnSO_4$ PAU recommendation = 1% solution of zinc sulphate (1 kg of zinc sulphate + 1/2 kg of unslaked lime in 100 liters of water). Given two sprays at fortnightly intervals between June and July.

3.2.1 Treatment application

The various nano-micronutrient solutions were applied during morning hours to the selected guava plants as per the treatment details. For the winter season crop, the First application of nano zinc and nano copper solution was done in the second fortnight of June and the second application was done in the second fortnight of July. A total of approximately 4-5 liters of spray solution per plant as per the treatment combination were sprayed on guava plants.

3.3 Duration of the study

The study was conducted for the winter season crop of guava. The reproductive cycle for the winter season crop was started in June before the emergence of flowers.

Total replication = 3

Total treatments= 10
Total plants/replication = 2
Total of plants = 60

Table no. 3.2 Treatments

Treatments	Combinations
T_1	Control (Recommended NPK application, PAU)
T_2	nano-Zn_1
T_3	nano-Zn_2
T_4	nano-Cu_1
T_5	nano-Cu_2
T_6	nano-Zn_1+ nano-Cu_1
T_7	nano-Zn_1+ nano-Cu_2
T_8	nano-Zn_2+ nano-Cu_1
T_9	nano-Zn_2+ nano-Cu_2
T_{10}	$ZnSO_4$ (PAU recommendation)

3.3 Field Layout

Fig no. 3.1: Layout of experimental site

3.1 Growth parameters

The growth traits are usually multigenic traits that show a continuous variation and are greatly influenced by environmental factors. To record the observations, healthy shoots from all directions on a healthy selected plant were tagged to record the data. The common Growth traits recorded were:

3.1.1 Plant height (meters): A measuring pole was used to determine the tree's height from the ground to the top of the crown. Measurements were conducted both before the application of nano-fertilizer in June (initial reading) and again in December after harvest (final reading). The difference between these readings represents the increase in plant height (in meters).

3.1.2 Plant spread (E-W) (N-S) (meters): Plant Spread was determined in East-West (E-W) as well as in North-South (N-S) direction. The measurement was taken before the application of nano-fertilizer in June (i.e., initial reading) and the final reading in the month of December (i.e., final reading), the difference is represented as an increase in plant spread (in meters) in both directions.

3.1.3 No. of leaves/shoot: number of leaf (EW/NS) of the plants were counted before the spray of nano-micronutrients in June (i.e., initial reading) and final reading in the month of December (final reading) and the difference is represented as the increase in the number of leaves/shoots.

3.1.4 Chlorophyll content index (LCI): Plants get their distinctive green hue from a pigment called chlorophyll. In leaf tissue, chlorophyll a is typically three times more abundant than chlorophyll b. Using a SPAD meter, the chlorophyll index was measured in August and compared to the control.

3.1.5 Leaf area: leaves were collected from the selected plants in August month and measurements were taken by using a digital leaf area meter. Readings were presented in centimeter square (cm^2) and compared the treatments with the control.

3.2 Flowering parameters

Flowering parameters refer to the various factors and characteristics associated with the process of flowering in plants. Several factors influence and characterize the flowering process like temperature, light quality, genetic factors, plant age, hormones, environmental stress, pollination, and nutrient availability. In this experiment, we have made changes in nutrient availability to find out the effect of nano-zinc and nano-copper. The following traits were considered under flowering parameters.

3.2.1 No. of flowers per shoot: For counting the No. of flowers per shoot we have randomly selected shoots in each of the four directions (eastern, western, northern, southern) on the selected plants. In the guava tree flower flush continues for about 75 to 90 days so for the flower count, we started counting in June month and was marked with the thread. The new flowers are counted on selected shoots at an interval of fifteen days and marked by the thread so they can be identified as counted flowers. The results were expressed as the average No. of flowers per shoot by mean data.

3.2.2 Fruit set (%): In guava, For estimation of fruit set percent, we have counted the total number of fruits set from flowers and marked them by thread so they can identified as counted and again counted on a fifteen-day interval. The fruit set percent is estimated by using the formula,

$$\textbf{Fruit set } (\%) = \frac{\textbf{Total number of fruit set}}{\textbf{Total number of flowers}} \times \mathbf{100}$$

3.2.3 Fruit retention (%): Fruit retention is the number of fruit harvested. And fruit retention percent is calculated by the following formula,

$$\textbf{Fruit retention } (\%) = \frac{\textbf{Total number of fruit harvested}}{\textbf{Total number of fruit set}} \times \mathbf{100}$$

3.2.4 Fruit drop (%): Fruit drop, defined as the premature shedding of fruits before harvest, is determined by subtracting the total number of harvested fruits from the total number of fruits initially set. The fruit drop percentage is then calculated using the following formula:

$$\textbf{Fruit drop } (\%) = \frac{\textbf{Total number of fruit set} - \textbf{Total number of fruit harvested}}{\textbf{Total number of fruit set}} \times \mathbf{100}$$

3.3 Yield and quality parameters

3.3.1 No. of fruits/shoot: The fruits counted on healthy selected shoot in each direction (east, west, north, south). The mean of every replication is represented as average no. of fruits per shoot.

3.3.2 Average fruit weight (g): Average fruit weight was determined by selecting ten fruits randomly from each plant and measuring their individual weights using an electronic balance. The average fruit weight for each treatment was then calculated and reported in grams (g).

3.3.3 Fruit volume (cm^3): Ten fruits chosen at random were utilized to measure fruit volume. Fruit volume was determined using the water displacement method, and the average fruit volume was expressed in cubic centimeters (cm^3).

3.3.4 Fruit yield per plant (Kg/plant): Due to their varying maturity interval, guava fruits were harvested twice or three times. The average yield per plant, reported in grams, was derived by adding the weight of fruit from each treated plant for all harvests and calculating the mean.

3.3.5 Estimated yield (kg/ha): The average yield per plant was multiplied by the total number of plants per hectare, and the result is presented as quintals per hectare (kg/ha).

3.4 Leaf nutrients analysis

For analysis of guava plant leaves, a sample of fifty leaves from 5-7month old mid shoot leaves from non-fruiting terminals in the month of August-October was selected. From each plant collection 4-8 leaves per tree from each direction (North, East, South and West) at working height of 1-2 m by taking one leaf per shoot. Sample along diagonals (X pattern) from about 10-20 percent trees from selected blocks in the orchard was selected (Package of practices for cultivation of fruits, PAU, Ludhiana July, 2021). The gathered leaves underwent a meticulous cleaning process with running tap water, followed by a rinse with 0.1 percent HCl and two subsequent rinses with distilled water. Subsequently, the leaf samples were dried in an oven for 48 hours. The washing, cleaning, grinding, & storage of the leaf samples were conducted in accordance with the procedures outlined by Chapman (1964). Samples were estimated for macro and micronutrients.

3.5 Shelf-life studies

Shelf-life studies were conducted on freshly harvested fruits at 4-day intervals for observation. The fruits harvested based on treatments were brought to the laboratory, thoroughly washed with distilled water, and then stored under ambient conditions. Regular investigations of the fruits were needed to determine the optimal treatment combination for enhancing the fruits' shelf life. Evaluation of the fruit samples was performed using the aforementioned physical and chemical analysis parameters.

3.5.1 Total soluble solids (˚B): The index of refraction was used to calculate the total soluble solids (TSS) content of the solution. A digital refractometer was used to measure the TSS of ripe fruit juice by applying a few drops of juice on the sensor. Prior to the usage, refractometer was calibrated using purified water. According to A.O.A.C. (1995), the total soluble solids are represented in ^{0}B unit.

3.5.2 Titratable acidity (%): Fruit juice's titratable acidity, which was measured by titrating the juice against a standard NaOH solution, indicates the amount of acids present. Juice neutralization starts when NaOH solution was introduced, and the amount of NaOH solution known to be needed to completely neutralize organic acids reflects the juice's acidity. Ten grams of the fruit sample were crushed and were made upto 100ml by filling it with distilled water. Following filtering, 10 milliliters of the filtrate were moved to an independent conical flask where they were titrated using phenolphthalein as an indicator against 0.1N (4g/1000g) sodium hydroxide. A light pink hue appeared, which served as the endpoint. The measurements were recorded, and the acidity was computed.

3.5.3 Antioxidants (DPPH): The DPPH assay was carried out according to Bozin *et al.* (2006) instructions. Samples in the range of 0.2 to 500 $\mu g \cdot mL^{-1}$ were combined with 1 mL of a 90 µM DPPH solution and then filled to a final volume of 4 mL with 95% methanol. After one hour at room temperature, the absorbance of the resultant solutions and the blank were measured. As a positive control, butylated hydroxytoluene (BHT) was employed. For every sample, three replicates' worth of data were gathered. Using a spectrophotometer, the disappearance of DPPH was investigated spectrophotometrically at 515 nm. The following formula was used to get the percent (%) of inhibition of free radical (DPPH):

$$\mathbf{I\%} = 100 - \frac{A(blank) - A(sample)}{A(sample)}$$

Where; A(blank) is the absorbance of the control reaction mixture excluding the test compounds, and A(sample) is the absorbance of the test compounds.

3.5.4 Ascorbic acid (mg/100g): Ascorbic acid is an effective reducing agent that oxidizes itself after reducing 2, 6-dichlorphenol-indophenol (DCPIP) color. Therefore, the amount of standard dye solution decreased during titration is directly proportional to the ascorbic acid level in the absence of any reducing or oxidizing chemical as contaminant. Fruit's vitamin-C content was calculated using the AOAC recommendations (Horwitz and Latimer, 2000).

3.5.5 Total soluble solids: acid ratio (TSS: Acid ratio): Fruit's TSS/acidity ratio is simply a measurement of the sugar concentration compared to acidity, which gives fruits their distinct flavor and taste. The ^{0}B of the fruit is typically used to determine the TSS, or sugar concentration. By dividing the TSS by titratable acidity, the solution was found.

3.5.6 Total sugars (%): 4 ml of anthrone reagent was added to 1 ml of juice. The sample water bath at 100^{0}C for 8 minutes and check the O.D. at 630nm. And calculation for total sugars did by using the formula;

$$\textbf{Total sugars}\ (\%) = \frac{weight\ of\ glucose}{Volume\ of\ test\ sample} \times 100$$

3.5.7 Reducing sugars (%): It was calculated by using Nelson – Somogyi method. Take 1ml of guava juice and volume was made upto 3ml by adding distilled water into it 3ml of the DNS reagent was added and kept in the water bath at 100^{0}C for five minutes. Afterwards 1 ml of 40% Rochelle salt was added. Then it was allowed to cool down and take O.D. at 510nm. And calculation for reducing sugars did by using the formula,

3.5.8 Non-reducing sugars (%): The calculation involved subtracting reducing sugars from total sugars (Shaheen *et al.,* 2015).

$$\boldsymbol{Non-reducing\ sugars}\ (\%) = \boldsymbol{Total\ sugars - reducing\ sugars}$$

3.5.9 Firmness (kg/in^2): Penetrometer was used for measuring the firmness of selected fruits.

3.5.10 Pectin content (%): The pectin content of guava fruit was assessed using a modified procedure adapted from Ranganna (1997). Pectin was precipitated as calcium pectate from an acidified solution. A blended sample weighing fifty grams was placed into a 1000 ml beaker and combined with 400 ml of 0.05 N HCl, then boiled for approximately 2 hours until complete evaporation occurred. Subsequently, the sample was cooled, and the volume was adjusted to 500 ml with distilled water. 100 ml aliquots were transferred into a conical flask, mixed with 250 ml of distilled water, and neutralized with 1 N NaOH using an indicator, then left overnight. Following this, 50 ml of 1 N acetic acid, followed by 25 ml of 1 N calcium chloride, were added to the solution and allowed to stand at room temperature for 1 hour, then boiled for 1-2 minutes, filtered through a pre-weighed filter, and the precipitate was subsequently dried in an oven and reweighed. The pectin content was quantified as calcium pectate and expressed as a percentage.

3.5.11 Spoilage (%): To assess fruit spoilage, ten freshly harvested fruits from each replication were tested in the laboratory, thoroughly washed with distilled water, and subsequently stored under ambient storage conditions. Spoilage was judged by visual observation and spoiled fruits were discarded at an interval of 4 days. Calculation done by the formula,

$$\boldsymbol{Spoilage}\ (\%)\frac{\boldsymbol{Spoiled\ fruits}}{\boldsymbol{Total\ fruits\ stored}}\times \mathbf{100}$$

3.6 Economic of treatments (Based on current prevailing market price)

It was calculated by following parameters:

3.6.1 **Cost of cultivation:** Cost of cultivation includes, the cost of N, P, K, nano-Zn, Cu, FYM, Labor, Irrigation, Orchard management, Leased land rent, Interest of leased land, etc.

3.6.2 **Gross Income:** To calculate, multiply the crop yield (measured in kg/ha) by the selling price (in Rs./kg).

3.6.3 **Net Return:** This calculation is done by the subtracting the cost of cultivation from Gross income.

3.6.4 **B:C Ratio:** This parameter calculated by dividing the cost of cultivation to net income

RESULT AND DISCUSSION

4.1 Growth parameter

4.1.1 Increase in plant height (m)

Table 4.1 presents data illustrating the changes in plant height observed throughout the two-years experimental period (2022 and 2023), along with the aggregated data. A thorough examination of the data reveals a notable impact of various nano micronutrient treatments on the plant height of Guava (cv. Allahabad Safeda) across the trials. The data shown in table no. 4.1 and figure no. 4.1 as the increase in the height of the plant.

In 2022, notable observations were recorded regarding the maximum enhancement in plant height. Treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] demonstrated the highest increase of 0.41 meters, substantially surpassing both T_1 (Control) and all other treatments administered to the experimental plants. Generally, all treatments recorded in a substantial elevation increased plant height compared to T_1 (Control), where a height increase of 0.20 meters was noted.

In 2023, a consistent pattern of plant height augmentation was observed across all treatments. The most substantial rise in plant height (0.65 meters) was documented in treatment T_8 [nano-Zn2(60ppm) + Cu1(20ppm)], markedly surpassing both treatment T_1 (Control) and all other experimental treatments. Conversely, the least increase in plant height (0.42 meters) was noted in treatment T_1 (Control).

Examination of the combined data reveals a consistent pattern of plant height augmentation, mirroring the trends observed over the two years of the study. Treatment T_8 [nano-Zn2(60ppm) + Cu1(20ppm)] emerged as the most effective among all treatments, registering a substantial increase in plant height of 0.53 meters, substantially surpassing all other treatments. Conversely, treatment T_1 (Control) yielded the lowest increase in plant height at 0.31 meters.

The rise in tree height observed may be attributed to the involvement of zinc in tryptophan synthesis, which acts as a precursor for the production of IAA, a hormone known to stimulate tissue growth and development, as documented by Swietlik (2010). Moreover, an optimal zinc level in plants facilitates essential processes including photosynthesis, nucleic acid metabolism, and protein synthesis. These consequences are consistent with the outcomes of Dawood *et al.* (2001), who conducted similar research on Washington Navel oranges involving zinc application.

It is well recognized that zinc can change the production of natural auxin (IAA) and activate a number of enzymes involved in metabolic activities, such as glucose metabolism and protein synthesis. Plant height, leaf count, and fresh and dry weight were among the growth traits of pomegranate plants that were substantially impacted by the foliar nutrition of nano-Zn (Morab *et al*., 2021).

4.1.2 Plant spread (E-W) (N-S)

Table no. 4.1 presents the data related to the increase in Plant spread over the course of the two-year experiment (2022 and 2023). Various concentrations of nano-micronutrient had a substantial impact on enhancement of plant size throughout the duration of the experiment. In table no. 4.1 and figures no. 4.2 as well as 4.3, the data shows plant spread in (EW/NS).

In 2022, an increase in plant spread (E-W) was observed during the study. Treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] and T_7 [nano-Zn_1(40ppm) + Cu_2(30ppm)] showed the highest increase of 0.75 and 0.69 meters, respectively, this was substantially maximum than the treatment T_1 with lowest increases of 0.59 meters. In rest of the treatments found a substantial increase in plant spread (E-W).

In 2023, the study revealed findings about the increase in Plant spread (E-W). Treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] showed a maximum increase of 1.04 meters. This was comparable to the T_8, T_6, T_3, and T_2 treatments, which ranged from 1.00 to 0.95 meters. Conversely, the least amount of plant spread (E-W) (0.83 meters) was increased by treatment T_1 (Control).

The combined data from the two years (2022 and 2023) of experimentation showed that treatment T_6 [nano-Zn_1(40ppm) + Cu_1(20ppm)] had the maximum percent increase in Plant spread (E-W) (0.88 meters) followed by treatments T_8 and T_9 that is 0.86 and 0.84 meters respectively and was at nominal. However, treatment T_1 resulted the lowest enhancement in Plant Spread at 0.71 meters, which was found to be at nominal with T_4.

In 2022, plant spread (N-S) shows increase curve during the study. Treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] showed substantially the highest plant spread of 0.70 meters. Instead, treatment T_1 (Control) showed the lowest increase in the plant spread (N-S) at 0.58 meters and was at nominal alongside T_2, T_4, as well as T_5.

In 2023, the study revealed findings about the increase in Plant spread (N-S). Treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] showed a maximum increase of 0.73 meters. This was at nominal with treatments T_9, and T_{10}, that is 0.70 and 0.69 meters respectively. Instead, treatment T_1 (Control) resulted in the least increase in Plant spread (N-S) (0.68 meters) and this at nominal with T_2, T_4, and T_5 ranging 0.62 to 0.63 meters.

The combined data from the two years (2022 and 2023) of experimentation showed that treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] had the maximum percent increase in Plant spread (N-S) (0.71 meters) which is substantially the highest with all the treatments. However, treatment T_1 resulted the lowest increase in Plant Spread (N-S) at 0.59 meters, which was found to be at nominal with T_2, T_4, and T_5 ranging from 0.61 to 0.62 meters.

The increase in both plant height and canopy spread observed with the application of nano-Zn and Cu can be attributed to the higher concentration of auxin, which leads to enhanced apical growth. This connection is described by the requirement of zinc for tryptophan synthesis, which serves as a precursor for auxin, as highlighted by Kumar *et al*. (2015). Furthermore, Bowler *et al*. (1994) indicate that zinc plays a vital role in the functioning, structure, and regulation of numerous enzymes. Moreover, Singh *et al*. (1989) findings collectively support the understanding that the positive effects of zinc on plant growth are attributed to its involvement in auxin concentration, enzymatic processes, and cellular development. The observed increase in vegetative growth parameters in the current study, resulting from the zinc and copper foliar spray, that is consistent with the findings of previous research. Similarly, In citrus Khan *et al*. (2012) reported same outcomes, Meena *et al*. (2021) observed comparable results in aonla, and Dhurve *et al*. (2018) noted similar effects in pomegranate. These studies collectively support the notion that the application of nano-zinc and copper can positively influence vegetative growth parameters in various plant species.

The enhancement in the vegetative growth of trees through the spray of macro and micronutrients may be attributed to the increase in their endogenous levels. These nutrients play a crucial role in the activities of photosynthetic enzymes, leading to an overall improvement in tree growth (Alloway, 2008). Previous observations have indicated that reduced levels of photosynthesis resulted in lower food reserves and subsequently hindered the growth of guava trees (Alloway, 2008; Ashraf *et al*., 2010). Similarly, research studies have reported that macro nutrients and application of secondary nutrients can effectively promote the growth of mandarin and sweet orange fruits (Khan *et al*., 2015). These findings underscore the significance of nutrient availability and their role in supporting photosynthetic processes and overall tree growth.

Table no. 4.1: Effect of nano-Zn and nano-Cu on increase in plant height, increase in plant spread (E-W) (N-S) of guava.

	Increase in plant height (meter)			Increase in plant spread (meter)					
				E-W			N-S		
Treatments	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	0.20 ± 0.01^{a}	0.42 ± 0.01^{a}	0.31 ± 0.008^{a}	$0.59\pm.006^{a}$	0.83 ± 0.01^{a}	0.71 ± 0.012^{a}	$0.58\pm.007^{a}$	0.60 ± 0.006^{a}	0.59 ± 0.006^{a}
T_2	0.30 ± 0.006^{bc}	0.48 ± 0.006^{b}	0.39 ± 0.005^{b}	$0.69\pm.006^{c}$	0.95 ± 0.02^{cd}	0.82 ± 0.011^{def}	$0.59\pm.01^{a}$	0.62 ± 0.01^{ab}	0.61 ± 0.008^{ab}
T_3	0.33 ± 0.004^{cd}	0.51 ± 0.008^{c}	0.42 ± 0.005^{bc}	$0.62\pm.01^{b}$	0.99 ± 0.03^{cd}	0.80 ± 0.026^{cde}	$0.64\pm.01^{cd}$	0.68 ± 0.01^{de}	0.66 ± 0.010^{cde}
T_4	0.31 ± 0.008^{bcd}	0.48 ± 0.01^{b}	0.39 ± 0.006^{b}	$0.63\pm.01^{b}$	0.82 ± 0.02^{a}	0.72 ± 0.003^{ab}	$0.61\pm.01^{abc}$	0.63 ± 0.01^{abc}	0.6 ± 0.017^{abc}
T_5	0.32 ± 0.01^{cd}	0.53 ± 0.008^{c}	0.42 ± 0.006^{c}	$0.67\pm.003^{c}$	0.86 ± 0.02^{ab}	0.77 ± 0.014^{bc}	$0.60\pm.01^{ab}$	0.62 ± 0.01^{ab}	0.6 ± 0.010^{ab}
T_6	$0.28. \pm.01^{b}$	0.52 ± 0.01^{c}	0.40 ± 0.01^{b}	$0.76\pm.008^{d}$	1.00 ± 0.003^{cd}	0.88 ± 0.005^{g}	$0.63\pm.01^{bcd}$	0.65 ± 0.014^{bcd}	0.64 ± 0.012^{bcd}
T_7	$0.35\pm.01^{d}$	0.52 ± 0.006^{c}	0.43 ± 0.012^{cd}	$0.69\pm.008^{cd}$	0.90 ± 0.02^{abc}	0.80 ± 0.013^{cde}	$0.65\pm.004^{cd}$	$0.67\pm0.0.003^{cde}$	0.66 ± 0.003^{cde}
T_8	$0.41\pm.01^{e}$	0.65 ± 0.005^{e}	0.53 ± 0.010^{e}	$0.75\pm.008^{d}$	0.98 ± 0.04^{cd}	0.86 ± 0.021^{fg}	$0.70\pm.01^{e}$	0.73 ± 0.01^{f}	0.71 ± 0.01^{f}
T_9	$0.33\pm.01^{cd}$	0.58 ± 0.008^{d}	0.46 ± 0.008^{d}	$0.63\pm.01^{b}$	1.04 ± 0.03^{d}	0.84 ± 0.020^{efg}	$0.65\pm.01^{cd}$	0.70 ± 0.01^{ef}	0.67 ± 0.01^{de}
T_{10}	$0.34\pm.009^{cd}$	0.54 ± 003^{c}	0.44 ± 0.005^{cd}	$0.63\pm.003^{b}$	0.93 ± 0.03^{bc}	0.78 ± 0.017^{cd}	$0.66\pm.01^{d}$	0.69 ± 0.01^{def}	0.68 ± 0.018^{e}
S. Em (±)	0.009	0.011	0.009	0.01	0.015	0.010	0.007	0.007	0.007

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ Cu_2(30ppm)], T_{10} [$ZnSO_4$]

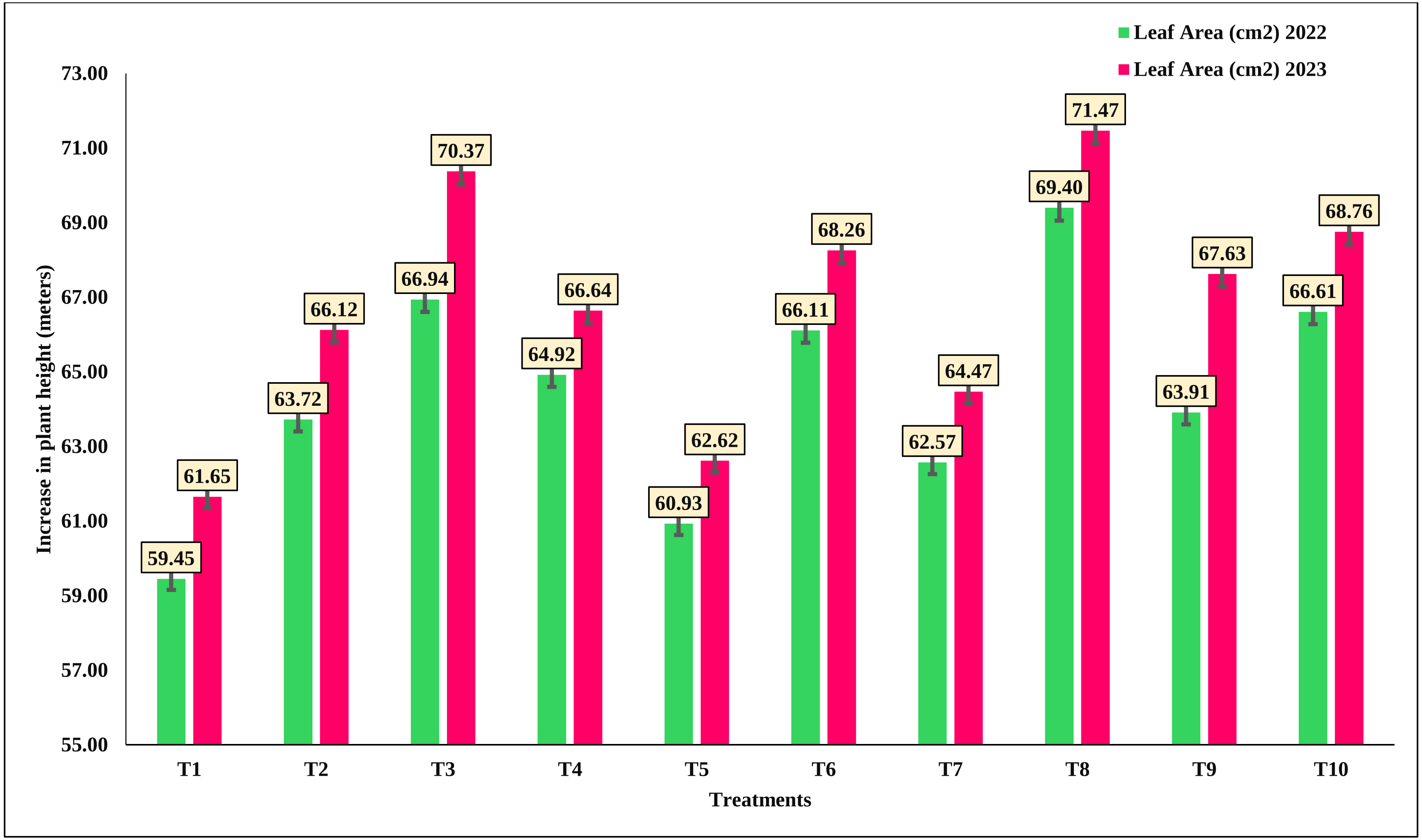

Fig. 4.1: Effect of nano-Zn and nano-Cu on increase in plant height in guava

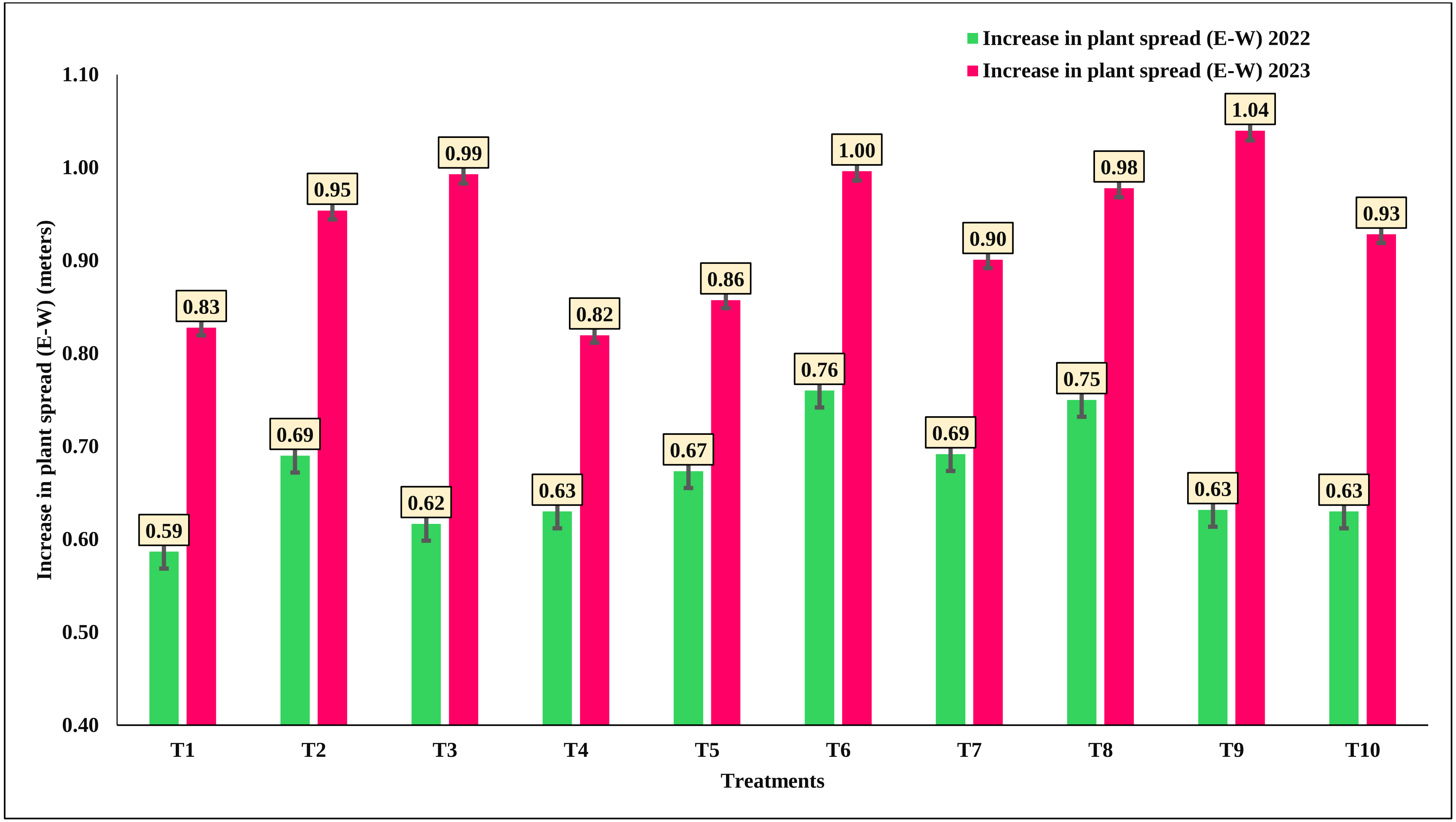

Fig. 4.2: Effect of nano-Zn and nano-Cu on increase in plant spread (E-W) in guava

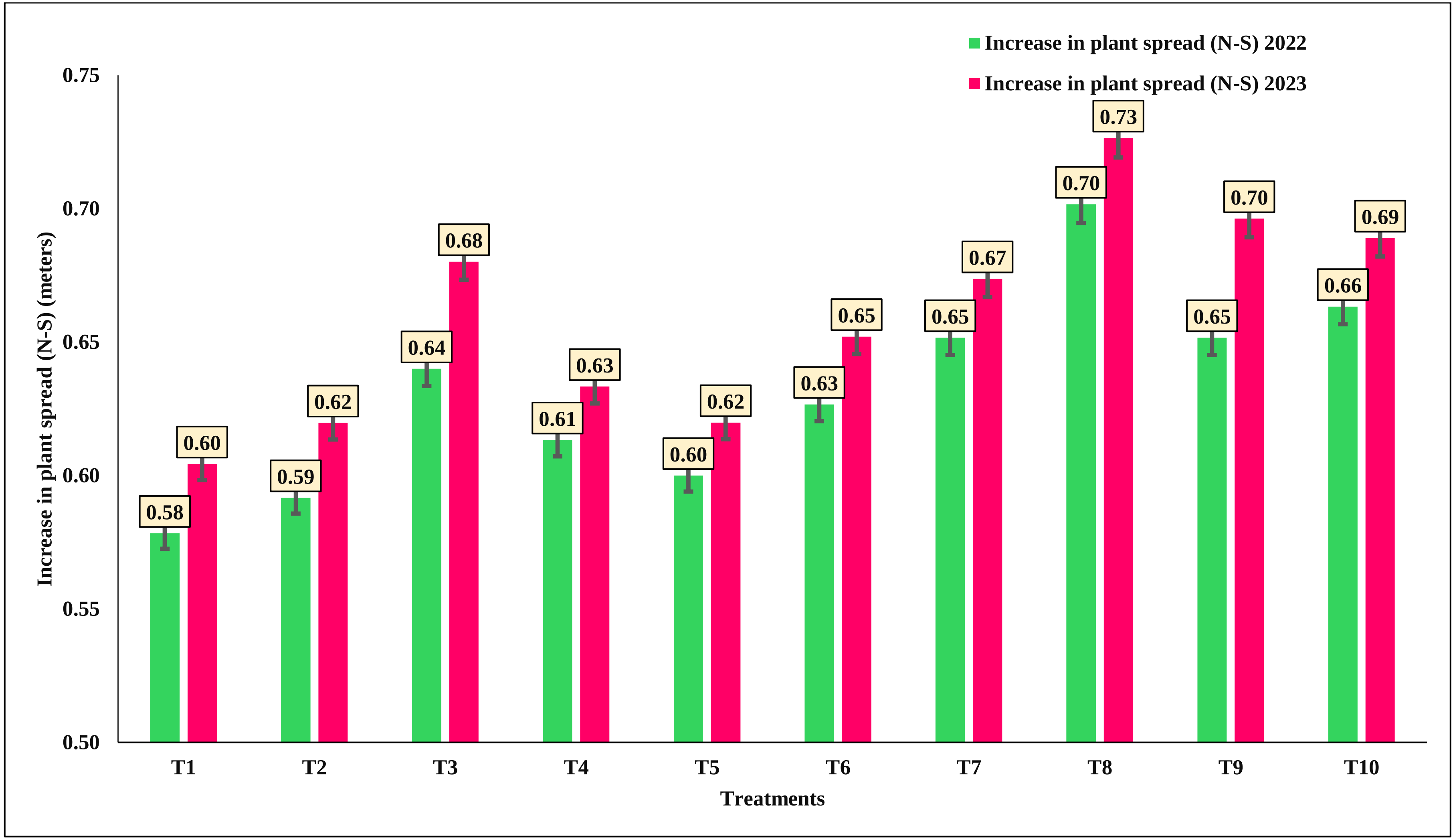

Fig. :4.3 Effect of nano-Zn and nano-Cu on increase in plant spread (N-S) in guava

4.1.3 Increase in no. of leaves per shoot

Table no. 4.2 displays the variation in number of leaves per shoot throughout the two-year experiment (2022 and 2023). A thorough examination of the data reveals a remarkable impact of nano-micronutrient on the no. of leaves/shoot of the Guava plant during both years of the experiment in table 4.2 and figure no. 4.4.

In the experimental year of 2022, treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] resulted in the maximum increase, with 18.13 leaves per shoot, at nominal with treatments T_9, and T_{10} which had an increased leaf number 17.29 and 17.42, respectively. Statistically, there was a substantial difference in the no. of leaves between the treatments. Instead, treatment T_1 (Control) recorded the lowest increase of leaves per shoot, with 10.92.

During the 2023 trial, the treatment T_8, which included the application of nano-Zn_2(60ppm) + Cu_1(20ppm), resulted in the more increase in no. of leaves per shoot, with an increase of 19.16. In contrast, the treatment T_1 (Control) had the lowest increase in the number of leaves per shoot, with an increase of 11.73.

The pooled data from the two years (2022 and 2023) of the experiment showed that treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] recorded the more increase in the no. of leaves per shoot, with 18.64 leaves, at nominal with T_{10}. This was found to be substantially higher than T_1. Whereas treatment T_1 (Control) had found lowest leaves number, 11.33 leaves, this was at nominal with T_2 which is 11.93 leaves.

The spray of nano-Zn and Cu spray on trees resulted in a maximum increase in leaf numbers, indicating an enhancement in vegetative growth. Previous studies have reported that a decrease in carbonic anhydrase activity can lead to a substantial reduction of photosynthesis, resulting in decreased food reserves and negatively impacting plant growth (Alloway, 2008). Moreover, Zn and Cu in previous research promoted the growth of plants, as reported by Dawood *et al*. (2001), Razzaq *et al*. (2013), and Ullah *et al*. (2012).

The foliar nutrition of nano-micronutrient was studied by Morab *et al*. (2021) on the number of leaves of pomegranate plants increase upon application of nano-zinc. This might be the case since zinc is known to activate several enzymes involved in metabolic processes, including protein synthesis and glucose metabolism, as well as to alter the generation of natural auxin (IAA). In the study of Patel *et al.* (2020) they investigated in the guava plants the highest leaves per shoot (26.38) in the treatment applied with Zinc.

4.1.4 Chlorophyll content index

Table no. 4.2 presents the data on the variation in Chlorophyll content index during the two-year experiment (2022 and 2023). A detailed analysis of the data reveals a substantial impact of various nano-micronutrient treatments on the Chlorophyll content index of the Guava during both years of the experiment is expressed in table no. 4.2 and figure no. 4.5.

During the first year of the experiment (2022), treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] was recorded with the highest Chlorophyll content index of 39.60. This was at nominal with T_3, T_6, T_9, and T_{10} ranging from 38.20 to 39.27. Minimum Chlorophyll content index (32.17) was recorded in T_1 (Control).

In 2023, the treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] resulted in the maximum Chlorophyll content index, which was 43.04 which was substantially higher than T_1 (Control) with a value of Chlorophyll content index 33.35.

Aggregate data from both the years (2022 and 2023), shows that the treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] resulted in the maximum Chlorophyll content index, with a value of 41.32 this was at nominal with T_3, and T_9, with the value of 40.24 and 40.06 respectively. Instead, the treatment T_1 (Control) observed with the lowest Chlorophyll content index, measuring 32.76.

High levels of $ZnSO_4$ and $CuSO_4$ combinations positively impacted vegetative parameters in Washington Navel Orange trees, correlating with improved nutritional status. Specifically, the 600 mg/L $ZnSO_4$ + 400 mg/L $CuSO_4$ treatment showed substantial enhancement in leaf chlorophyll and mineral content (El-Gioushy *et al*., 2021). The effect of Zn supply was observed in mung bean plant growth rate, protein, minerals and chlorophyll contents of mung bean leaves. Plant growth, chlorophyll contents, crude proteins and Zn contents were noted to be higher when greater supply of zinc doses was applied (Samreen *et al.,*2017).

4.1.5 Leaf area (cm^2)

Table no. 4.2 and figure no. 4.6 showcases the data encompassing the fluctuations in Leaf area observed during the two-year experiment (2022 and 2023).

In an experiment performed in 2022, the treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] exhibited the maximum Leaf area (69.40 cm^2), treatments T_3, was at nominal which 66.94 cm^2. In contrast, the treatment T_1 (Control) resulted in the minimum leaf area, measuring 59.45 cm^2.

During the experimental year of 2023, the treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] had a maximum Leaf area of 71.46 cm². Treatments T_3 and T_{10} were at nominal, recording a Leaf area of 70.37 cm², and 68.75 cm² respectively. Alternatively, the treatment T_1 (Control) had a minimum Leaf area of 61.65 cm². Two years of data recorded the maximum Leaf area (70.43 cm^2) under the treatment T_8. The lowest Leaf area (60.55 cm^2) was resulted in T_1 (Control).

From the pooled data of the two years (2022 and 2023), the experimental data revealed that the treatments T_8 exhibited the maximum Leaf area, measuring 70.43 cm² each which was substantially higher than T_1. In contrast, the treatment T_1 (Control) displayed a minimum Leaf area of 60.55 cm².

Zinc and copper nanoparticles can act as antioxidants, protecting plant cells from oxidative stress. This protection can lead to healthier and larger leaves by preventing damage from reactive oxygen species. It also works on plant hormone levels, such as auxins and cytokinins, which are involved in cell division and expansion. Modulation of these hormones can contribute to increased leaf area.

Nano-zinc at 0.4 ppm substantially increased grapevine leaf area compared to control. However, a higher concentration of 1.2 ppm led to even greater enhancements in leaf area, highlighting the potential of nano-fertilizers to improve foliar characteristics and overall vine health (Morab *et al*., 2021). Similar results also found in runner bean plants shows positive changes in growth parameters that were correlated with some modifications of the specific leaf area (calculated per fresh weight), leaf density and pigment composition were observed in the plants treated with Cu at an intermediate growth stage (Maksymeic and Baszynski *et al.,* 1996)

Table no. 4.2: Effect of nano-Zn and nano-Cu on increase in number of leaves per shoot, chlorophyll content index and leaf area of guava.

Treatments	Increase in number of leaves per shoot			Chlorophyll content index			Leaf area		
	2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_1	10.92±0.3^{a}	11.73±0.59^{a}	11.33±0.47^{a}	32.17±0.9^{a}	33.35±0.36^{a}	32.76±0.50^{a}	59.45±0.4^{a}	61.65±0.36^{a}	60.55±0.38^{a}
T_2	11.71±0.4^{b}	12.15±0.53^{a}	11.93±0.48^{a}	34.76±0.5^{b}	37.16±0.62^{b}	35.96±0.56^{b}	63.72±1.4^{cd}	66.12±0.62^{cd}	64.92±1.53^{cd}
T_3	16.96±0.3^{ef}	16.95±0.47^{cd}	16.95±0.43^{cd}	39.27±0.7^{d}	41.21±0.18^{de}	40.24±0.39^{de}	66.94±1.5^{ef}	70.37±0.18^{ef}	68.66±1.64^{ed}
T_4	16.25±0.2^{de}	16.87±0.07^{cd}	16.56±0.15^{cd}	35.98±0.3^{b}	37.95±0.17^{b}	36.97±0.26^{bc}	64.92±0.7^{cde}	66.63±0.17^{cd}	65.78±0.66^{cd}
T_5	14.96±0.4^{bc}	15.07±0.52^{b}	15.01±0.50^{b}	36.06±.08^{b}	37.75±0.29^{b}	36.91±0.17^{bc}	60.93±0.1^{ab}	62.61±0.29^{ab}	61.77±0.22^{ab}
T_6	15.75±0.1^{cd}	16.43±0.28^{c}	16.09±0.15^{c}	38.47±.03^{d}	40.62±0.29^{d}	39.54±0.04^{d}	66.11±0.3^{de}	68.25±0.07^{de}	67.18±0.40^{de}
T_7	14.17±0.1^{b}	14.89±0.37^{b}	14.53±0.23^{b}	36.55±0.8^{bc}	39.21±0.27^{c}	37.88±0.54^{c}	62.57±0.5^{bc}	64.46±0.27^{bc}	63.52±0.59^{bc}
T_8	18.13±0.1^{g}	19.16±0.34^{e}	18.64±0.26^{e}	39.60±0.6^{d}	43.04±0.71^{f}	41.32±0.59^{e}	69.40±0.7^{f}	71.46±0.71^{f}	70.43±0.76^{f}
T_9	17.29±0.1^{fg}	17.77±0.40^{d}	17.53±0.28^{d}	38.20±0.2^{cd}	41.92±0.13^{e}	40.06±0.16^{de}	63.91±0.6^{cd}	67.62±0.13^{de}	65.77±0.48^{cd}
T_{10}	17.42±0.1^{fg}	17.90±0.28^{d}	17.66±0.21^{de}	38.99±0.6^{d}	40.56±0.36^{d}	39.77±0.46^{d}	66.61±0.6^{e}	68.75±0.36^{def}	67.68±0.60^{de}
S. Em (±)	0.4	0.44	0.43	0.4	0.50	0.46	0.5	0.50	0.58

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm) + Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm) + Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)], T_{10} [$ZnSO_4$]

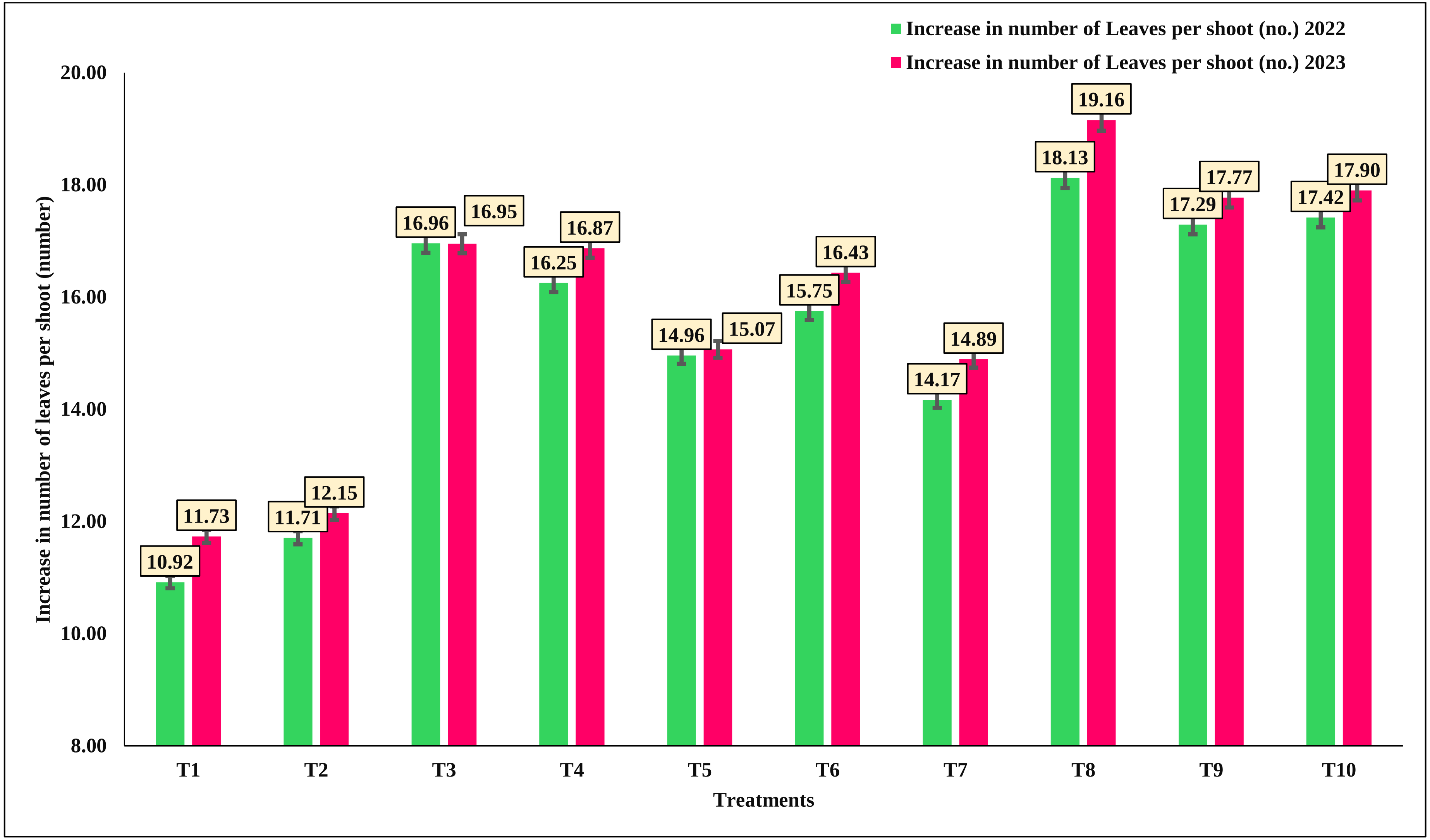

Fig. 4.4: Effect of nano-Zn and nano-Cu on increase in number of leaves per shoot in guava

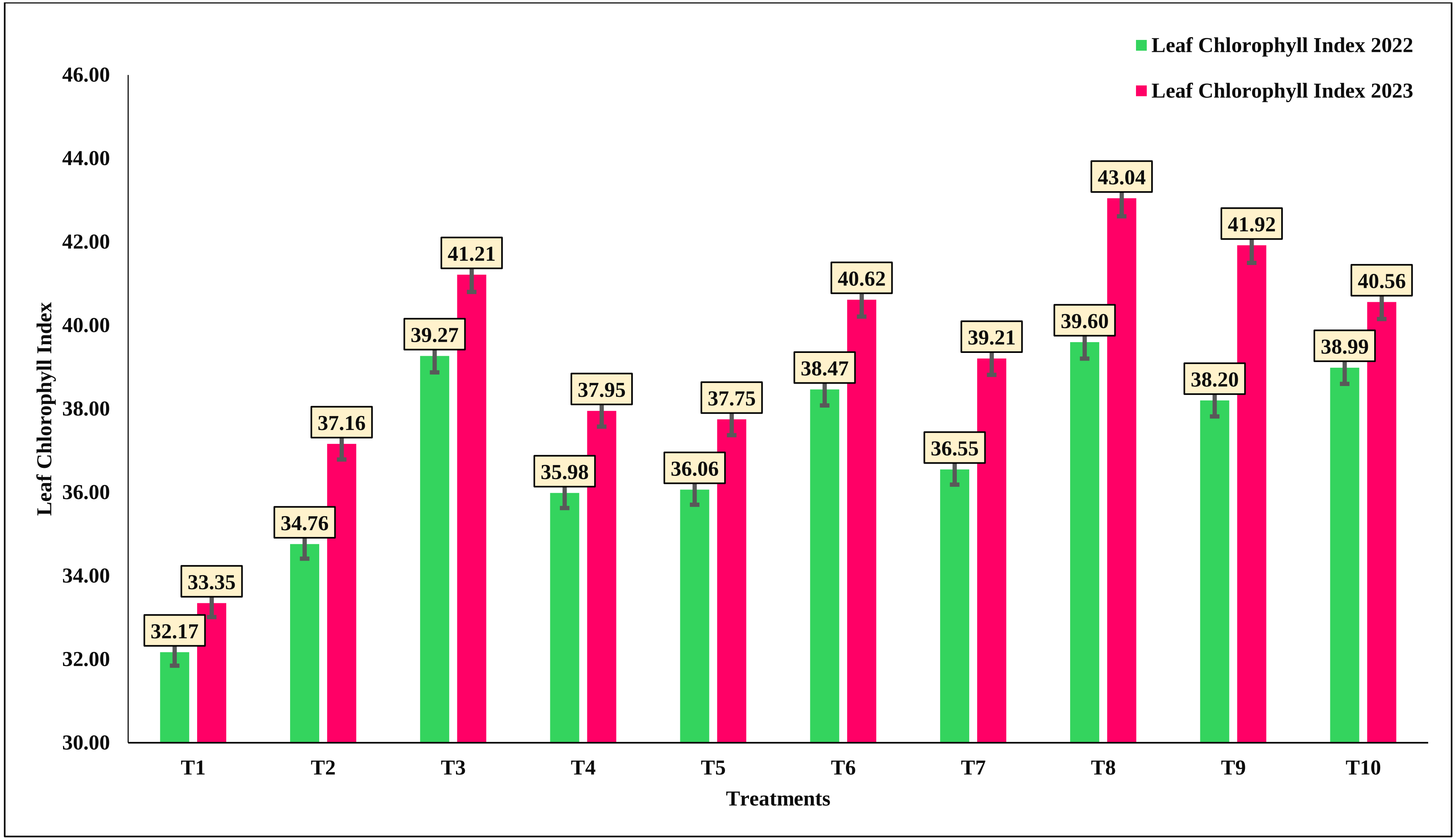

Fig. :4.5 Effect of nano-Zn and nano-Cu on chlorophyll content index in guava

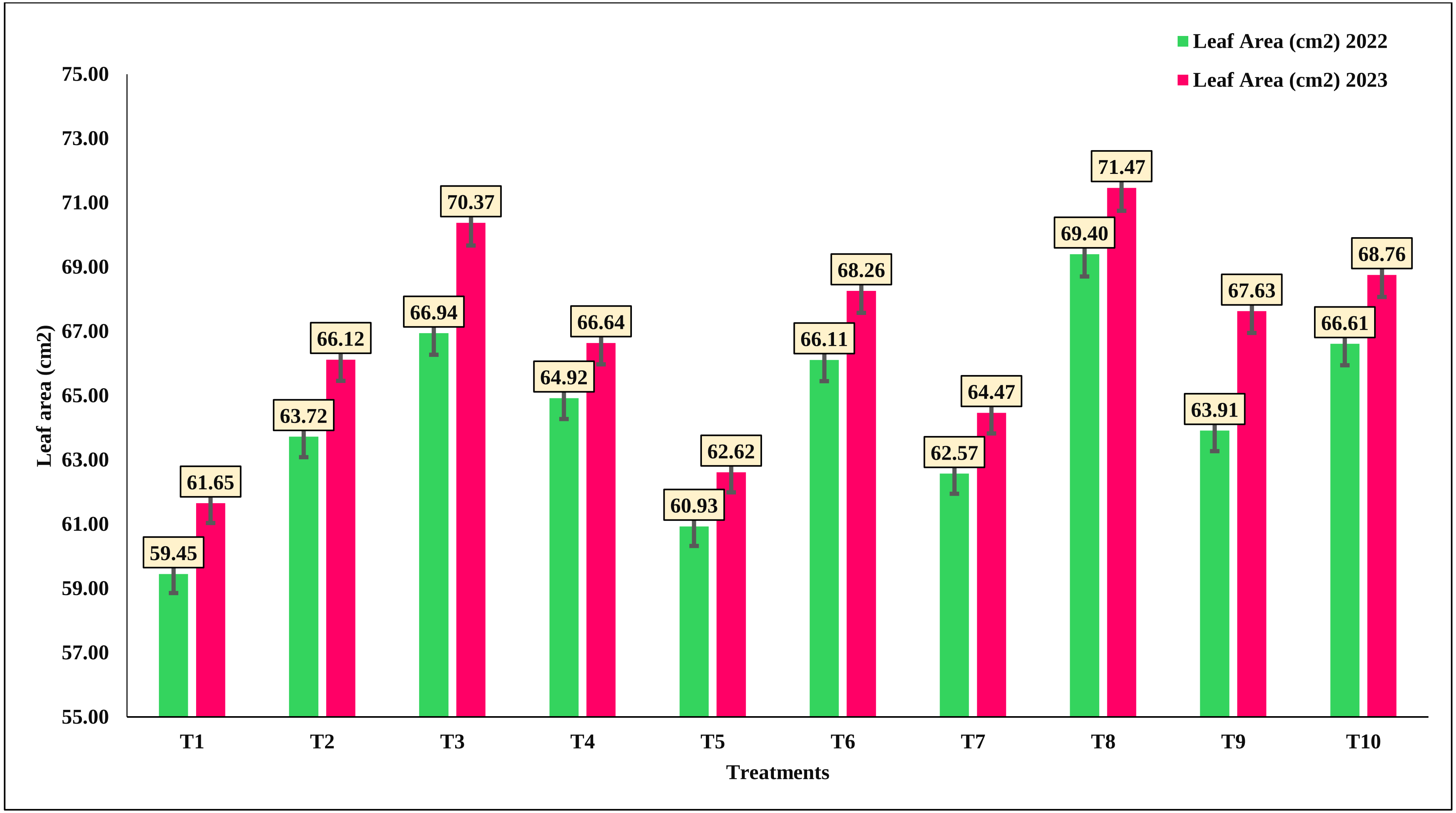

Fig. :4.6 Effect of nano-Zn and nano-Cu on leaf area (cm^2) in guava

4.2 Flowering Parameters

4.2.1 No. of Flowers per shoot

Data represented in Table no. 4.3 as well as 4.4 shows the discrepancy in the no. of Flowers per shoot throughout the two-year experiment (2022 and 2023). A thorough inspection of the data reveals in table 4.3, 4.4 and figure no. 4.7, 4.8, 4.9, 4.10, 4.11, 4.12 and 4.13 a remarkable impact of nano-micronutrient on the No. of Flower/shoot during both years of the experiment.

4.2.2 No. of Flowers per shoot (at 0 Day)

In the experimental year of 2022, any of the treatments was not found to be a substantial difference in the experiment.

During the 2023 trial, the treatment T_5, which included the application of Cu_2 (30ppm), resulted in the maximum no. of flowers/shoot (1.94). Treatments T_3, T_4, T_6, and T_9, this at nominal ranging from 1.69 to 1.83. In contrast, the treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] had the lowest No. of flowers per shoot (1.46), the treatment at nominal with T_1, T_2, T_7, T_9, and T_{10} ranging from 1.46 to 1.69.

The pooled data from the two years (2022 and 2023) of the experiment showed that treatment T_5 [Cu_2(30ppm)] recorded the maximum no. of flower/shoot (1.76), this was at nominal with treatment T_2, T_3, T_4, T_6, T_7, T_9, and T_{10} ranging from 1.51 to 1.63. This was found to be substantially higher than T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)], this was at nominal with T_1, T_2, T_3, T_4, T_6, T_7, T_9, and T_{10}, which ranging from 1.41 to 1.60.

4.2.3 No. of flowers per shoot (at 15th Day)

In 2022, any of treatment was not create to substantial be difference in the number of flowers/shoots at fifteen days.

During the trial of 2023, the treatment T_3, which included the application of nano-Zn_2 (60ppm), resulted in the maximum no. of flower/shoot (3.11). Treatment T_1, T_2, T_5, T_6, T_7, T_9, as well as T_{10}, were at face value from 2.69 to 2.96. In contrast, the treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)]) had the lowest No. of flowers per shoot (2.48), the treatment at nominal with T_1, T_2, T_4, T_5, T_6, T_7, T_9, and T_{10} ranging from 2.59 to 2.96.

The pooled data from both the years (2022 and 2023) of the experiment showed that treatment T_3 [nano-Zn_2(60ppm)] recorded the maximum No. of flowers per shoot (2.91), at nominal with T_1, T_2, T_4, T_5, T_6, T_7, T_9, and T_{10} ranging from 2.57 to 2.79. This was found to be substantially higher than T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)], at nominal with T_1, T_2, T_4, T_5, T_6, T_7, T_9, and T_{10}, which ranging from 2.57 to 2.79.

4.2.4 No. of flowers per shoot (at 30th Day)

In an experiment performed in 2022, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] exhibited the maximum number of flowers with a substantial difference (5.92). In contrast, the treatment T_1 (Control) resulted in the minimum number of flowers (4.80).

During the experimental year of 2023, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had a maximum number of flowers of 6.15. Treatments T_8 and T_{10} were at nominal, recording several flowers of 5.96, and 5.95 respectively. Alternatively, the treatment T_1 (Control) had a least no. of flowers of 5.02. Two years of data recorded the maximum number of flowers (6.03) under the treatment T_9. The minimum number of flowers (4.91) was resulted in T_1.

From the pooled data of the two years (2022 and 2023), the experimental data revealed that the treatment T_9 exhibited the maximum no. of flowers (6.03) each which was substantially higher than T_1. In contrast, the treatment T_1 (Control) displayed a minimum number of flowers, 4.91.

4.2.5 No. of Flowers per shoot (at 45th Day)

In 2022, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was recorded with the highest number of flowers of 13.96. This was at nominal with T_6, T_8, and T_{10} ranging from 13.75 to 13.81. Lowest no. of flowers (12.44) was recorded in T_1 (Control).

In 2023, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gives highest no. of flowers, the value (14.23). At comparable with T_3, T_4, T_6, T_8, and T_{10} ranging from 13.78 to 14.15, which was substantially higher than T_1 (Control) with a value 12.69 number of flowers.

Aggregate data from both the years (2022 and 2023), shows that the treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] resulted in the maximum number of flowers, with a value of 14.10 at nominal with T_6, T_8, and T_{10} ranging from 13.87 to 13.92. However, the treatment T_1 observed with the lowest number of flowers (12.57).

Table no. 4.3: Effect of nano-Zn and nano-Cu on flowers (number) 0 day, 15 days, 30 days, and 45 days of guava.

Flowers (number) per shoot												
Treatments	**No. of days (0)**			**No. of days (15)**			**No. of days (30)**			**No. of days (45)**		
	2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_1	1.28 ± 0.10^{a}	1.54 ± 0.11^{ab}	1.41 ± 0.11^{a}	2.60 ± 0.05^{a}	2.89 ± 0.11^{ab}	2.75 ± 0.08^{ab}	4.80 ± 0.06^{a}	5.02 ± 0.03^{a}	4.91 ± 0.05^{a}	12.44 ± 0.25^{a}	12.69 ± 0.26^{a}	12.57 ± 0.25^{a}
T_2	1.45 ± 0.14^{a}	1.64 ± 0.12^{ab}	1.55 ± 0.13^{ab}	2.44 ± 0.09^{a}	2.71 ± 0.13^{ab}	2.58 ± 0.11^{ab}	5.27 ± 0.02^{b}	5.38 ± 0.07^{b}	5.33 ± 0.04^{b}	13.40 ± 0.03^{bc}	13.73 ± 0.14^{bc}	13.57 ± 0.08^{bc}
T_3	1.37 ± 0.03^{a}	$1.76 \pm o.03^{bc}$	1.57 ± 0.03^{ab}	2.72 ± 0.15^{a}	3.11 ± 0.30^{b}	2.91 ± 0.22^{b}	5.39 ± 0.04^{bc}	5.62 ± 0.11^{b}	5.51 ± 0.08^{c}	13.52 ± 0.11^{cde}	13.80 ± 0.02^{bcd}	13.66 ± 0.05^{bcd}
T_4	1.36 ± 0.70^{a}	1.83±0.04bc	1.60 ± 0.14^{ab}	2.56 ± 0.11^{a}	2.59 ± 0.10^{a}	2.57 ± 0.10^{ab}	5.39 ± 0.05^{bc}	5.55 ± 0.08^{b}	5.47 ± 0.06^{bc}	13.40 ± 0.04^{bc}	13.78 ± 0.17^{bcd}	13.59 ± 0.10^{bc}
T_5	1.58 ± 0.20^{a}	1.94 ± 0.10^{c}	1.76 ± 0.04^{b}	2.61 ± 0.05^{a}	2.70 ± 0.08^{ab}	2.66 ± 0.06^{ab}	5.29 ± 0.14^{b}	5.58 ± 0.16^{b}	5.43 ± 0.08^{bc}	13.20 ± 0.05^{b}	13.58 ± 0.16^{b}	13.39 ± 0.10^{b}
T_6	1.49 ± 0.08^{a}	1.77 ± 0.008^{bc}	1.63 ± 0.10^{ab}	2.45 ± 0.09^{a}	2.69 ± 0.16^{ab}	2.57 ± 0.12^{ab}	5.46 ± 0.03^{c}	5.62 ± 0.03^{b}	5.54 ± 0.01^{c}	13.75 ± 0.03^{def}	14.15 ± 0.10^{cd}	13.95 ± 0.06^{de}
T_7	1.48 ± 0.21^{a}	1.63 ± 0.10^{ab}	1.56 ± 0.12^{ab}	2.55 ± 0.02^{a}	2.96 ± 0.14^{ab}	2.76 ± 0.07^{ab}	5.27 ± 0.04^{b}	5.52 ± 0.03^{b}	5.40 ± 0.002^{bc}	13.49 ± 0.04^{bcd}	13.69 ± 0.07^{bc}	13.59 ± 0.04^{bc}
T_8	1.32 ± 0.12^{a}	1.46 ± 0.13^{a}	1.39 ± 0.04^{a}	2.38 ± 0.15^{a}	2.48 ± 0.16^{a}	2.43 ± 0.16^{a}	5.77 ± 0.03^{d}	5.96 ± 0.06^{c}	5.86 ± 0.05^{d}	13.81 ± 0.03^{ef}	14.02 ± 0.11^{bcd}	13.92 ± 0.07^{cde}
T_9	1.33 ± 0.03^{a}	1.69 ± 0.05^{abc}	1.51 ± 0.04^{ab}	2.60 ± 0.09^{a}	2.78 ± 0.09^{ab}	2.69 ± 0.09^{ab}	5.92 ± 0.17^{e}	6.15 ± 0.06^{c}	6.03 ± 0.04^{e}	13.96 ± 0.02^{f}	14.23 ± 0.14^{d}	14.10 ± 0.06^{e}
T_{10}	1.36 ± 0.05^{a}	1.46 ± 0.06^{a}	1.41 ± 0.04^{a}	2.70 ± 0.05^{a}	2.88 ± 0.02^{ab}	2.79 ± 0.02^{ab}	$5.760.02^{d}$	5.95 ± 0.08^{c}	5.86 ± 0.05^{d}	13.81 ± 0.01^{ef}	13.92 ± 0.06^{bcd}	13.87 ± 0.03^{cde}
S. Em (±)	0.03	0.03	0.03	0.03	0.05	0.04	0.05	0.06	0.05	0.08	0.08	0.08

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm) + Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm) + Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)], T_{10} [$ZnSO_4$]

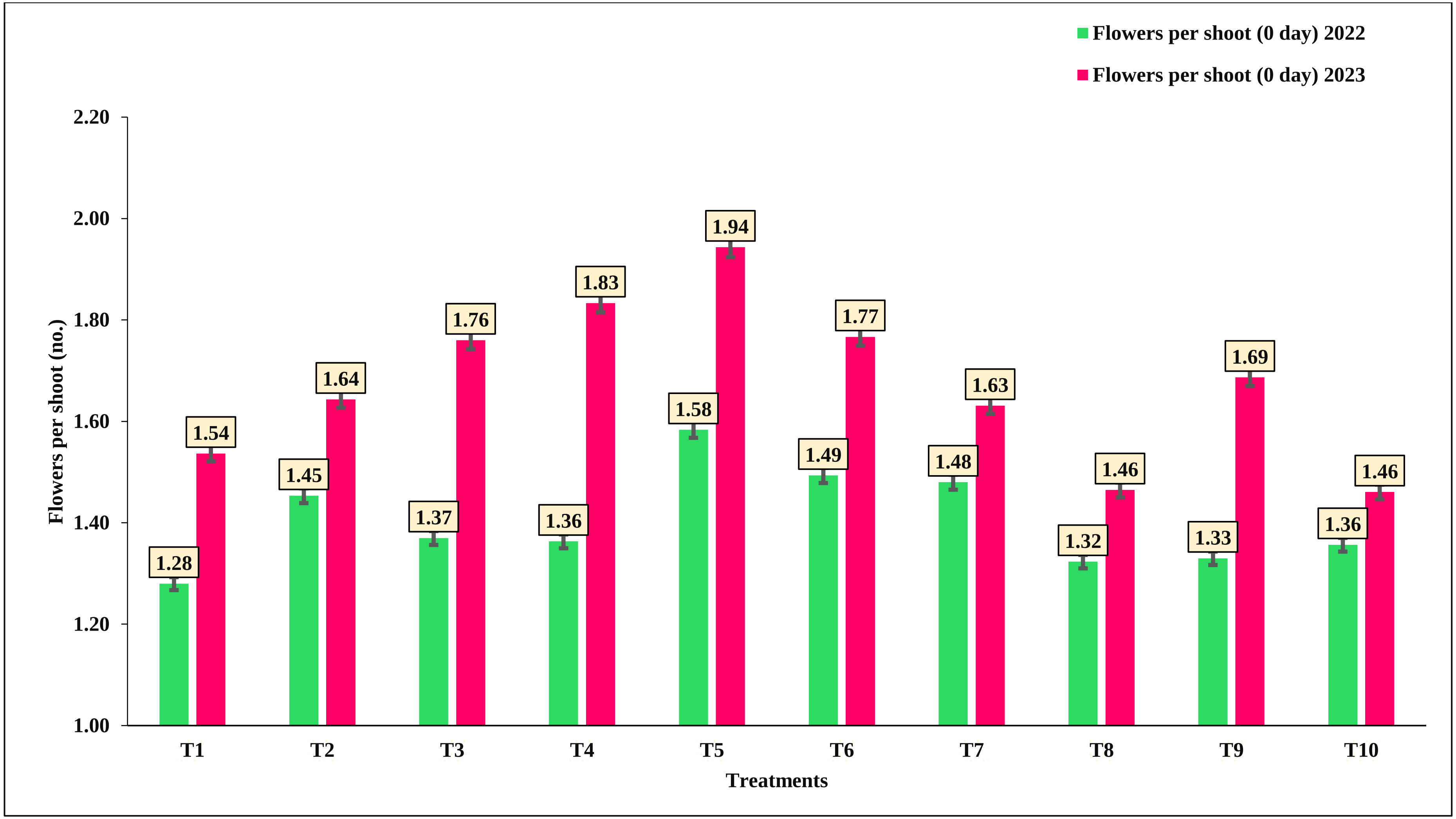

Fig. :4.7 Effect of nano-Zn and nano-Cu on flowers per shoot (0 Day) in guava

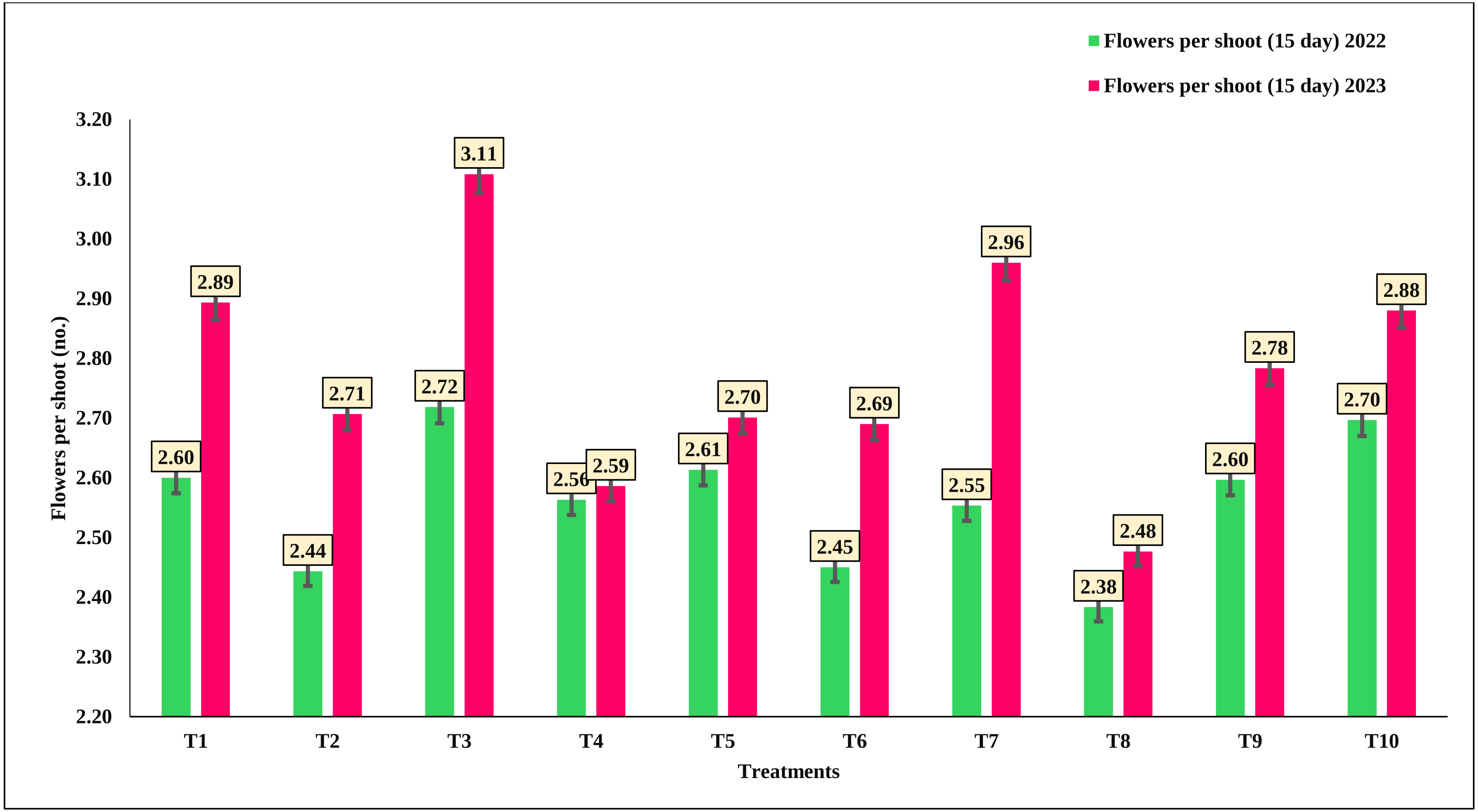

Fig. :4.8 Effect of nano-Zn and nano-Cu on flowers per shoot (at 15 day) in guava

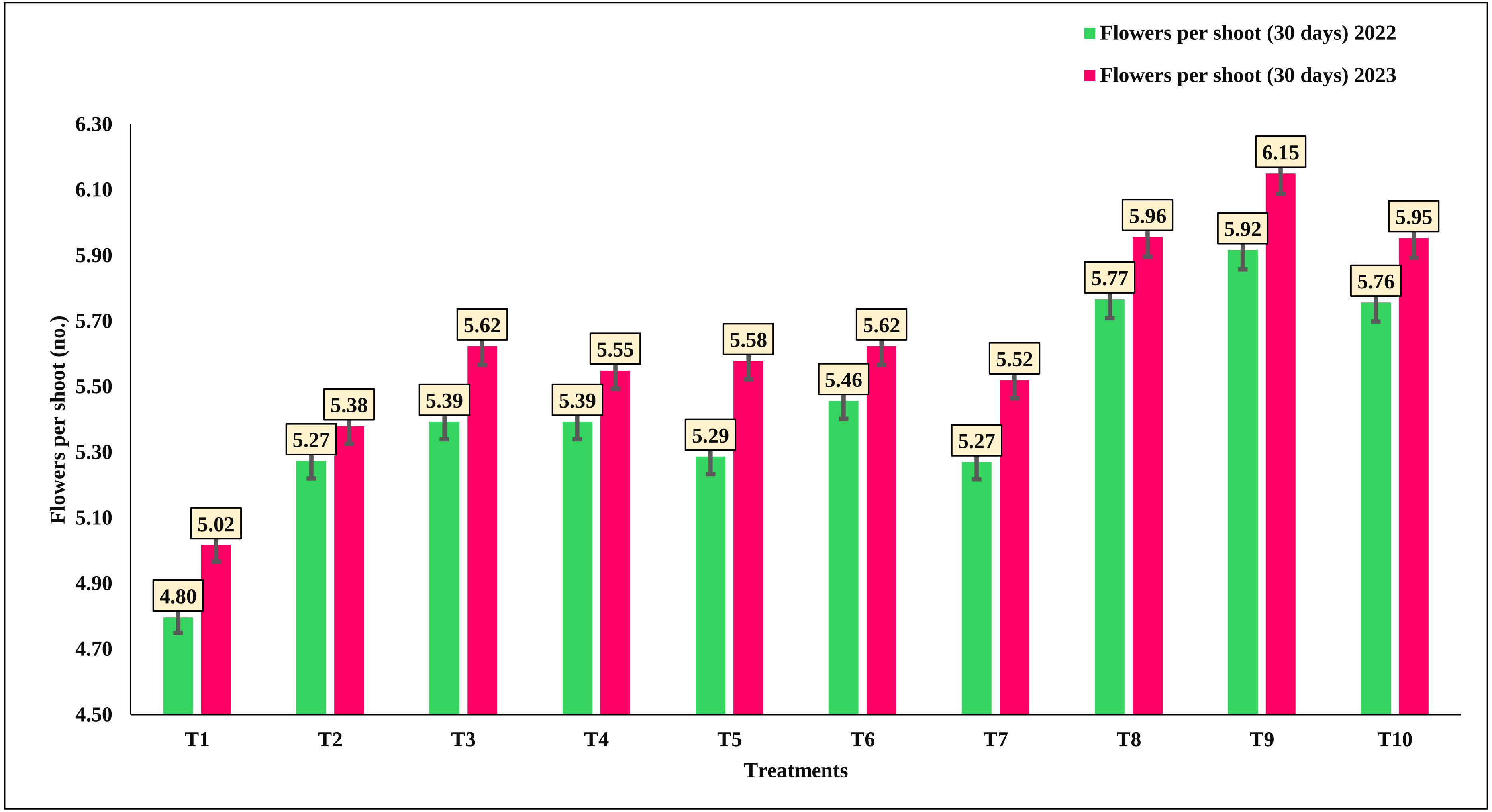

Fig. :4.9 Effect of nano-Zn and nano-Cu on flowers per shoot (30 day) in guava

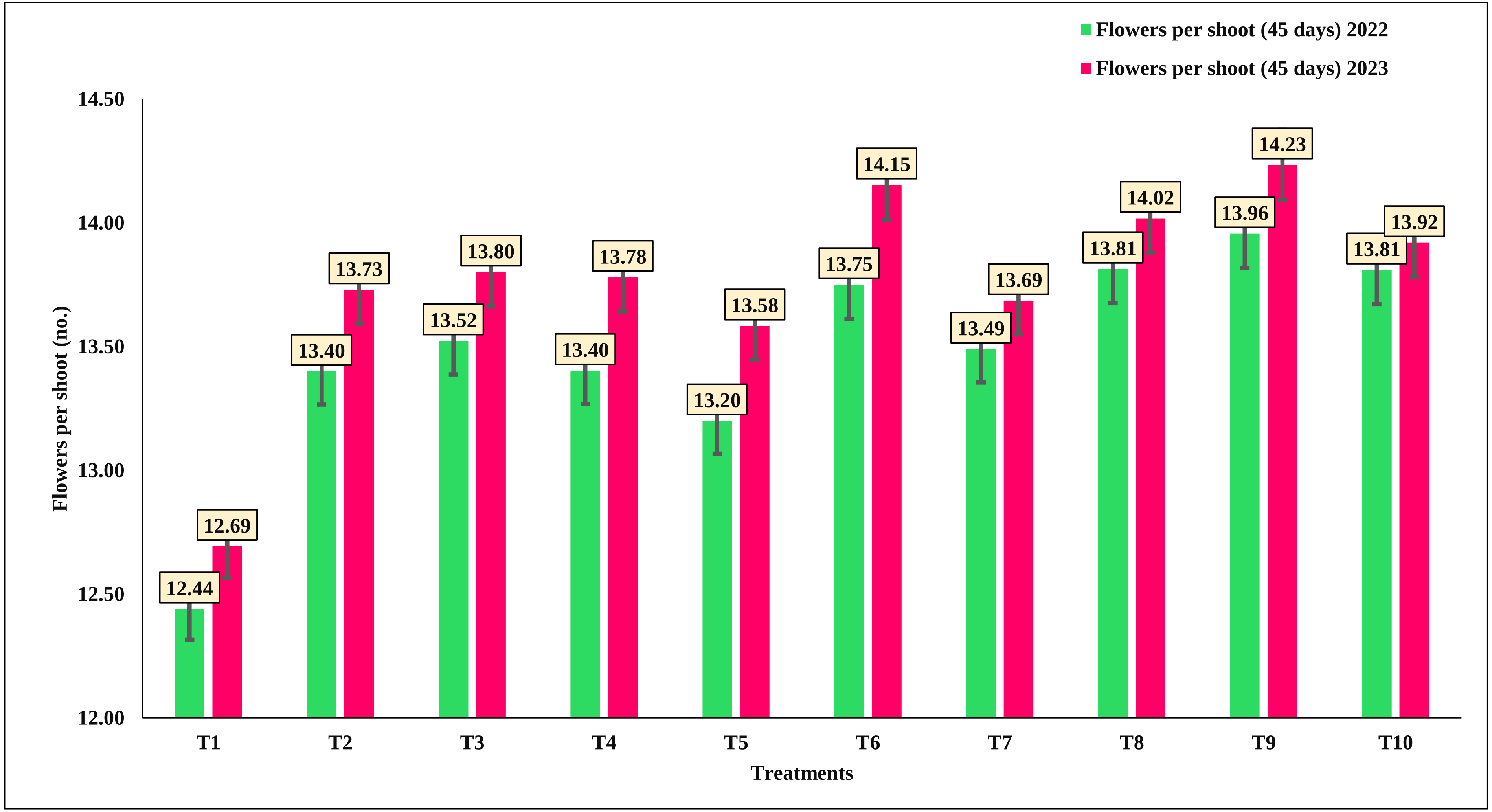

Fig. 4.10: Effect of nano-Zn and nano-Cu on flowers per shoot (at 45 day) in guava

4.2.6 No. of Flowers/shoot (at 60th Days)

In 2022, The number of flowers (at 60th days) was observed during the study. Treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] showed the highest number of flowers (5.83), which was substantially maximum than the treatment T_1 with the lowest number of 5.27 comparable with T_2, T_3, T_4, and T_6, as well as T_7 values 5.28 to 5.67.

In 2023, the experiment revealed findings about the no. of flowers. Treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] showed a maximum number of 6.10. At nominal with T_3, T_4, T_6, T_9, and T_{10}, ranging from 5.58 to 6.01. Instead, treatment T_1 (Control) resulted in the lowest no. of flowers (5.45) T_2, T_3, T_4, T_5, as well as T_7 from 5.54 to 5.83.

The combined data from the two years (2022 and 2023) of experimentation showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum number of flowers (5.92) At nominal with T_2, T_3, T_6, T_8, and T_{10} that was ranging from 5.52 to 5.91. Instead, treatment T_1 (Control) and T_7 recorded at nominal value the lowest number of flowers (5.36 and 5.41 respectively), which was found to be at nominal with T_2, T_3, T_4, T_5, and T_6 ranging from 5.46 to 5.91.

4.2.7 No. of flowers per shoot (at 75th Day)

In an experiment performed in 2022, the treatment T_7 [nano-Zn_1(40ppm) + Cu_2(30ppm)] exhibited the maximum number of flowers (2.50) with no substantial difference. In contrast, the treatment T_1 (Control) resulted in the minimum number of flowers (2.18).

During the experimental year of 2023, the treatment T_6 [nano-Zn_1(40ppm) + Cu_1(20ppm)] had a maximum number of flowers of 2.80. Treatments T_2, T_3, T_4, T_5, T_7, T_8, T_9 and T_{10} were at nominal value, recording several flowers ranging from 2.51 to 2.77. Conversely, the treatment T_1 (Control) had a least no. of flowers of 2.33, at nominal with treatments T_2, T_3, T_5, T_7, T_8, and T_{10} ranging from 2.51 to 2.69.

From the combined data of the two years (2022 and 2023), the experimental data revealed that the treatment T_6 exhibited the maximum number of flowers (2.64) each which was substantially higher than T_1. In contrast, the treatment T_1 (Control) displayed a minimum number of flowers (2.26).

4.2.8 No. of flowers per shoot (at 90th Day)

In the initial year of the experiment (2022), observations were made regarding the maximum number of flowers. Treatment T_{10} ($ZnSO_4$) exhibited a maximum number of flowers of 1.35 which was substantially higher than T_1 (Control). Among the remaining treatments, a substantial number of flowers was observed. However, treatment T_1 (Control) recorded the minimum number of flowers of 0.53.

In the second trial (2023), the maximum number of flowers (1.58) was in T_{10} ($ZnSO_4$), which was substantially higher than treatment T_1 (Control) recording the least number of flowers of 0.66. Among the remaining treatments, a substantial number of flowers was observed.

The combined data from both years (2022 and 2023) revealed that treatment T_{10} ($ZnSO_4$) exhibited the maximum number of flowers of 1.46 which was meaningfully higher than other treatments. Instead, treatment T_1 (Control) resulted in a minimum number of flowers was 0.60.

Table no. 4.4: Effect of nano-Zn and nano-Cu on flowers (number), at 60th day, at 75th day, and at 90th day of Guava.

Flowers									
Treatments	No. of days (60)			No. of days (75)			No. of days (90)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	5.27 ± 0.02^{a}	5.45 ± 0.12^{a}	5.36 ± 0.07^{a}	2.18 ± 0.09^{a}	2.33 ± 0.08^{a}	2.26 ± 0.07^{a}	0.530. ±09 ^{a}	0.66 ± 0.13^{a}	0.60 ± 0.11^{a}
T_2	5.43 ± 0.02^{abc}	5.6 ± 0.11^{ab}	5.52 ± 0.07^{abcd}	2.38 ± 0.12^{a}	2.51 ± 0.18^{ab}	2.45 ± 0.15^{ab}	1.14 ± 0.11^{abc}	1.50 ± 0.09^{bc}	1.32 ± 0.10^{abc}
T_3	5.53 ± 0.05^{abc}	5.83 ± 0.16^{abc}	5.68 ± 0.08^{abcd}	2.42 ± 0.06^{a}	2.54 ± 0.08^{ab}	2.48 ± 0.07^{ab}	1.05 ± 0.14^{abc}	1.31±o.19^{abc}	1.18 ± 0.17^{abc}
T_4	5.44 ± 0.10^{abc}	5.58 ± 0.16^{abc}	5.51 ± 0.13^{abc}	2.50 ± 0.10^{a}	2.77 ± 0.18^{b}	2.63 ± 0.11^{b}	0.85 ± 0.26^{abc}	1.21 ± 0.25^{abc}	1.03 ± 0.24^{abc}
T_5	5.34 ± 0.05^{bc}	5.57 ± 0.02^{ab}	5.46 ± 0.02^{ab}	2.40 ± 0.03^{a}	2.60 ± 0.07^{ab}	2.50 ± 0.05^{ab}	0.62 ± 0.07^{ab}	0.77 ± 0.10^{ab}	0.70 ± 0.08^{ab}
T_6	5.67 ± 0.02^{abc}	5.82 ± 0.06^{abc}	5.74 ± 0.03^{abcd}	2.48 ± 0.08^{a}	2.80 ± 0.12^{b}	2.64 ± 0.09^{b}	1.30 ± 0.11^{bc}	1.42 ± 0.07^{abc}	1.36 ± 0.09^{bc}
T_7	5.28 ± 0.35^{a}	5.54 ± 0.28^{ab}	5.41 ± 0.32^{a}	2.50 ± 0.07^{a}	2.58 ± 0.02^{ab}	2.54 ± 0.05^{ab}	0.79 ± 0.23^{abc}	1.10 ± 0.39^{abc}	0.95 ± 0.31^{abc}
T_8	5.71 ± 0.01^{bc}	6.10 ± 0.15^{c}	5.91 ± 0.08^{cd}	2.42 ± 0.11^{a}	2.59 ± 0.04^{ab}	2.50 ± 0.07^{ab}	1.00 ± 0.25^{abc}	1.22 ± 0.24^{abc}	1.11 ± 0.24^{abc}
T_9	5.83 ± 0.03^{c}	6.01 ± 0.06^{bc}	5.92 ± 0.04^{d}	2.44 ± 0.04^{a}	2.74 ± 0.02^{b}	2.59 ± 0.03^{ab}	1.07 ± 0.02^{abc}	1.33 ± 0.37^{abc}	1.20 ± 0.30^{abc}
T_{10}	5.71 ± 0.02^{bc}	5.95 ± 0.12^{bc}	5.83 ± 0.07^{bcd}	2.30 ± 0.20^{a}	2.69 ± 0.13^{ab}	2.50 ± 0.16^{ab}	1.35 ± 0.03^{c}	1.58 ± 0.24^{c}	1.46 ± 0.28^{c}
S. Em (±)	0.04	0.05	0.04	0.03	0.03	0.03	0.07	0.08	0.07

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ Cu_2(30ppm)], T_{10} [$ZnSO_4$].

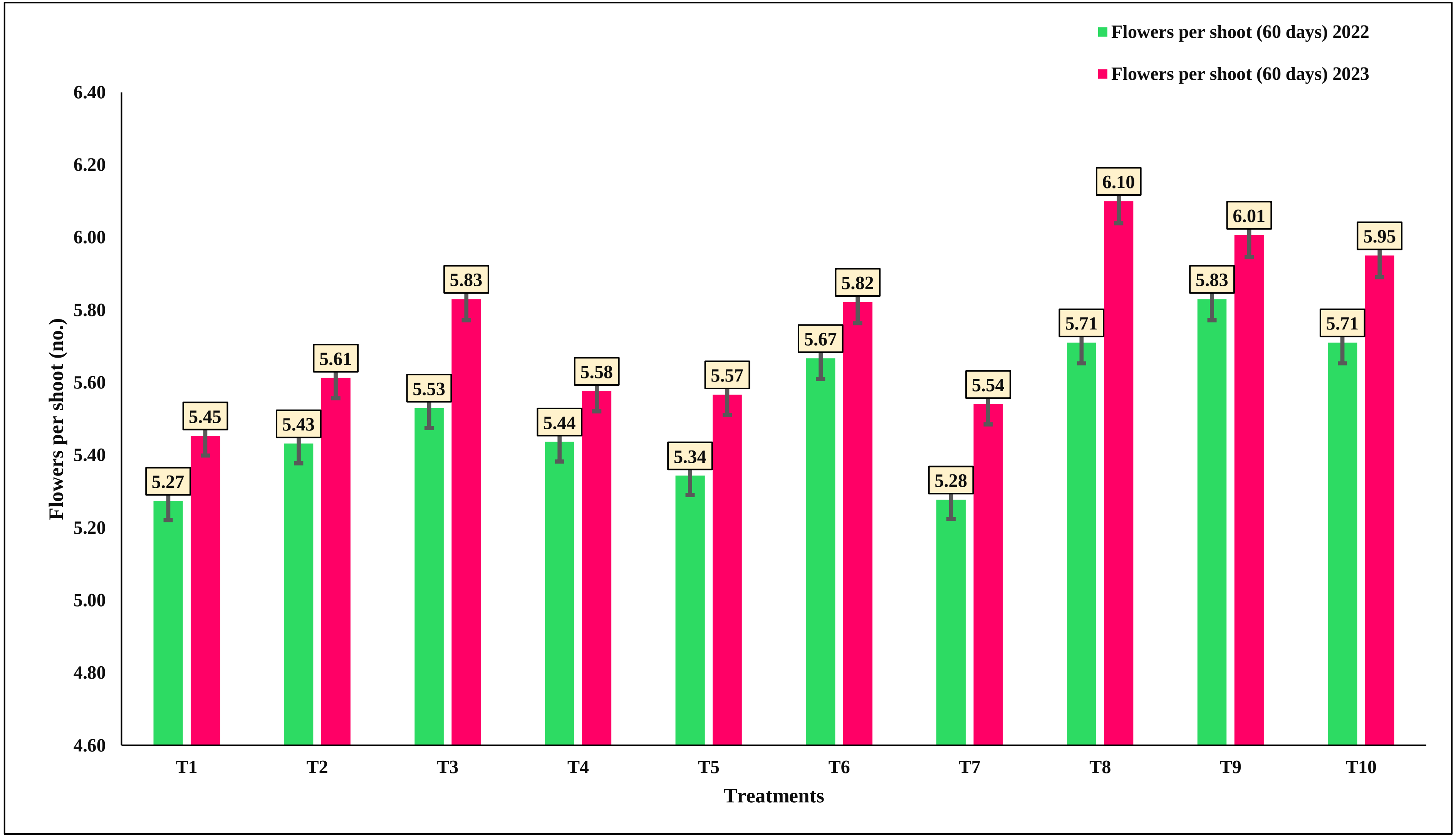

Fig. 4.11: Effect of nano-Zn and nano-Cu on flowers per shoot (at 60 day) in guava

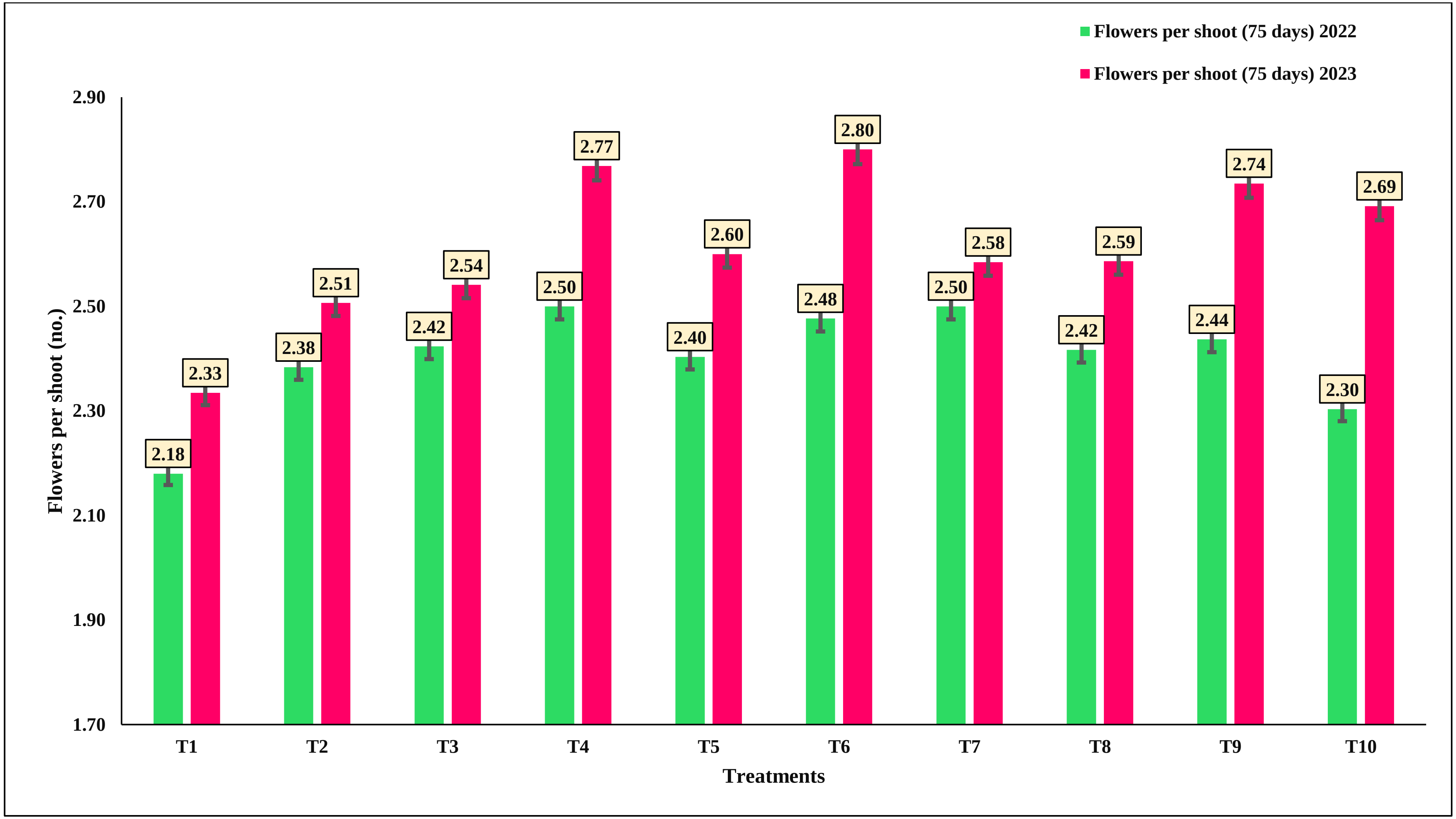

Fig. :4.12 Effect of nano-Zn and nano-Cu on flowers per shoot (at 75 day) in guava

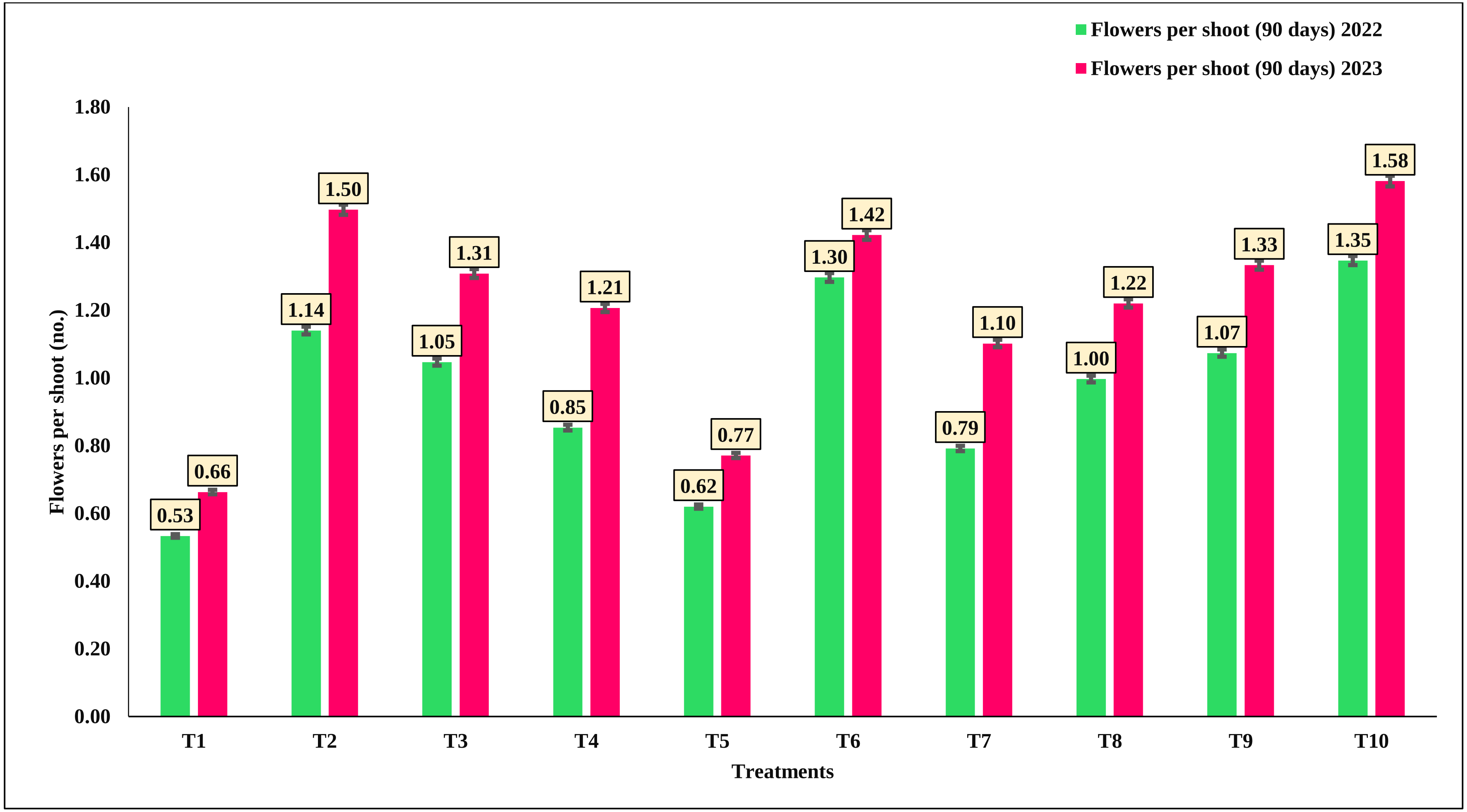

Fig. 4.13: Effect of nano-Zn and nano-Cu on flowers per shoot (at 90 day) in guava

4.2.9 No. of fruits per shoot:

Table no.4.5 and 4.6 shows the variation in the number of fruits per shoot throughout the two-year experiment (2022 and 2023). A thorough examination of the data reveals impact nano-micronutrient on the no. of fruit/shoot of the Guava plant during both years of the experiment in table 4.5 and 4.6 and figure 4.13, 4.14, 4.15, 4.16, 4.17, 4.18, 4.19, and 4.20.

4.2.10 Number of fruits per shoot (0 Day)

During both the experimental years (2022 and 2023), it was noted that fruit did not set on these dates of the trial.

4.2.11 No. of fruit/shoot (15 Days)

In both the experimental years (2022 and 2023), it was observed that a few fruits were settled on the fifteenth day of the trial. And found no substantial difference in the number of fruits per shoot in both years.

4.2.12 No. of fruit/shoot (30 Days)

In the initial year (2022) of the experimental trial, no substantial no. of fruit/shoot was found and very few numbers of fruits were settled on the selected shoots.

In the second trial (2023), the more no. of fruits per shoot (1.79) was in T_4 [Cu_1 (20ppm)], which was substantially higher than treatment T_1 (Control) recording the least number of fruits of 1.34. Among the remaining treatments, a substantial number of fruits was observed.

From the combined data of the two years (2022 and 2023), the experimental data revealed that the treatment T_4 exhibited the maximum number of fruits (1.55) which was substantially higher than T_1 and T_2.

4.2.13 No. of fruits per Shoot (45 Days)

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was recorded with the highest number of fruits 3.09. This was substantially higher with the treatment T_1. Minimum number of fruits (2.32) was observed in T_1 (Control).

In 2023, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum number of fruits, which was 3.22. This was at nominal with T_8, this result substantially maximum than T_1 (Control) with the no. of fruit 2.56.

Table no. 4.5: Effect of nano-Zn and nano-Cu on fruits (number) 0 day, 15 days, 30 days, and 45 days of guava.

Fruits (number) per shoot												
	No. of days (0)			No. of days (15)			No. of days (30)			No. of days (45)		
Treatments	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	0.00^{a}	0.00^{a}	0.00^{a}	0.62±0.04^{a}	0.89±0.09^{a}	0.76±0.05^{a}	1.26±0.02^{a}	1.34±0.03^{a}	1.30±0.02^{a}	2.32±0.04 ^{a}	2.56±0.16^{a}	2.44±0.03^{a}
T_2	0.00^{a}	0.00^{a}	0.00^{a}	0.72±0.07^{a}	0.89±0.06^{a}	0.80±0.04^{a}	1.21±0.05^{a}	1.39±0.12^{a}	1.30±0.07^{a}	2.57±0.04^{b}	2.85±0.08^{bc}	2.71±0.05^{b}
T_3	0.00^{a}	0.00^{a}	0.00^{a}	0.65±0.03^{a}	0.96±0.18^{a}	0.81±0.10^{a}	1.19±0.09^{a}	1.50±0.05^{ab}	1.35±0.07^{ab}	2.65±0.03^{bc}	2.77±0.07^{ab}	2.71±0.05^{b}
T_4	0.00^{a}	0.00^{a}	0.00^{a}	0.67±0.04^{a}	0.86±0.04^{a}	0.76±0.04^{a}	1.31±0.09^{a}	1.79±0.08^{b}	1.55±0.06^{b}	2.65±0.04^{bc}	2.86±0.09^{bc}	2.75±0.05^{bc}
T_5	0.00^{a}	0.00^{a}	0.00^{a}	0.77±0.08^{a}	0.97±0.10^{a}	0.87±0.09^{a}	1.30±0.01^{a}	1.52±0.01^{ab}	1.41 ±0.01^{a}	2.60±0.01^{bc}	2.93±0.05^{bc}	2.77±0.03 ^{bc}
T_6	0.00^{a}	0.00^{a}	0.00^{a}	0.5±0.22^{a}	0.91±0.25^{a}	0.71±0.23^{a}	1.24±0.05^{a}	1.4±0.070^{a}	1.32±0.05^{a}	2.68±0.04^{c}	2.91±0.16^{bc}	2.80±0.09 ^{bc}
T_7	0.00^{a}	0.00^{a}	0.00^{a}	0.71±0.05^{a}	0.92±0.05^{a}	0.82±09.05^{a}	1.27±0.008^{a}	1.3±0.048^{a}	1.33±0.02^{a}	2.62±0.02^{bc}	2.83±0.10^{b}	2.73±0.06 ^{bc}
T_8	0.00^{a}	0.00^{a}	0.00^{a}	0.61±0.06^{a}	1.04±0.07^{a}	0.83±0.04^{a}	1.18±0.08^{a}	1.5±0.20^{ab}	1.35±0.13^{ab}	2.94±0.02^{d}	3.13±0.01^{cd}	3.03±0.006^{de}
T_9	0.00^{a}	0.00^{a}	0.00^{a}	0.65±0.02^{a}	0.67±0.02^{a}	0.66±0.02^{a}	1.30±0.06^{a}	1.53±0.05^{ab}	1.42±0.06^{ab}	3.09±0.02^{e}	3.22±0.07^{d}	3.15±0.05^{e}
T_{10}	0.00^{a}	0.00^{a}	0.00^{a}	0.64±0.02^{a}	0.72±0.04^{a}	0.68±0.03^{a}	1.29±0.15^{a}	1.42±0.05^{a}	1.36±0.03^{ab}	2.85±0.01^{d}	2.94±0.04^{bc}	2.90±0.02^{cd}
S. Em (±)	0	0	0	0.02	0.03	0.02	0.01	0.03	0.02	0.03	0.03	0.03

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(nano-Cu_1(20ppm)], T_5 [nano-Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ nano-Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ nano-Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ nano-Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ nano-Cu_2(30ppm)], T_{10} [$ZnSO_4$]

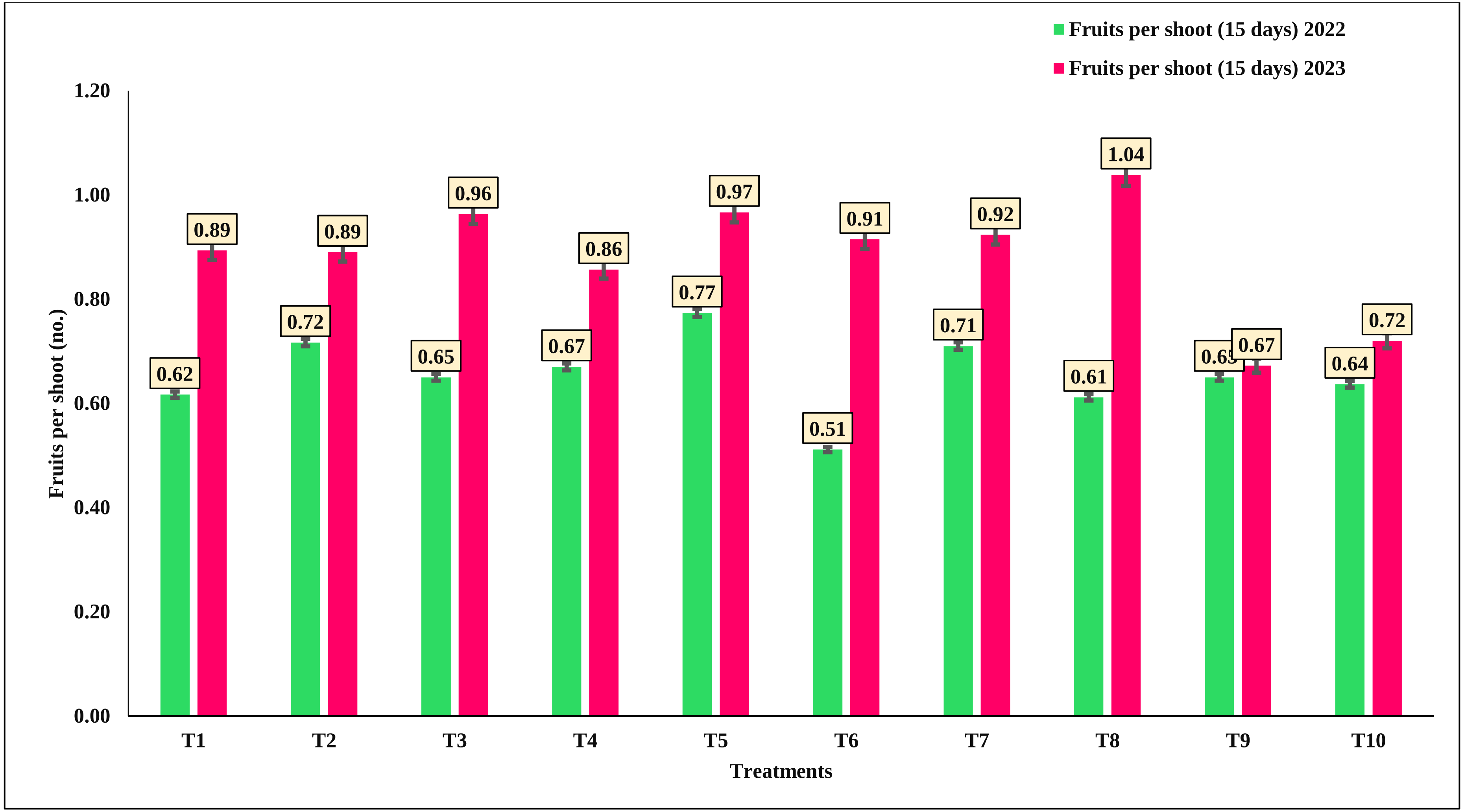

Fig. 4.14: Effect of nano-Zn and nano-Cu on fruits per shoot (at 15 day) in guava

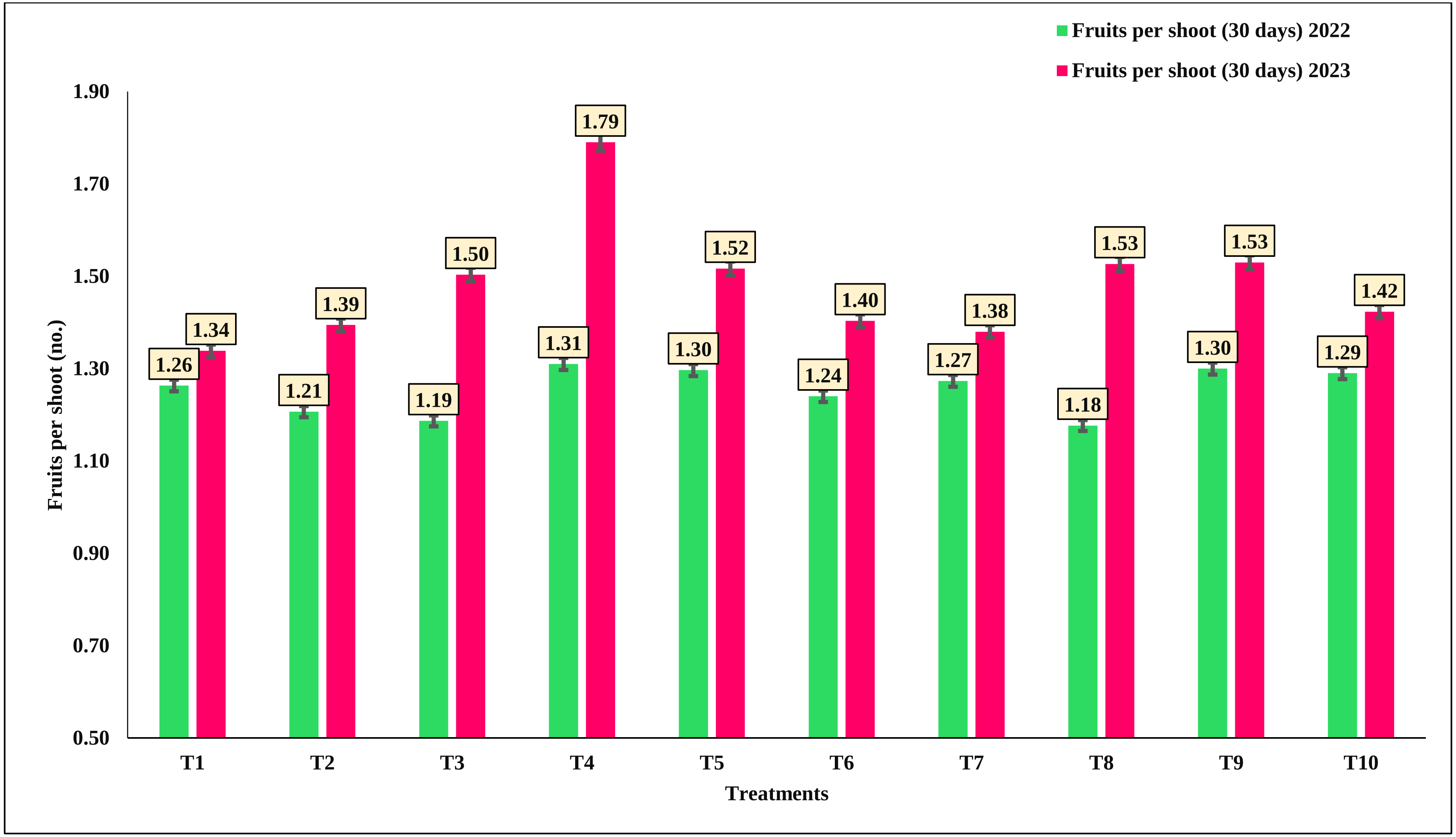

Fig. 4.15: Effect of nano-Zn and nano-Cu on fruits per shoot (at 30 day) in guava

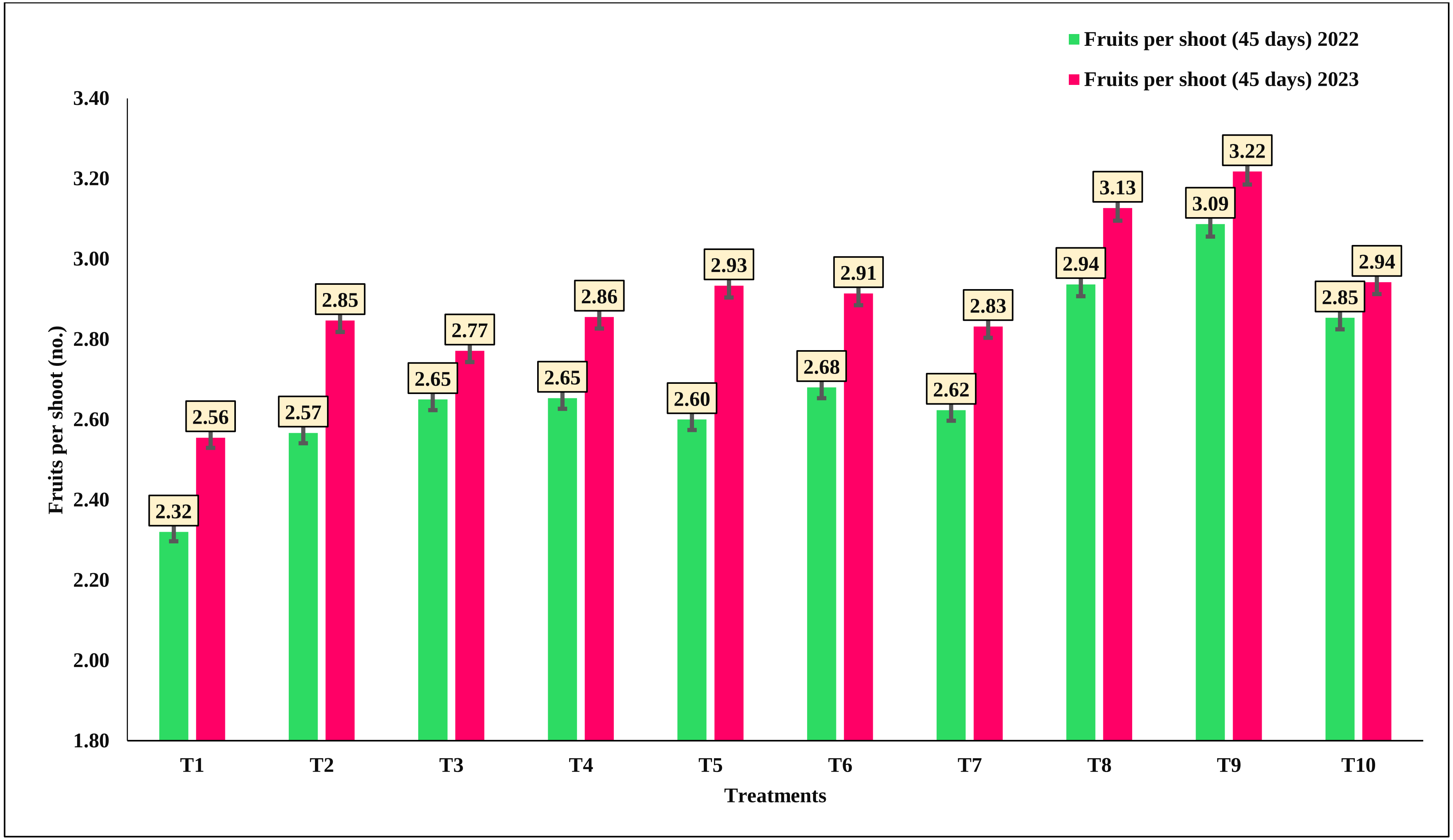

Fig. :4.16 Effect of nano-Zn and nano-Cu on fruits per shoot (at 45 day) in guava

Aggregate data from both the years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum number of fruits, with a value of 3.15 which was at nominal with T_8 (3.03). Instead, the treatment T_1 (Control) was observed with the lowest number of fruits (2.44).

4.2.14 No. of fruits/shoot (60 Days)

In the primary year of the experiment (2022), The number of fruits (at 60 days) was observed during the study. Treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] showed the highest number of fruits (8.17), This was at nominal with treatment T_9 (8.03), it was substantially maximum than the treatment T_1 with the lowest number of 6.20. Among the remaining treatments, a substantial no. of fruits per shoot was observed.

In 2023, the study resulted about the number of fruits/shoot. Treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] showed a maximum no. of 8.30. This was at nominal with treatments T_9, and T_{10}, that was 8.28 and 8.07 respectively. Instead, treatment T_1 (Control) resulted in the least no. of fruits per shoot (6.27).

The combined data from the two years (2022 and 2023) of experimentation showed that treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] had the more no. of fruits per shoot (8.23) at nominal with T_9 (8.15). Conversely, treatment T_1 (Control) recorded the lowest number of fruits (6.23).

4.2.15 Number of fruits per shoot (75 Days)

In an experiment performed in 2022, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] exhibited the maximum number of fruits (3.38). This is at nominal with T_8 (3.19) which was substantially high with the treatment T_1 (Control) this is at nominal with T_2, T_4, T_5, and T_7 ranging from 2.72 to 2.81.

During the experimental year of 2023, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had a maximum number of fruits of 3.57. This is at nominal with T_8, and T_{10}, recording several fruits at 3.42 and 3.35 respectively. Alternatively, treatment T_1 (Control) had a minimum number of fruits of 2.86, at nominal with treatments T_3, T_4 and T_5, ranging from 2.90 to 3.14.

From the combined data of the two years (2022 and 2023), the experimental data revealed that the treatment T_9 exhibited the maximum no. of fruits (3.48) each which was substantially higher than T_1. In contrast, the treatment T_1 (Control) displayed a minimum number of fruits, 2.74. This was at nominal then T_5 (2.81).

4.2.16 Number of fruits per shoot (90 Day)

In an experiment performed in 2022, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] exhibited the maximum number of fruits with a substantial difference (1.57). This was at nominal with treatment T_8 (1.43). In contrast, the treatment T_1 (Control) resulted in the minimum number of fruits (1.02).

In 2023, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had a maximum number of fruits of 1.89. Treatments T_2, T_3, T_4, T_5, T_6, T_7, T_8, and T_{10} were at nominal value, recording several fruits ranging from 1.58 to 1.72. Alternatively, the treatment T_1 (Control) had a least number of fruits of 1.27. at nominal value with T_2, T_3, T_5, T_6, and T_7 values varying from 1.59 to 1.63.

From the combined data of the two years (2022 and 2023), the experimental data revealed that treatment T_9 exhibited the maximum no. of fruits (1.73) at nominal value with T_7 and T_8 with the no. of fruits, 1.51 and 1.57 which was suggestively higher than T_1. In contrast, the treatment T_1 (Control) displayed a minimum number of fruits, 1.15.

Table no. 4.6: Effect of nano-Zn and nano-Cu on fruits (number) at 60 days, 75 days, and 90 days of guava.

Fruits (number) per shoot									
	No. of days (60)			No. of days (75)			No. of days (90)		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_1	6.20±0.12 ^{a}	6.27±0.10^{a}	6.23±0.11^{a}	2.61 ±0.02^{a}	2.86±0.09^{a}	2.74±0.05^{a}	1.02±0.05^{a}	1.27±0.003^{a}	1.15±0.02^{a}
T_2	6.73±0.01^{bc}	6.93±0.02^{b}	6.83±0.008^{b}	2.79±0.01^{ab}	3.18±0.13^{bcd}	2.99±0.07^{bc}	1.22±0.06^{b}	1.60±0.16^{ab}	1.41±0.10 ^{b}
T_3	6.81±0.05^{bc}	7.26±0.04^{cd}	7.03±0.04^{c}	2.85±0.03^{bc}	3.14±0.15^{abcd}	2.99±0.07^{bc}	1.29±09.03^{bc}	1.59±0.09^{ab}	1.44 ±0.06^{b}
T_4	6.84±0.02^{c}	7.05±0.11^{bc}	6.95±0.06^{bc}	2.810,04^{abc}	3.05±0.05^{abc}	2.93±0.01^{bc}	1.30^{b}±0.04^{c}	1.67±0.14^{b}	1.49 ±0.09^{b}
T_5	6.66 ±0.04^{b}	6.97±0.12^{b}	6.82±0.04^{b}	2.72±0.02^{ab}	2.90±0.006^{ab}	2.81±0.01^{ab}	1.23±0.02^{b}	1.63±0.13^{ab}	1.43 ±0.07^{b}
T_6	7.60±0.01^{e}	7.73±0.05^{e}	7.67±0.02^{e}	3.00±0.01^{cd}	3.17±0.05^{bcd}	3.09±0.03^{cd}	1.35±0.04^{bc}	1.58±0.05^{ab}	1.47 ±0.05^{b}
T_7	7.28±0.05^{d}	7.41±0.09^{d}	7.35±0.07^{d}	2.72±0.18^{ab}	3.22±0.05^{cd}	2.97±0.11^{bc}	1.39±0.03^{bc}	1.63±0.01^{ab}	1.51±0.01^{bc}
T_8	8.17±0.03^{g}	8.30±0.05^{f}	8.23±0.04^{g}	3.19±0.02^{de}	3.42±0.08^{de}	3.30±0.03^{e}	1.430.05^{cd}	1.72±0.09^{b}	1.57±0.04^{bc}
T_9	8.03±0.03^{g}	8.28±0.03^{f}	8.15±0.02^{g}	3.38^{e}±0.02	3.57±0.03^{e}	3.48±0.008^{f}	1.57±0.02^{d}	1.89±0.18^{b}	1.73±0.09^{c}
T_{10}	7.78±0.008^{f}	8.07±0.05^{f}	7.93±0.02^{f}	3.12±0.01^{d}	3.35±0.09^{de}	3.23±0.05^{de}	1.33±0.10^{bc}	1.66±0.06^{b}	1.49±0.08^{b}
S. Em (±)	0.11	0.11	0.11	0.04	0.04	0.42	0.02	0.03	0.03

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(nano-Cu_1(20ppm)], T_5 [nano-Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm) + nano-Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm) + nano-Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)], T_{10} [$ZnSO_4$]

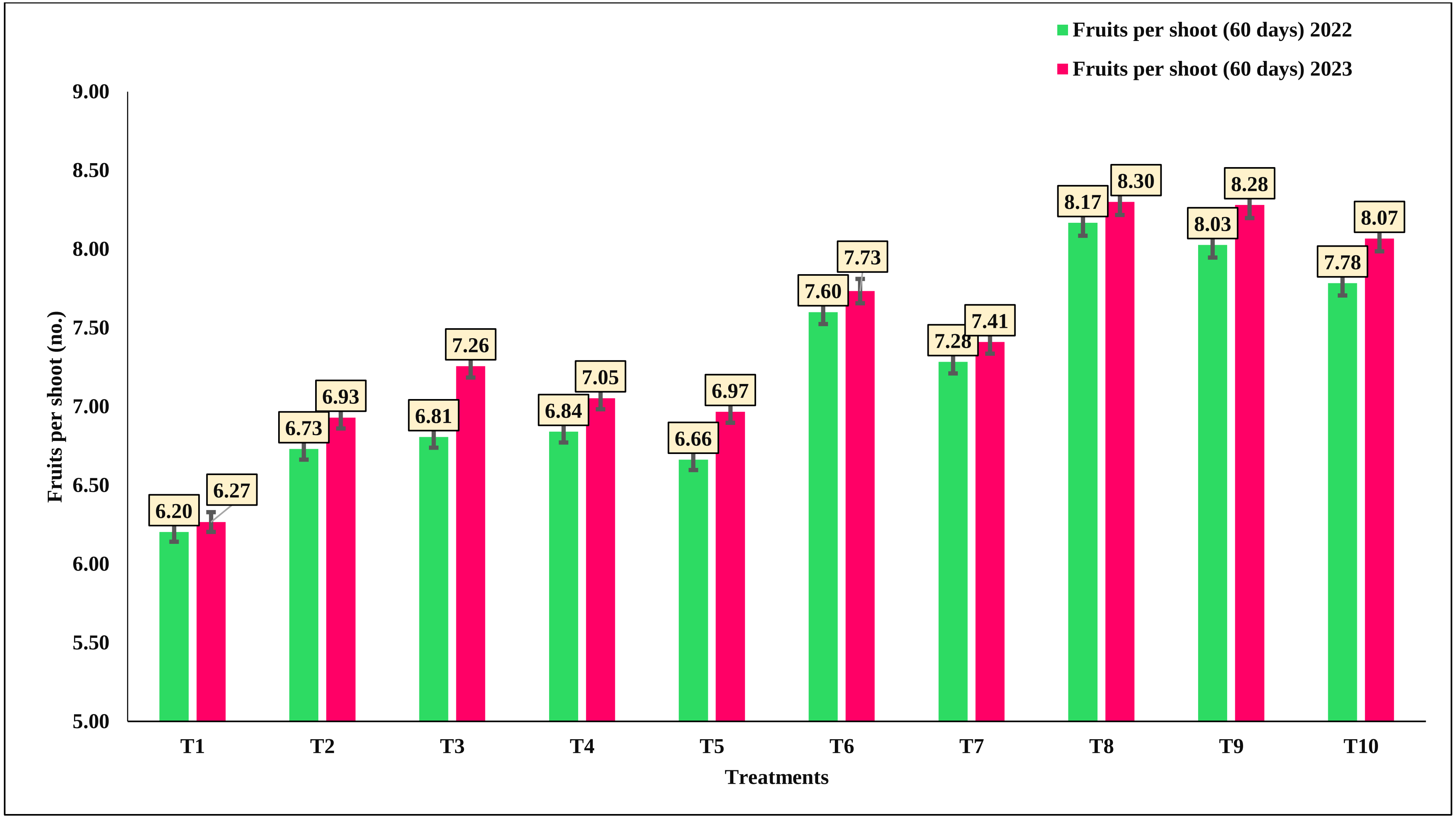

Fig. :4.17 Effect of nano-Zn and nano-Cu on fruits per shoot (at 60 day) in guava

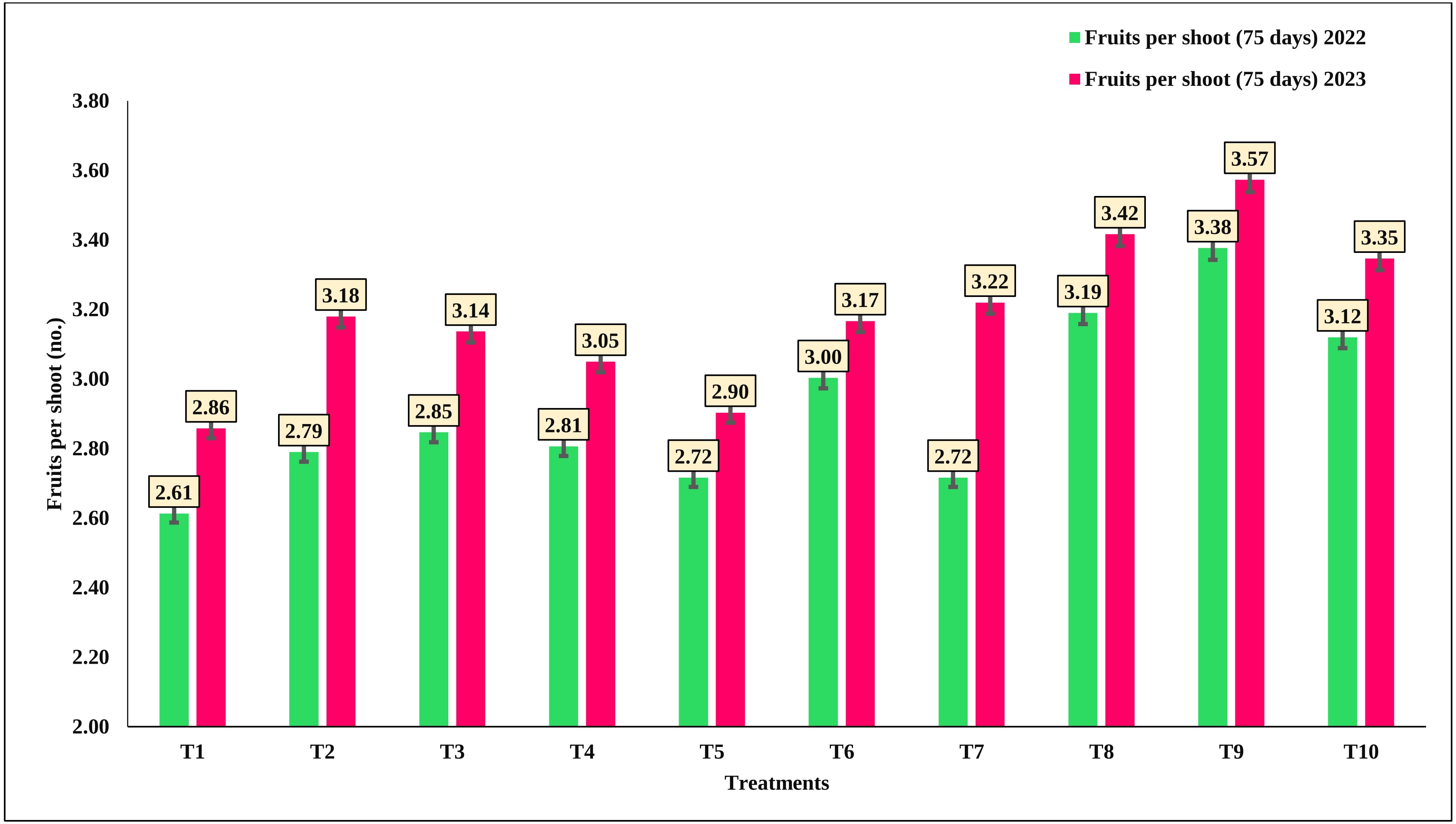

Fig. 4.18: Effect of nano-Zn and nano-Cu on fruits per shoot (at 75 day) in guava

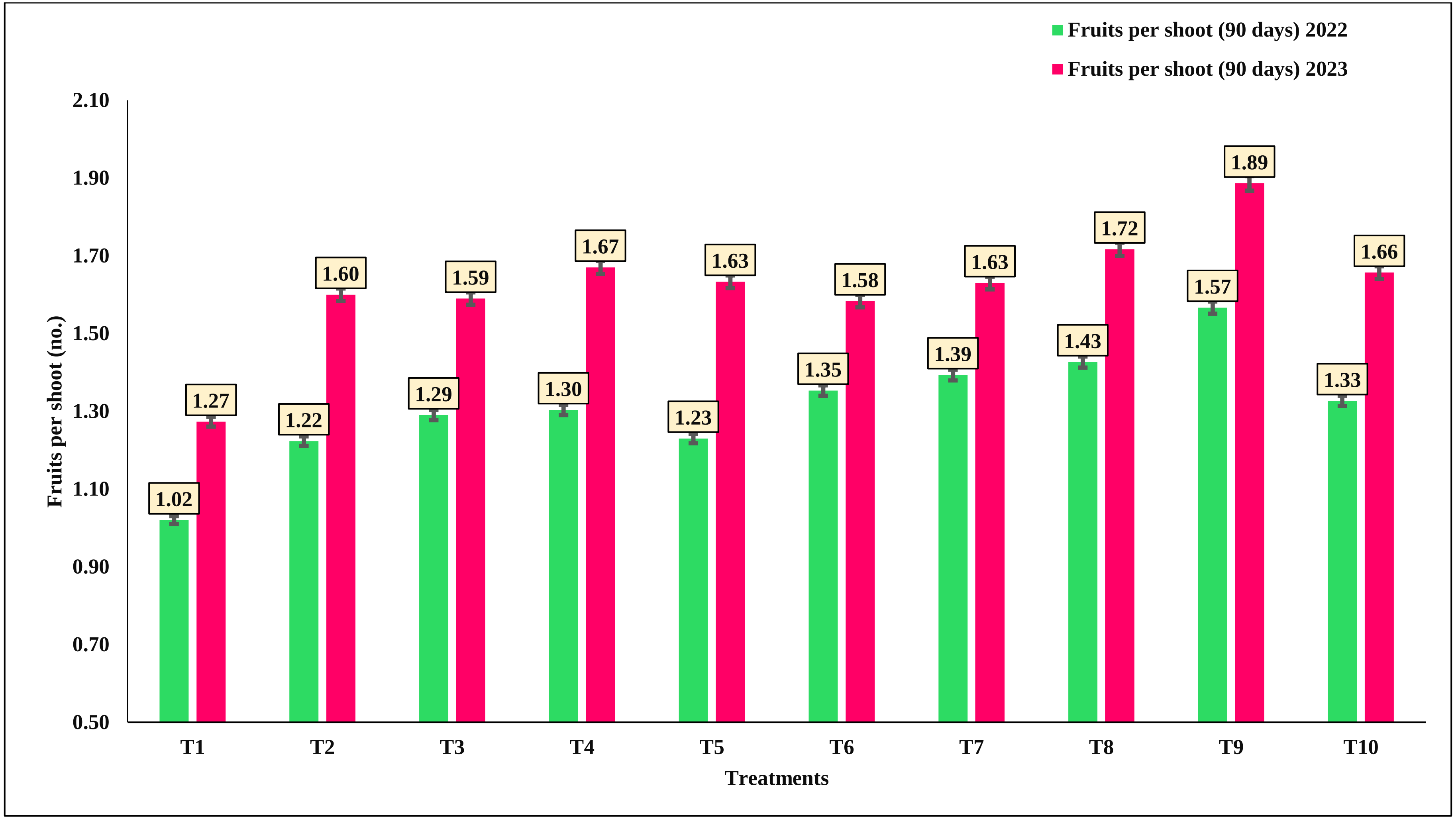

Fig. 4.19: Effect of nano-Zn and nano-Cu on fruits per shoot (at 90 day) in guava

4.2.17 Total no. of flowers per shoot

Table no. 4.7 displays information about the variation in the total no. of flowers per shoot during the two years of the experiment (2022 and 2023). Upon analysing the data, it was found that nano-micronutrient treatments made a substantial impact on the total no. of flowers per shoot in Guava throughout the two years of the trial in table no.4.7 and figure no. 4.21.

In the study conducted in 2022, treatment T_9 [nano-Zn_2 (60ppm) + Cu_2 (30ppm)] had highest flowers per shoot (33.14), At nominal with T_3, T_6, T_8, and T_{10} ranging from 32.01 to 32.98 which was substantially higher than treatment T_1. Conversely, treatment T_1 (Control) had the lowest no. of flowers per shoot, with 29.11.

During the 2023 trial, flowers per shoot in guava followed a similar pattern. Treatment T_9 [nano-Zn_2 (60ppm) + Cu_2 (30ppm)] yielded the maximum flowers per shoot, reaching 34.93 At nominal with T_3, T_6, T_8, and T_{10} ranging from 32.99 to 33.71. Which was substantially higher than T_1. Conversely, treatment T_1 (Control) had the lowest no. of flowers per shoot (30.59). These results demonstrated a statistically substantial impact on the flower production of the guava tree.

The two-year (2022 and 2023) aggregated data also noted a trend similar to that observed in the two-year trial. Maximum flowers per shoot (34.03) were in T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was substantially maximum than T_1. The lowest flowers/shoot (29.85) were in T_1 (Control).

Nano zinc (Zn) and nano copper (Cu) applications can enhance flower production by stimulating flowering processes, regulating plant hormones, improving pollination efficiency, mitigating environmental stress, facilitating nutrient uptake, and reducing genetic variability. Overall, nano Zn and Cu can positively impact flower numbers in plants. Similar results found in the study of Bisen *et al*. (2020), applying zinc sulphate (0.6%) via double spray on guava trees resulted in the lowest flower and fruit loss, maximum fruit weight per tree, and highest yield per hectare. This suggests a positive influence of zinc sulphate concentration and foliar spraying frequency on flowering and fruit production in guava trees. It also seen in the study of Sachin *et al*. (2019) found that spray of 1g/L $ZnSO_4$, 1g/L borax, and 1g/L $CuSO_4$ (T_8) led to the highest no. of flowers/shoot (29.90), fruit set% (79.30%), and fruit retention% (63.20%) in guava. Additionally, T_8 resulted in the least fruit drop (36.8%) and the shortest time to fruit maturity (116.33 days), indicating its positive impact on flowering and fruiting.

4.2.18 Total number of fruit set per shoot

Table no. 4.7 shows the total no. of fruit set/shoot data for the duration of the experiment, encompassing the years 2022 and 2023. The table also includes the combined data. Examination of the data reveals a substantial impact of various nano-micronutrient treatments on the total number of fruit set per shoot levels in guava throughout both years of the experiment shown in table 4.7 and figure no. 4.22.

In 2022, the increase in total no. of fruit set/shoot was under T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)], recording 18.01. This results substantially maximum than treatment T_1. The lowest total no. of fruit set/shoot (14.04) was measured with treatment T_1 (Control).

In the subsequent year of the experiment (2023), observations were made regarding the total number of fruit sets per shoot variations. The treatment T_8, involving the application of nano-Zn_2(60ppm) + Cu_1(20ppm), exhibited the highest total no. of fruit set/shoot (19.19). This was at nominal with T_9, which was 19.16. These results substantially maximum than T_1. Conversely, the T_1 (Control) demonstrated the lowest total number of fruit sets per shoot of 15.46.

Combined data from both years (2022 and 2023), it was observed that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] demonstrated the highest total no. of fruit set/shoot (18.58) which was substantially higher than T_1. Remarkably, this finding was at nominal with the total no. of fruit sets per shoot observed in treatment T_8. Conversely, treatment T_1 (Control) displayed the lowest total number of fruit set per shoot (14.75).

The application of nano zinc (Zn) and copper (Cu) can impact fruit yield through multifaceted mechanisms. These nanoparticles may enhance flowering by modulating hormone levels and improving flower quality, thus increasing fruit set. Additionally, they can enhance pollination efficiency, leading to more successful fertilization and higher fruit numbers. Nano Zn and Cu also play roles in nutrient uptake and stress tolerance, which can contribute to overall fruit development and retention. However, optimal concentrations and application timings are crucial as excessive levels may lead to toxicity. Understanding the complex interactions between nano materials and plants is essential for maximizing fruit yield while minimizing any potential negative impacts. Similar results found the study of Patel *et al*. (2020) that combining micronutrients, specifically $ZnSO_4$ and boric acid in T_9, resulted in the highest fruit yield and quality parameters in guava. This treatment exhibited superior fruit set, reduced fruit drop, and increased total production compared to the control group. A study on tomato plants revealed that the application of zinc and copper significantly impacted the yield of fruits per plant (Johura, 2017). Similarly, research on Lemon trees (cv. Meyer) demonstrated that foliar spraying with boron, zinc, and iron nutrients during flowering and fruit set influenced the physical characteristics of the fruits. These nutrients were applied either individually or in combination. The study measured viable pollen percentage, hermaphrodite flowers, flowers with aborted ovaries, total flowers, fruit set, and initial fruit set across both seasons. Statistical analysis showed that the treatment combining iron chelate, boron oxide, and zinc chelate yielded the highest values compared to the control group (Mohammed *et al*., 2018).

4.2.20 Number of fruits harvested per shoot

Table no. 4.7 shows the data on the variation in the no. of fruits harvested per shoot during the two years of the experiment (2022 and 2023) along with the pooled data. A keen perusal of the data indicates that impact of nano-micronutrient treatments on no. of fruits harvested/shoot in guava during both the years of the experiment in table no. 4.7 and figure no. 4.23.

In 2022, the greater number of fruits harvested per shoot was under T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 10.22 fruits were recorded which was substantially different from treatment T_1. The lesser no. of fruits harvested per shoot (6.40) was observed in treatment T_1 (Control).

In the second trial year (2023), statistically, treatments made a substantial impact on the no. of fruits harvested per shoot of guava fruits. More no. of fruits harvested per shoot (10.42) was substantially higher than treatment T_1. The no. of fruit harvested/shoot (6.70) was in T_1 (Control).

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the maximum number of fruits harvested per shoot, with a value of 10.32 which was substantially higher than treatment T_1. In contrast, treatment T_1 had the lowest number of fruits harvested per shoot, with a value of 6.55.

Spray of nano-Zn and Cu enhances fruit yield by stimulating flower initiation, improving pollination efficiency, and regulating stress responses. These nanoparticles optimize nutrient uptake, leading to robust flower and fruit development. Additionally, they modulate gene expression associated with fruiting processes. Nano materials also promote enzymatic activities essential for fruit growth, resulting in increased fruit set and ultimately higher yields per plant. Overall, nano zinc and copper enhance fruit production through multifaceted physiological and biochemical mechanisms.

Patel *et al*. (2020) observed substantial variations in guava growth and yield at Naini Agricultural Institute. Treatment T_9, containing ZnSO4 and boric acid, yielded the highest fruit quantity and quality parameters per plant. This highlights the efficacy of micronutrient combinations in enhancing fruit set, reducing fruit drop, and improving overall guava sensory qualities.

Similarly, Spray application of chelated form of Zn and Cu either separately or in combination had resulted in significant increase in yield of lemon as compared to control and sulphate form of Zn and Cu. Maximum yield (22.9 kg/plant) was obtained with foliar application of 0.4% ZnEDT A + 0.2% CuEDTA which was 13.6 kg/plant more than control (Sharma *et al.,*1999).

Table no. 4.7: Effect of nano-Zn and nano-Cu on total number of flowers, total number of fruit set, and number of fruits harvested of guava.

	Total no. of flowers			Total no. of fruit set			No. of fruits harvested		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_1	29.11±0.05^{a}	30.59±0.14^{a}	29.85±0.17^{a}	14.04±0.17^{a}	15.46±0.13^{a}	14.75±0.15^{a}	6.40±0.08^{a}	6.70±0.22^{a}	6.55±0.14^{a}
T_2	31.53±0.06^{bc}	33.08±0.32^{bc}	32.30±0.31^{bcd}	15.23±0.16^{b}	16.72±0.29^{b}	15.98±0.20^{b}	7.67±0.05^{b}	7.99±0.18^{b}	7.83±0.11^{b}
T_3	32.01±0.03^{bcd}	33.97±0.12^{cde}	32.99±0.11^{bcde}	15.43±0.03^{b}	17.37±0.10^{bc}	16.40±0.04^{bc}	8.10±0.02^{c}	8.46±0.07^{cd}	8.28±0.04^{c}
T_4	31.51±0.04^{bc}	33.30±0.41^{bcd}	32.41±0.47^{bcd}	15.58±0.09^{bc}	17.89±0.36^{bc}	16.74±0.21^{bc}	8.10±0.09^{c}	8.44±0.13^{cd}	8.27±0.11^{c}
T_5	31.05±0.02^{b}	32.74±0.42^{b}	31.90±0.37^{b}	15.28±0.08^{b}	16.78±0.21^{bc}	16.03±±0.07^{bc}	7.98±0.06^{c}	8.34±0.13^{bc}	8.16±0.08^{c}
T_6	32.59±0.04^{cd}	34.28±0.33^{de}	33.43±0.34^{de}	16.39±0.27^{d}	18.27±0.33^{cd}	17.33±0.30^{de}	8.75±0.12^{d}	8.93±0.18^{e}	8.84±0.15^{d}
T_7	31.36±0.03^{bc}	33.02±0.59^{bc}	32.19±0.65^{bc}	16.00±0.29^{cd}	17.29±0.27^{bcd}	16.65±0.28^{cd}	8.69±0.13^{d}	8.85±0.11^{de}	8.77±0.12^{d}
T_8	32.410.05^{cd}	33.82±0.36^{bcde}	33.12±0.37^{cde}	17.51±0.17^{f}	19.19±0.25^{e}	18.35±0.21^{f}	9.53±0.10^{e}	9.63±0.08^{f}	9.58±0.09^{e}
T_9	33.14±0.02^{d}	34.93±0.48^{e}	34.03±0.36^{e}	18.01±0.02^{g}	19.16±0.14^{e}	18.5±0.06^{f}	10.22±0.006^{f}	10.42±0.06^{g}	10.32±0.03^{f}
T_{10}	32.98±0.10^{d}	34.44±0.14^{de}	33.71±0.16^{e}	17.01±0.08^{e}	18.24±0.16^{d}	17.62±0.10^{e}	9.38±0.10^{e}	9.64±0.02^{f}	9.51±0.06^{e}
S. Em (±)	0.02	0.23	0.23	0.21	0.21	0.21	0.19	0.18	0.18

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ Cu_2(30ppm)], T_{10} [$ZnSO_4$]

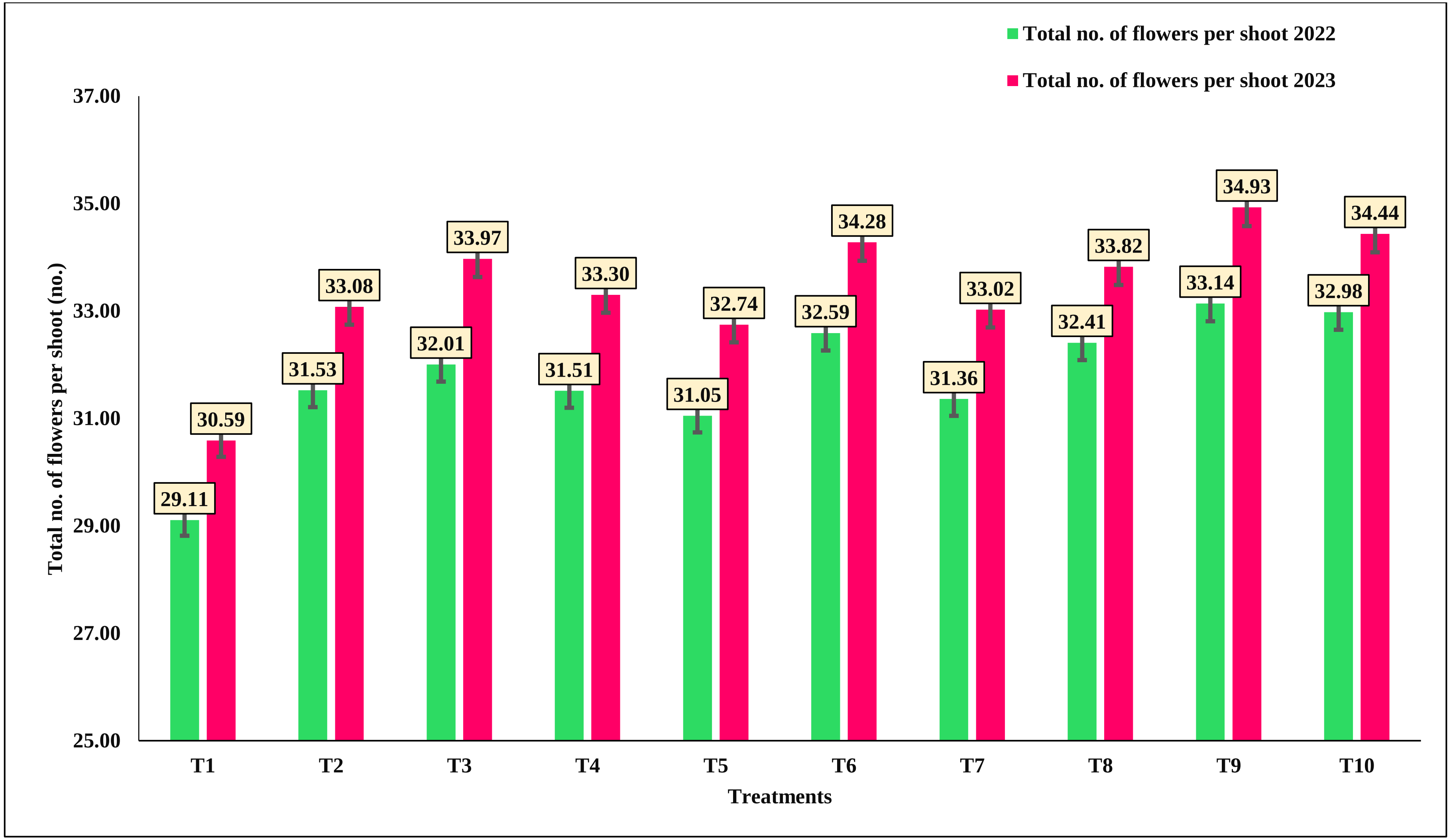

Fig. 4.20: Effect of nano-Zn and nano-Cu on total number of flowers per shoot (number) in guava

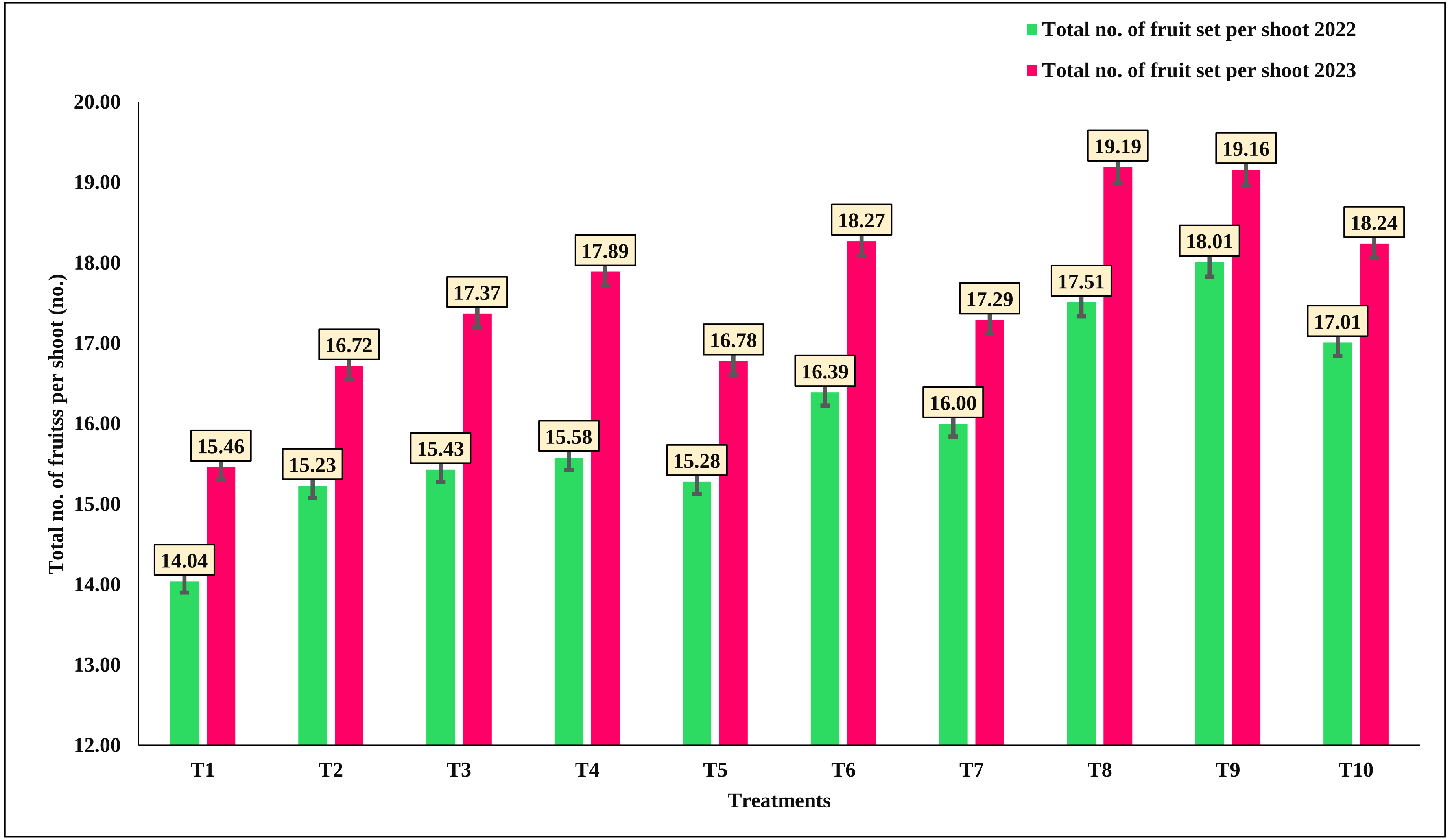

Fig. 4.21: Effect of nano-Zn and nano-Cu on total number of fruits per shoot (number) in guava

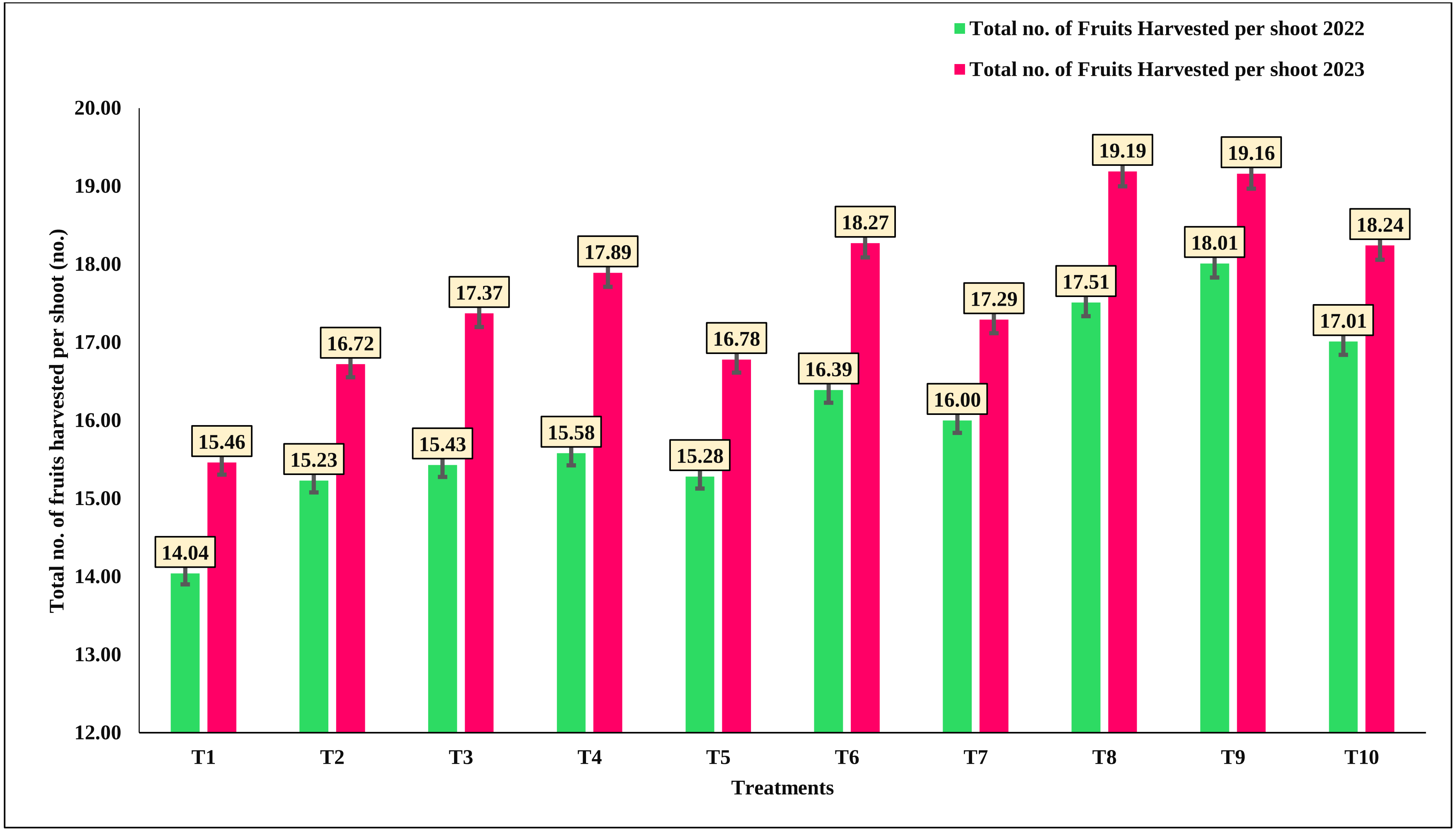

Fig. 4.22: Effect of nano-Zn and nano-Cu on total number of fruits harvested per shoot (number) in guava

4.2.21 Fruit set (%)

Table no.4.8 provides information about the variation in fruit set observed throughout the two years of the experiment (2022 and 2023). A keen perusal of the data indicates there is a substantial effect of nano-micronutrients on fruit set in guava during both the years of the experiment shown in table no. 4.8 and graphical represented in figure 4.24.

In 2022, the highest fruit set percent was in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 54.34 percent was recorded at nominal with T_8 (54.03). Lowest fruit set percent was resulted in T_1 (Control) At nominal with T_2, T_3, T_4, and T_5 ranging from 48.32 to 49.47 percent. Statistically, all the treatments made a substantial impact on the fruit set percentage of the Guava plants.

In 2023, highest fruit set percent (56.55%) was recorded in treatment T_8, using nano-Zn_2(60ppm) + Cu_1(20ppm). This result was at nominal with treatment T_9 (54.86%) which was substantially higher with treatment T_1. Alternatively, treatment T_1 (Control) recorded the lowest fruit set percent (49.64%) which was at nominal with T_2 (50.93%), T_3 (50.69%), T_4 (51.87%), T_5 (51.71%), and T_6 (51.68%).

Data combined for two years (2022 and 2023) showed that treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] had the maximum fruit set percentage (55.29%). This was at nominal with treatment T_9 (54.60). Instead, treatment T_1 (Control) resulted in the lowest fruit set percentage, measuring 48.93% which is at nominal with treatments T_2 (49.63%), T_3 (49.45%), and T_5 (50.46%). Statistically, all the treatments made a substantial impact on the fruit set percentage of the Guava plants.

Spray of nano-Zn and Cu enhances fruit set % through multiple mechanisms. Nano zinc and copper stimulate flower initiation and development by regulating hormone levels, particularly auxins and cytokinins, which are essential for flower induction and growth. Additionally, these nanoparticles improve pollination efficiency by enhancing floral attractiveness and pollen viability. Moreover, nano materials can mitigate environmental stressors, such as drought and nutrient deficiencies, ensuring optimal conditions for flower fertilization and subsequent fruit set. Overall, nano zinc and copper promote fruit set by optimizing floral development and pollination processes. Similar results were found in the study of Devarpanah *et al*. (2016) the impact of nano-fertilizers containing Zn and B on pomegranate yield and biochemical properties. Spray of low concentrations of nano-B and nano-Zn substantially increased fruit yield, primarily by boosting the number of fruits per tree. The highest doses improved fruit biochemical characters such as maturity index, indicating potential benefits for fruit set percentage.

4.2.22 Fruit retention (%)

Table no. 4.8 provides information about the variation in fruit retention observed throughout the two years of the experiment (2022 and 2023). Data in table 4.8 and figure 4.25 indicates there is a noteworthy effect of nano-micronutrients on fruit retention in Guava at the time of trial.

During 2022, maximum fruit retention percent was in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 56.74 percent was recorded which was substantially higher than treatment T_1. Lowest fruit retention percent was recorded in treatment T_1 (Control) which was 45.60 percent. Statistically, all the treatments made a substantial impact on the fruit retention percentage of the Guava plants.

In 2023, highest fruit retention percent (54.41%) was recorded in treatment T_9, using nano-Zn_2(60ppm) + Cu_2(30ppm). This result was at nominal with treatment T_{10} (53.09%) which was substantially higher with treatment T_1. Instead, treatment T_1 (Control) recorded the lowest fruit retention percent (44.15%).

Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum fruit retention percentage (55.57%). This was at nominal with treatment T_{10} (54.11%). Instead, treatment T_1 (Control) resulted in the lowest fruit retention percentage, measuring 44.87%. Statistically, all the treatments made a substantial impact on the fruit retention percentage of the Guava plants.

Nano zinc and copper foliar application can positively impact fruit retention percentage by improving nutrient uptake, stimulating flower development, and regulating stress responses. These micronutrients play crucial roles in plant physiology, enhancing hormone regulation and enzymatic activities essential for flower fertilization and fruit set. Additionally, nano materials mitigate environmental stresses, reducing premature fruit drop. By optimizing physiological processes and enhancing stress tolerance, nano zinc and copper help maintain fruit attachment, leading to higher fruit retention percentages. It was also studied by Sachin *et al.* (2019) they demonstrated that foliar application of micronutrients, particularly zinc sulfate, borax, and copper sulfate in treatment T8, substantially improved fruit retention percentage in guava plants. Compared to the control (T1), T8 exhibited the highest fruit retention percentage (63.20%), indicating the effectiveness of micronutrient supplementation in enhancing fruit retention and reducing fruit drop in guava cultivation. A similar study was conducted on pistachio crops, which found that the highest final fruit set percentage occurred with a combination of iron (Fe) and copper (Cu). The combination of Cu and Fe also resulted in the highest splitting rate, while the control group exhibited the lowest splitting rate (Soliemanzadeh *et al.,* 2013).

4.2.23 Fruit drop (%)

Table no. 4.8 provides information about the variation in fruit drop observed throughout the two years of the experiment (2022 and 2023). A keen perusal of the data indicates there is a substantial effect of nano-micronutrients on fruit drop in Guava at the time of trials and it represented in table no.4.8 and graphically represented in figure no. 4.26.

In 2022, the more fruit drop percent was in treatment T_1 (Control) where 54.40 percent was recorded which was substantially higher than treatment T_9. The minimum fruit drop percent was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 43.26 percent. Statistically, all the treatments made a substantial impact on the fruit drop percentage of the Guava plants.

In 2023, more fruit drop percent (55.85%) was resulted in T_1 (Control), which was substantially maximum with T_9. Instead, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] recorded the minimum fruit drop percent (45.59%) at nominal with T_{10} (45.91).

Data combined for two years (2022 and 2023) showed that treatment T_1 (Control) had the maximum fruit drop percentage (55.13%) that was substantially higher than treatment T_9. Instead, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the lowest fruit drop percentage, measuring 44.43% which is at nominal with treatment T_{10} (45.89%). Statistically, all the treatments made a substantial impact on the fruit drop percentage of the Guava plants.

Nano zinc and copper foliar application can mitigate fruit drop percentage by improving plant health and stress tolerance. These micronutrients play vital roles in enzymatic activities and hormone regulation, essential for flower and fruit development. Nano materials enhance nutrient uptake, ensuring adequate nourishment for fruit retention. Moreover, they regulate stress responses, reducing the impact of environmental stresses like drought or nutrient deficiencies, known contributors to premature fruit drop. By optimizing physiological processes and bolstering plant resilience, nano zinc and copper help maintain fruit attachment, resulting in lower fruit drop percentages.

It also confirmed by Patel *et al*. (2020) in their study highlighted substantial variations in guava growth, yield, and quality. Treatment T_9, incorporating $ZnSO_4$ and boric acid, exhibited superior plant parameters and fruit quality attributes, resulting in decreased fruit drop percentage compared to the control group. The findings underscore the effectiveness of micronutrient combinations in reducing fruit drop and enhancing overall guava sensory qualities, indicating the potential for improved fruit retention and maturity. Results are related to Sachin *et al*. (2019) on guava reproductive parameters revealed treatment T_8, comprising zinc sulfate, borax, and copper sulfate, as highly effective in reducing fruit drop percentage. Despite T_1 (control) having the shortest time to fruit maturity, T_8 exhibited the lowest fruit drop % (36.8%) and quickest time to eatable (116.33 days). These findings underscore the potential of micronutrient foliar application, particularly T_8, in mitigating fruit drop and optimizing guava fruit retention during the maturation process.

Table no. 4.8: Effect of nano-Zn and nano-Cu on fruit set %, fruit retention %, and fruit drop % of guava.

Treatments	Fruit set (%)			Fruit retention (%)			Fruit drop (%)		
	2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_1	48.22±0.27^{a}	49.64±0.22^{a}	48.93±o.24^{a}	45.60±0.33^{a}	44.15±1.4^{a}	44.87±0.90^{a}	54.40±0.33^{g}	55.85±1.47^{e}	55.13±0.90^{g}
T_2	48.32 ±0.28^{a}	50.93±1.1^{ab}	49.63±0.68^{ab}	50.33±0.18^{b}	47.48±1.4^{b}	48.90±0.67^{b}	49.67±0.18^{f}	52.52±1.42^{d}	51.10±0.67^{f}
T_3	48.210.14 ^{a}	50.69±0.48^{ab}	49.45±0.24 ^{ab}	52.52±0.26^{c}	49.11±0.60^{bc}	50.82±0.31^{cd}	47.48±0.26^{e}	50.89±0.60^{cd}	49.18±0.31^{de}
T_4	49.47 ±0.71^{ab}	51.87±0.50^{ab}	50.67±0.20^{bcd}	52.00±0.30^{c}	48.87±1.1^{bc}	50.43±0.70^{bc}	48.00±0.30^{e}	51.13±1.16^{cd}	49.57±0.70^{ef}
T_5	49.22±0.23 ^{ab}	51.71±1.35^{ab}	50.46±0.77^{abc}	52.25±0.18^{c}	49.31±1.4^{bc}	50.78±0.70^{cd}	47.75±0.18^{e}	50.69±1.43^{cd}	49.22±0.70^{de}
T_6	50.29±0.64^{bc}	51.68±0.70^{ab}	50.98±0.67^{bcd}	53.42±0.15^{d}	50.39±0.07^{bcd}	51.90±0.05^{cde}	46.58±0.15^{d}	49.61±0.07^{bcd}	48.10±0.05^{cde}
T_7	51.03±0.23^{c}	52.68±0.36^{bc}	51.86±0.20^{cd}	54.30±0.40^{e}	50.89±0.67^{cd}	52.59±0.53^{ef}	45.70±0.40^{c}	49.11±0.676^{bc}	47.41±0.53^{bc}
T_8	54.03±0.45^{d}	56.55±0.80^{d}	55.29±0.61^{e}	54.41±0.09^{ef}	50.38±0.21^{bcd}	52.39±0.06^{de}	45.59±0.09^{bc}	49.62±0.21^{bcd}	47.61±0.06^{cd}
T_9	54.340.47^{d}	54.86±0.39^{cd}	54.60±0.41^{e}	56.74±0.10^{g}	54.41±0.58^{e}	55.57±0.24^{g}	43.26±0.10^{a}	45.59±0.58^{a}	44.43±0.24^{a}
T_{10}	51.58±0.56^{c}	52.72±0.63^{bc}	52.15±0.42^{d}	55.14±0.37^{f}	53.09±0.48^{de}	54.11±0.19^{fg}	44.86±0.37^{b}	46.91±0.48^{ab}	45.89±0.19^{ab}
S. Em (±)	0.41	0.40	0.39	0.54	0.55	0.53	0.54	0.55	0.53

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(nano-Cu_1(20ppm)], T_5 [nano-Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ nano-Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ nano-Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ nano-Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ nano-Cu_2(30ppm)], T_{10} [$ZnSO_4$]

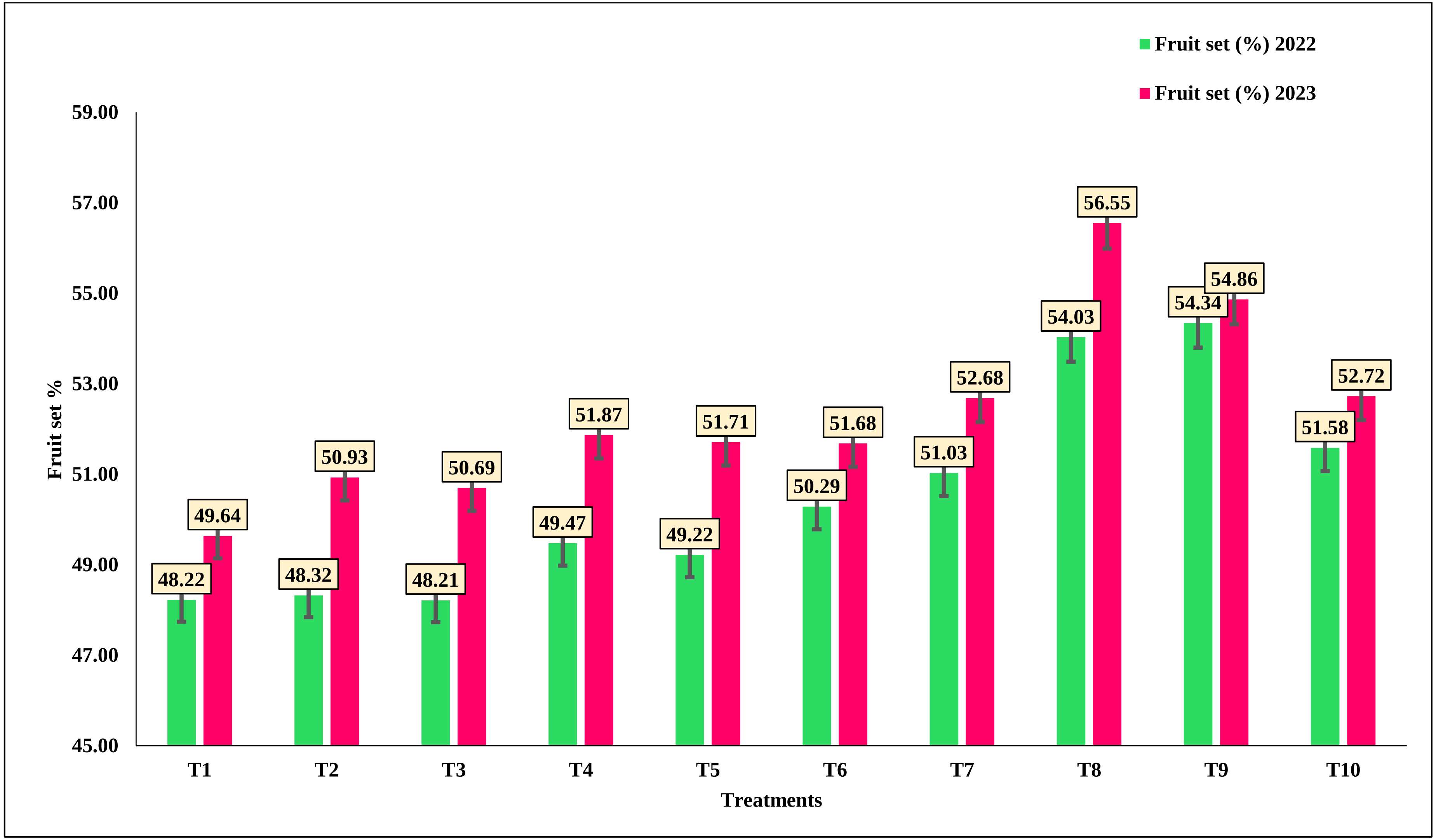

Fig. 4.23: Effect of nano-Zn and nano-Cu on fruit set % in guava

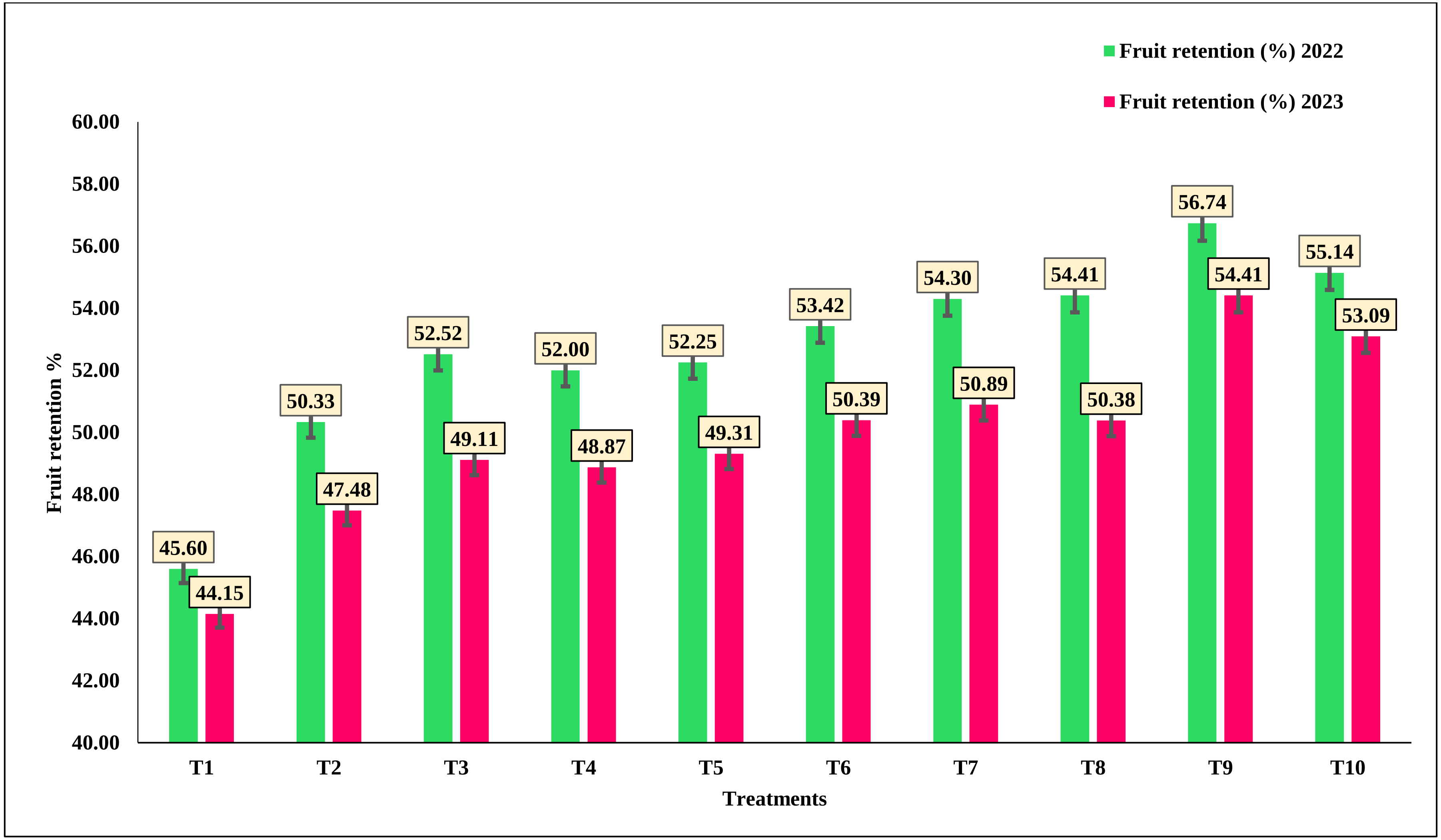

Fig. 4.24: Effect of nano-Zn and nano-Cu on fruit retention % in guava

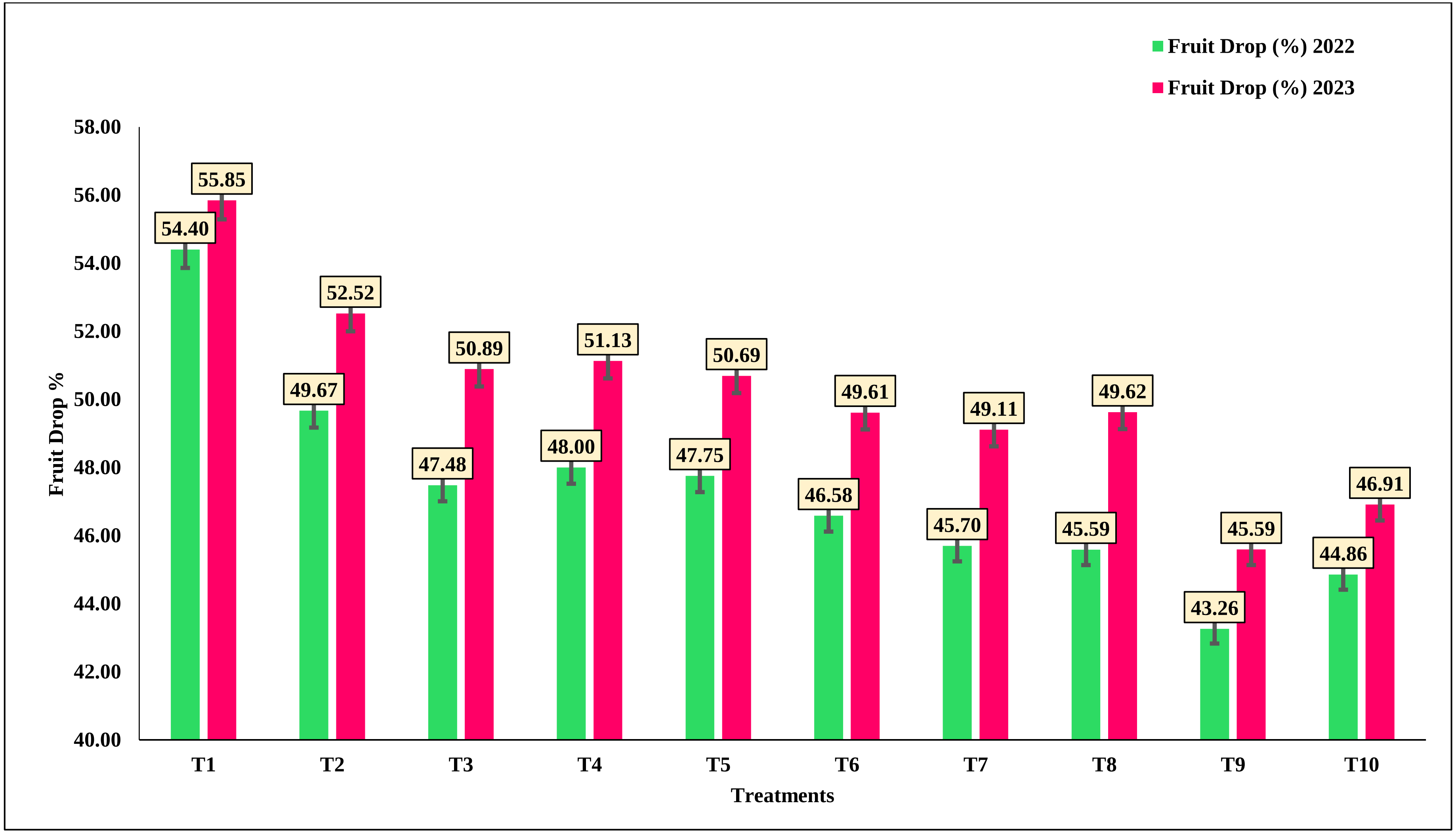

Fig. 4.25: Effect of nano-Zn and nano-Cu on fruit Drop % in guava

4.3 Yield parameters

4.3.1 No. of fruits/plant

A detailed analysis of the both experimental years data shown in table no. 4.9 and graphically presented in figure no. 4.27 reveals a substantial impact of various nano-micronutrient treatments on the no. of fruit/plant of the guava during experimental trials.

In 2022, T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] recorded with highest number of fruits/plant of 173.00 which is substantially higher with treatment T_1. Lowest number of fruits per plant (412.67) was resulted in treatment T_1 (Control).

In 2023, the same trend followed, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the more no. of fruits per plant, which was 176.72 which was meaningfully higher than T_1. Rest of the treatments showed substantial differences in no. of fruits per plant. Treatment T_1 resulted the lowest no. of fruit/plant of 144.83.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum number of fruits per plant, with a value of 143.75 which was substantial maximum than treatment T_1. Instead, the treatment T_1 (Control) observed with the lowest number of fruits per plant, measuring 143.75.

Foliar application of nano zinc and copper can positively impact the no. of fruits per plant by enhancing various physiological processes. Nano materials stimulate flower initiation and development, leading to increased flower production and subsequent fruit set. Additionally, they improve nutrient uptake and transport within the plant, ensuring adequate nourishment for fruit development and maturation. Nano zinc and copper also regulate hormone levels, optimize pollination efficiency, and mitigate environmental stresses, all of which contribute to higher fruit yields. By optimizing plant health and productivity, nano zinc and copper applications have the potential to substantially increase the number of fruits per plant in agricultural settings. It also confirmed by El-Hak El *et al*. (2019) found that foliar spraying of nano-zinc on flame seedless grapevines substantially affected fruit yield. Treatment with 0.4 ppm nano-zinc notably increased the number of clusters, cluster weight, and overall yield compared to the control. Moreover, nano-zinc application conserved zinc fertilizer usage while enhancing vegetative characteristics. Their study suggests that spraying grapevines with 0.4 ppm nano-zinc optimizes fruit yield, indicating the potential of nano-zinc in grape production.

Foliar spray with gibberellic acid (GA_3) at 25 and 50 mg L^{-1}, copper sulfate ($CuSO_4$) at 25 mg L^{-1} alone or in combination on yield, fruit quality, fruit seed number and shelf life. The obtained results showed that the combination between gibberellic acid (GA3) and copper sulfate ($CuSO_4$) treatment reduced the seed number per fruit ranged (4.66-7) and improved yield and fruit quality such as markedly increase in fruit weight, volume, SSC/acid ratio and ascorbic acid. Simultaneously, it reduced the weight loss % and decay loss % during shelf life in comparison to other treatments and control (Kheder *et al.,*2019).

4.3.2 Fruit weight (g)

Table no. 4.9 presents the data on the variation in fruit weight during the two-year experiment (2022 and 2023). A detailed analysis of the data reveals a substantial impact of various nano-micronutrient treatments on the weight of Guava fruit during both years of the experiment presented in table no. 4.9 and figure 4.28.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] recorded with highest fruit weight of 174.68 g which was substantially higher with treatment T_1. Minimum fruit weight (145.67 g) was recorded in T_1 (Control). Conversely, treatment T_1 (Control) recorded the lowest fruit weight of 145.67 g.

In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum fruit weight, which was 175.15 g which was substantially maximum than T_1. Rest treatments showed substantial differences in fruit weight. Treatment T_1 (Control) recorded the lowest fruit weight of 145.88 g.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum fruit weight, with a value of 174.92 g which was substantially higher than T_1. Instead, the treatment T_1 (Control) was observed with the lowest fruit weight, measuring 145.78 g.

Nano zinc and copper work on fruit weight by enhancing various physiological processes crucial for fruit development. These nanoparticles stimulate flower initiation and improve pollination efficiency, ensuring a higher number of healthy fruits. They also optimize nutrient uptake and transport within the plant, providing essential nutrients necessary for fruit growth and enlargement. Similar, study found in Patel *et al*. (2020) that combining micronutrients, particularly $ZnSO_4$ and boric acid in T_9, substantially increased fruit weight in guava plants compared to the control group. Similarly, Khasi Mandarin (*Citrus reticulata* Blanco) gives maximum fruit weight with application of Zn + Mn + B (Zoremtluangi *et al.,*2019).

4.3.3 Fruit volume (cc)

Table no. 4.9 showcases the data encompassing the fluctuations in fruit volume observed during the two-year experiment (2022 and 2023). An examination of the data indicates that there was a substantial effect of nano-micronutrient treatments on the overall fruit volume of Guava throughout both experimental years its graphically representation in figure no. 4.29.

In an experiment performed in 2022, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] exhibited the maximum fruit volume (169.67 cc) which was substantially different from treatment T_1. In contrast, the treatment T_1 (Control) resulted in the minimum fruit volume, measuring 143.00cc.

During the experimental year of 2023, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum fruit volume of 173.07cc which was substantially different from treatment T_1. Conversely, the treatment T_1 (Control) had a minimum fruit volume of 144.67cc.

Two years of data recorded maximum fruit volume (171.37cc) under the treatment T_9. Minimum fruit volume (143.83cc) was resulted in T_1.

From both data of the two years (2022 and 2023), the experimental data revealed that the treatments T_9 exhibited the maximum fruit volume, measuring 171.37cc each which was substantially higher than T_1. In contrast, the treatment T_1 (Control) displayed a minimum fruit size of 143.83cc.

The consequence of nano zinc (Zn) and nano copper (Cu) on guava fruit volume through foliar application can be multifaceted. These nanoparticles may enhance nutrient uptake, hormonal regulation, and stress tolerance, ultimately impacting fruit development and size. Nano Zn and Cu can potentially stimulate cell division and elongation, leading to larger fruit volume. It also confirmed by Meena *et al*. (2020) observed a substantial and positive correlation between zinc (Zn) and iron (Fe) concentrations in guava leaves and various fruit attributes, including fruit volume. Higher Zn and Fe levels were associated with increased fruit volume. Conversely, specific gravity, acidity, seed-related parameters showed negative correlations with Zn and Fe contents in guava leaves. Similarly, Zinc deficiency in pistachio tree decreased the nut size and number of fruits on the cluster, foliar application of zinc sulfate (600 mg L^{-1}) in Date palm increased fruit size compared with control (Soliemanzadeh *et el.,*2013).

Table no. 4.9: Effect of nano-Zn and nano-Cu on number of fruits/plant, fruit weight (g), fruit volume (cc) of guava.

	No. of fruits/Plant			Fruit weight (g)			Fruit volume(cc)		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_1	142.67±1.01^{a}	144.83±0.5^{a}	143.75±0.8^{a}	145.67±0.8^{a}	145.88±0.8^{a}	145.78±0.8^{a}	143.00±0.5^{a}	144.67±0.6^{a}	143.83±0.6^{a}
T_2	150.00±1.4^{b}	152.57±1.4^{b}	151.28±1.4^{b}	161.45±0.2^{c}	161.74±0.2^{c}	161.59±0.2^{c}	152.00±1.1^{c}	154.47±1.4^{c}	153.23±1.2^{c}
T_3	152.83±0.9^{bc}	154.85±1.0^{bc}	153.84±0.9^{bc}	164.28±0.08^{e}	164.59±0.1^{e}	164.43±0.1^{e}	156.33±1.2^{d}	158.33±0.8^{d}	157.33±1.0^{d}
T_4	151.17±1.9^{b}	153.33±2.1^{b}	152.25±2.0^{b}	161.57±0.3^{c}	161.86±0.3^{cd}	161.72±0.3^{cd}	150.00±0.5^{bc}	152.33±0.6^{bc}	151.17±0.6^{bc}
T_5	152.00±3.0^{bc}	154.18±3.3^{b}	153.09±3.0^{b}	160.37±0.2^{b}	160.65±0.2^{b}	160.51±0.2^{b}	147.00±1.0^{b}	149.03±1.5^{b}	148.02±1.2^{b}
T_6	159.67±1.1^{d}	162.22±1.1^{d}	160.94±1.1^{d}	162.64±0.1^{d}	162.91±0.1^{d}	162.77±0.1^{d}	160.00±1.5^{e}	162.80±1.8^{e}	161.40±1.6^{e}
T_7	156.33±0.4^{cd}	159.130±0.8^{cd}	157.73±0.5^{cd}	162.49±0.1^{cd}	162.72±0.1^{cd}	162.60±0.1^{b}	155.33±0.8^{d}	158.00±1.0^{d}	156.67±0.9^{d}
T_8	167.50±1.0^{e}	170.20±1.2^{e}	168.85±0.9^{e}	169.37±0.2^{f}	169.72±0.2^{f}	169.54±0.2^{f}	165.67±1.2^{f}	169.00±1.0^{f}	167.33±1.0^{f}
T_9	173.00±1.3^{f}	176.72±1.0^{f}	174.86±1.1^{f}	174.68±0.1^{g}	175.15±0.1^{g}	174.92±0.1^{g}	169.67±0.8^{g}	173.07±0.8^{g}	171.37±0.8^{g}
T_{10}	166.83±0.9^{e}	168.98±1.0^{e}	167.91±0.9^{e}	164.26±0.2^{e}	164.65±0.1^{e}	164.46±0.1^{e}	162.33±1.2^{e}	164.27±1.2^{e}	163.30±1.2^{e}
S. Em (±)	1.7	1.7	1.7	1.3	1.3	0.6	1.5	1.5	1.5

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ Cu_2(30ppm)], T_{10} [$ZnSO_4$]

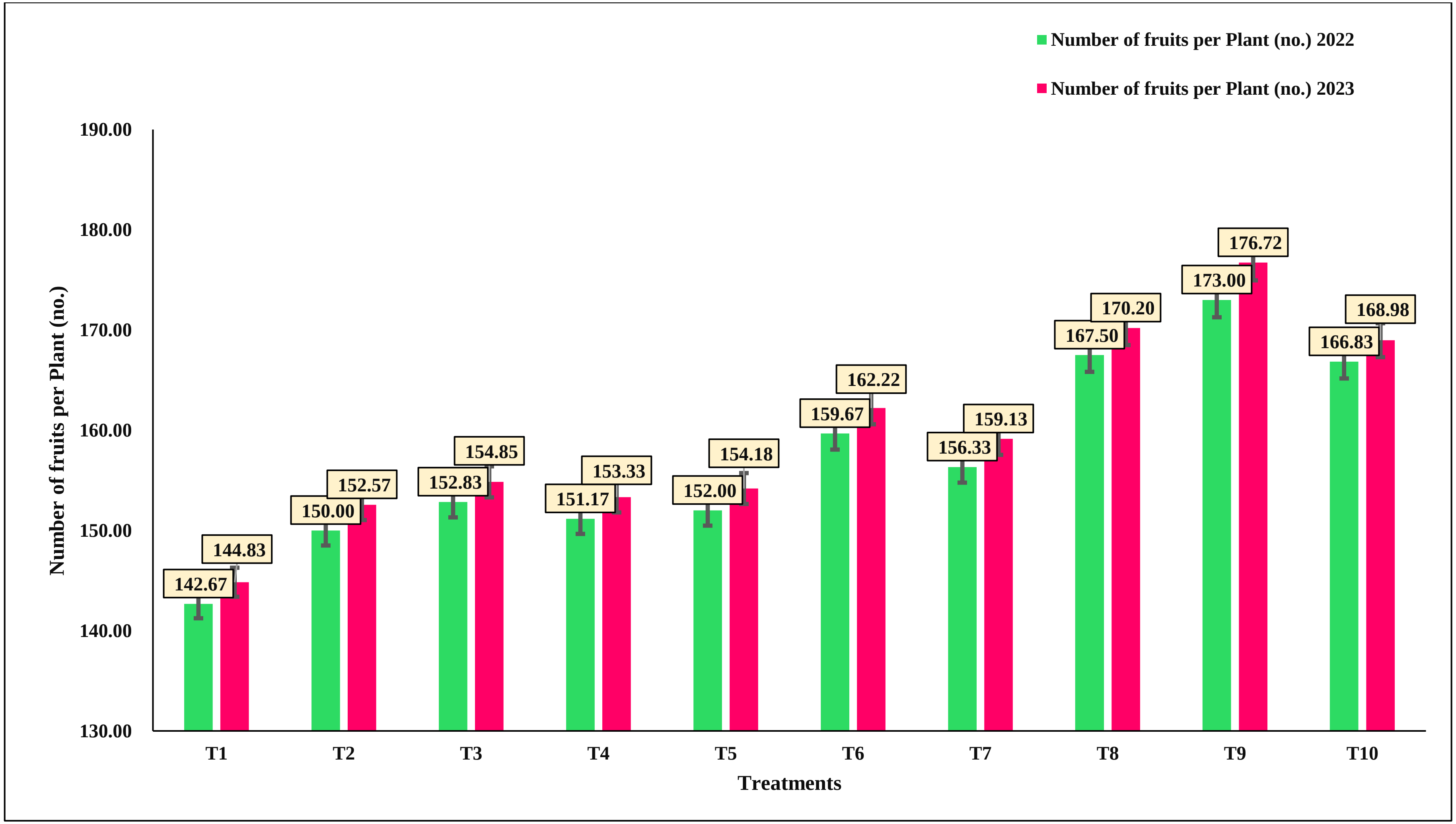

Fig. 4.26: Effect of nano-Zn and nano-Cu on number of fruits per plant (number) in guava

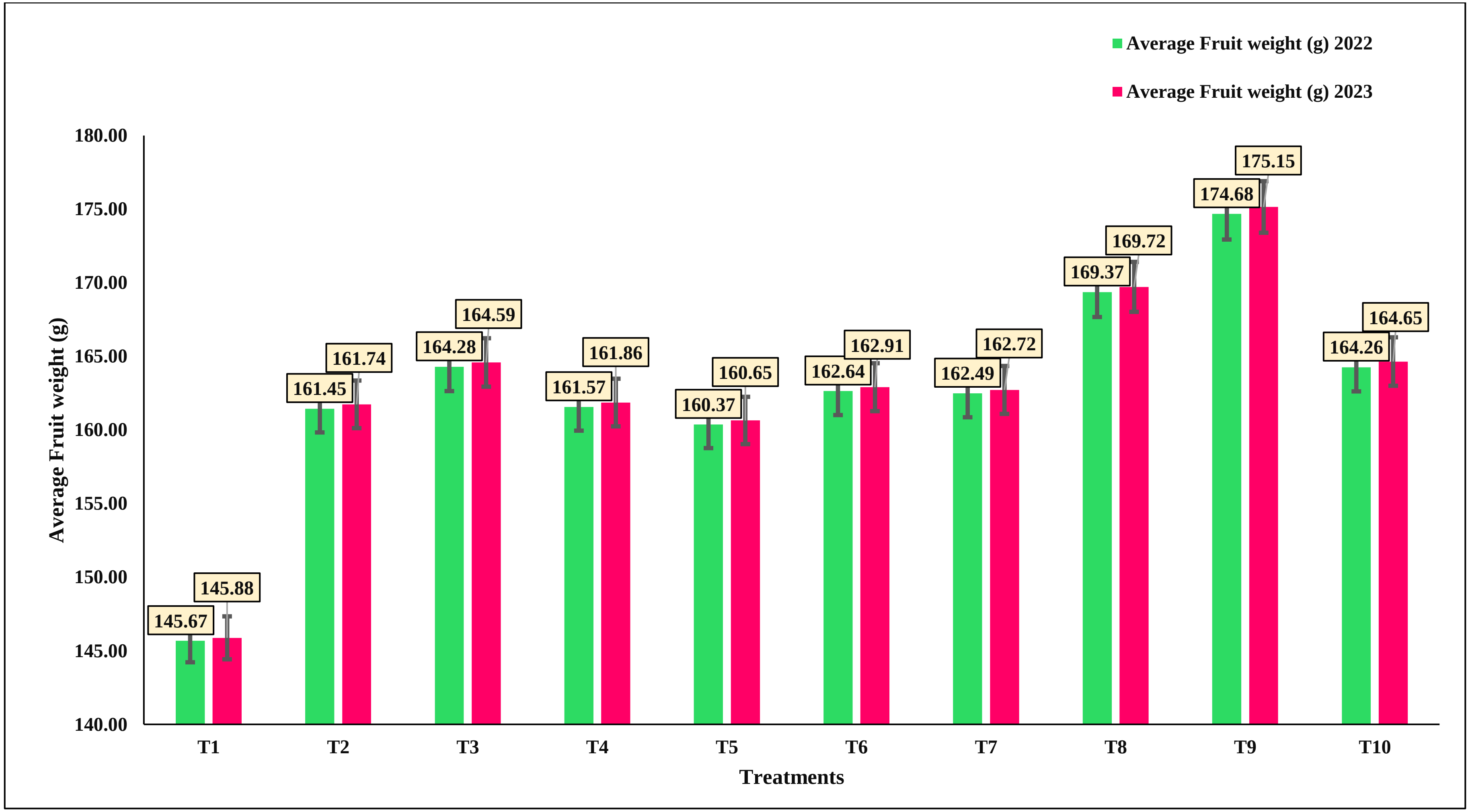

Fig. 4.27: Effect of nano-Zn and nano-Cu on average fruit weight (g) in guava

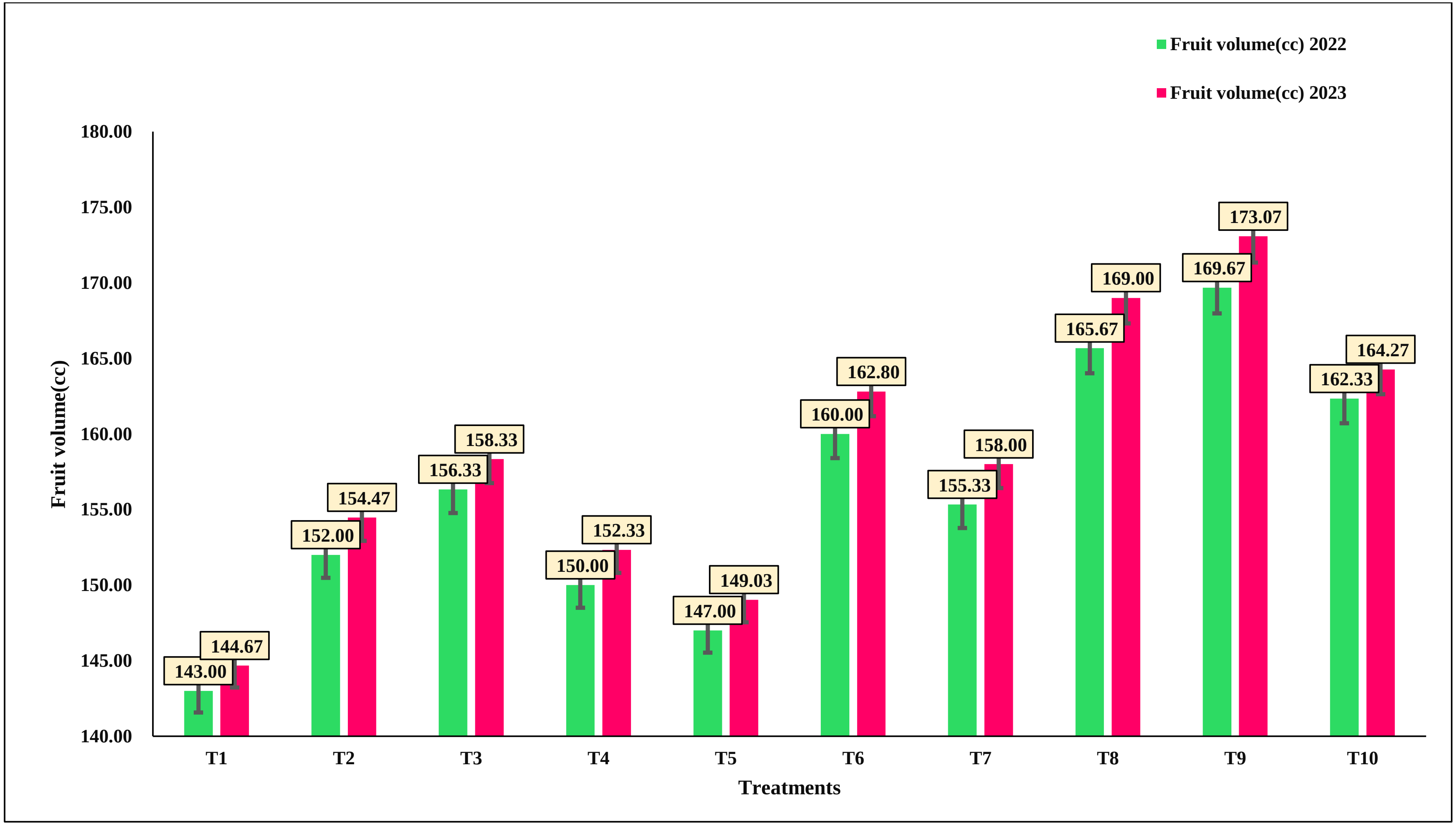

Fig. 4.28: Effect of nano-Zn and nano-Cu on fruit volume in guava

4.3.4 Fruit yield per plant (kg/plant)

Table no. 4.10 presents the data on changes in fruit yield over the two years of the trial (2022 and 2023) together with aggregated data. A keen observation of the data showed that there was a substantial impact of dissimilar nano-micronutrient treatments on the fruit yield of guava during the two years of the trial, graphically represented in figure no. 4.30.

During the first year of the experimentation (2022), the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] produced the maximum fruit yield, with 30.22 kg per plant which was substantial different from rest of the treatments. Instead, T_1 (Control) noted the minimum fruit yield, with 20.78 kg per plant.

In the second-year trial (2023), the fruit yield of guava trees followed a similar pattern. The maximum fruit yield of 34.35 kg per tree was observed in treatment T_9, where nano-Zn_2(60ppm) + Cu_2(30ppm) were applied. This was found to be substantial maximum than T_1. Alternatively, the lowest yield of fruit was 23.46 kg per tree in T_1 (Control).

The combined data from the both year trial (2022 and 2023) found the topmost fruit yield per plant was noted 34.35 kg per plant in the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was substantially higher with treatment $T_{1.}$ On the other side the lowest yield found in treatment T_1 (Control) which yielded 22.12 kg per plant.

Spraying nano-zinc and copper on the leaves of guava trees can improve the overall fruit yield. These treatments help with pollen germination, improved the pollen tube, fruit set, and ultimately increase the yield (Qinli, 2003). When copper and zinc are applied together, trees show a maximum no. fruit compared to untreated plants. This could be attributed to better retention on plant, which reduces fruit drop and increases the yield. Aligned results were found by Ismail (1994) who observed increased yield in Valencia oranges through zinc spray. The positive effects of zinc and copper sprays on citrus yield were also confirmed by Perveen and Rehman (2002), who noted that correcting nutrient deficiencies with these micronutrients led to higher citrus yields. However, boron alone did not produce satisfactory results. These findings align with Mishra *et al*. (2003) reported micronutrient can be useful for maximizing yield in Kinnow mandarins compared to untreated trees. Tariq *et al*. (2007) observed a positive link between Zn and B, which increased fruit set, lowered fruit drop, and ultimately led to higher yield in sweet oranges. Results of Razzaq *et al*. (2013) and Ullah *et al*. (2012) in guava, They spray of nano-zinc and copper, respectively, substantially increased the fruit yield.

It also confirmed by Giram *et al*. (2021), treatment T_{11}, comprising zinc sulfate, boron, copper sulfate, and magnesium sulfate, exhibited the maximum yield per tree (19.80 kg) and yield per ha (219.40 q/ha), highlighting the efficacy of micronutrient combinations in enhancing guava yield.

4.3.4 Yield per hectare (kg/ha computed)

Table no. 4.10 provides information about the variation in fruit yield per hectare observed throughout the two years of the experiment (2022 and 2023). A keen perusal of the data indicates there is a substantial effect of nano-micronutrients on fruit yield/hectare in guava during the experimental trials as shown in figure no. 4.31.

During 2022, the highest fruit yield/hectare was in T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 8371.17 kg per hectare was recorded, this is substantially maximum than treatment T_1. The lowermost yield/hectare was resulted in T_1 which was 5757.11 kg per hectare. Statistically, all the treatments made a substantial impact on the fruit yield per hectare of the guava plants.

In 2023, The maximum fruit yield/hectare (9515.57 kg/ha) was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)], which was substantially higher with treatment T_1. Conversely, treatment T_1 (Control) recorded the minimum fruit yield per hectare (6498 kg/ha).

Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum fruit yield per hectare (8943.37 kg/ha) that was substantially higher than treatment T_1. Instead, treatment T_1 (Control) resulted in the lowest fruit yield per hectare, measuring 6128.03 kg/ha. Statistically, all the treatments made a substantial impact on the fruit yield per hectare of the guava plants.

Foliar application of nano zinc (Zn) and copper (Cu) may enhance guava yield per hectare by optimizing physiological processes related to fruit development and yield. These nanoparticles potentially stimulate plant growth, leading to increased fruit production. Similar studied confirmed by Hernández *et al*. (2022) that foliar application of copper nanoparticles (NPs Cu) positively affected melon fruit weight and quality attributes. Optimal fruit weight and diameter were observed at higher Cu NP concentrations. The study suggests Cu NP usage as a potential strategy to improve melon yield per hectare and address copper deficiencies in diets. Similarly, the concentration with the best effect on the growth and yield of chili plants was 3ml/L copper nanoparticles, which increased the pod number (24.1%), pod length (17.5%), pod diameter (18.4%), single pod weight (16.9%) and the yield per hectare (45.7%) over control (Uddin *et al.,*2022).

Table no. 4.10: Effect of nano-Zn and nano-Cu on fruit yield per plant (kg), yield per hectare (kg/ha computed) of guava.

	Fruit yield per plant (kg)			Yield per hectare (q/ha computed)		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_1	20.78±0.2^{a}	23.46±0.4^{a}	22.12±0.1^{a}	5757.11±65.1^{a}	6,498.96±78.1^{a}	6,128.03±0.1^{a}
T_2	24.22±0.2^{b}	27.14±0.7^{bc}	25.68±0.3^{b}	6707.99±60.3^{b}	7,518.46±120.4^{bc}	7,113.23±0.3^{b}
T_3	25.11±0.1^{cd}	27.49±1.2^{bc}	26.30±0.4^{bc}	6954.87±40.2^{cd}	7,613.60±193.6^{bc}	7,284.24±0.4^{bc}
T_4	24.42±0.2^{bc}	27.48±0.9^{bc}	25.95±0.4^{bc}	6765.04±75.0^{bc}	7,613.13±149.5^{bc}	7,189.08±0.4^{bc}
T_5	24.38±0.5^{bc}	26.80±1.8^{b}	25.59±0.7^{b}	6752.77±145.9^{bc}	7,424.71±302.1^{b}	7,088.74±0.7^{b}
T_6	25.97±0.2^{e}	29.23±0.2^{d}	27.60±0.1^{de}	7193.27±60.3^{e}	8,095.74±37.5^{d}	7,644.51±0.1^{de}
T_7	25.40±0.06^{de}	28.56±0.6^{cd}	26.98±0.2^{cd}	7036.43±18.2^{de}	7,911.33±106.3^{cd}	7,473.88±0.2^{cd}
T_8	28.37±0.1^{g}	31.09±0.8^{e}	29.73±0.2^{f}	7858.09±36.4^{g}	8,610.79±135.1^{e}	8,234.44±0.2^{f}
T_9	30.22±0.2^{h}	34.35±0.3^{f}	32.29±0.2^{g}	8371.17±72.8^{h}	9,515.57±48.4^{f}	8,943.37±0.2^{g}
T_{10}	27.40±0.1^{f}	29.76±0.2^{de}	28.58±0.1^{e}	7591.09±48.3^{f}	8,242.48±32.9^{de}	7,916.79±0.1^{e}
S. Em (±)	0.4	2.8	0.4	128.0	146.0	0.4

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(nano-Cu_1(20ppm)], T_5 [nano-Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ nano-Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ nano-Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ nano-Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ nano-Cu_2(30ppm)], T_{10} [$ZnSO_4$]

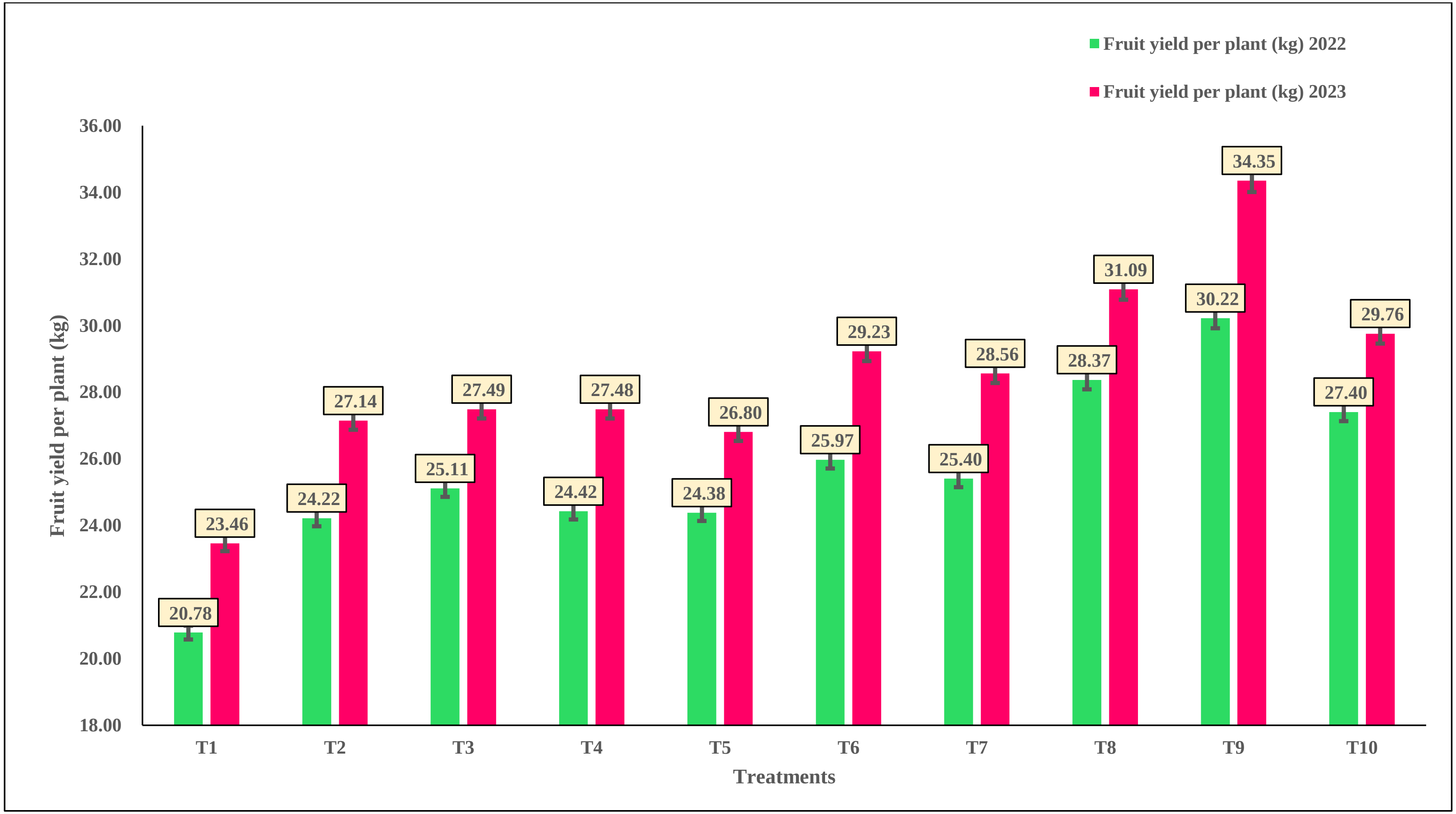

Fig. 4.29: Effect of nano-Zn and nano-Cu on fruit yield per plant (kg) in guava

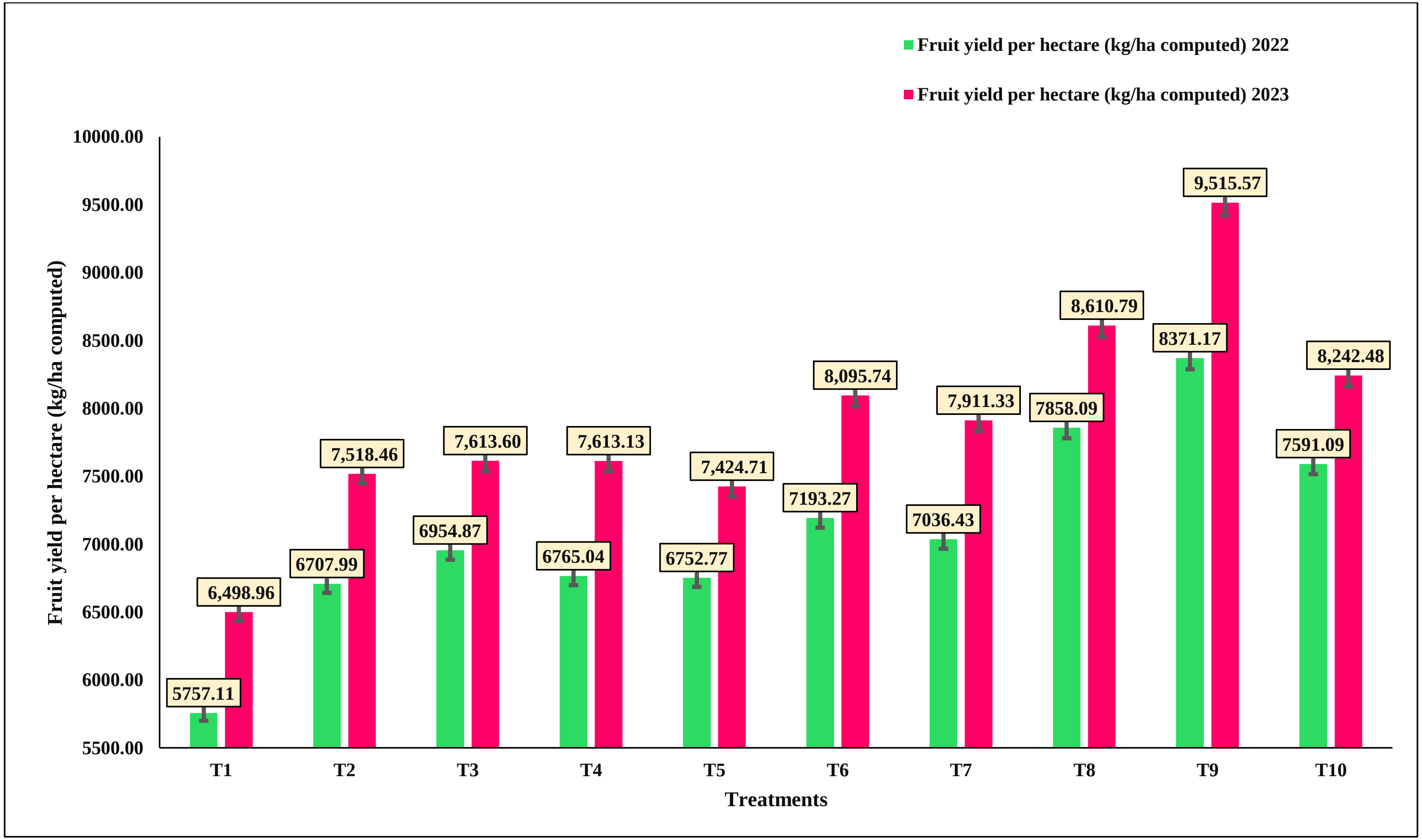

Fig. 4.30: Effect of nano-Zn and nano-Cu on fruit yield per hectare (kg/ha computed) in guava

4.4 Leaf nutrient status in guava

The findings of the study demonstrated a substantial enhancement in the levels of nitrogen (N), phosphorus (P), and potassium (K) in the leaves of the plants through the application of nano-Zn (zinc) and Cu (copper) via foliar spraying. Increase in essential macro-nutrients can be attributed to a synergistic interaction among N, P, and K with B and Zn. Previous research has documented the favorable impact of B and Zn on the mineral composition of leaves in mandarins, as well as 'Valencia' orange (Razzaq *et al*., 2013; Ullah *et al*., 2012). Likewise, studies indicated that spray of Zinc, and in conjunction with K, can elevate the concentrations of N, P, Zn, and K in the leaves of 'Washington Navel' orange trees (Omaima and ElMetwally, 2007). The increase in concentrations of Zn and B in the trees suggests the advantages of exogenously spray of boron and zinc to enhance tree health and nutrition.

4.4.1 Boron content in leaves (ppm)

Table no. 4.11 shows the data of boron in leaves during the two years of the experiment (2022 and 2023) along with the pooled data its graphical representation given in the figure no. 4.32.

In 2022, treatment T_1 (Control) exhibited the maximum boron content in leaves, measured 67.85 ppm, this value at nominal with T_3, T_6, and T_8 and maximum than remaining treatments. Conversely, T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] showed the lowest boron content in leaves, measuring 35.80 ppm at nominal with T_2 measuring 34.24 ppm.

Similar observations were made during the second year of experimentation (2023), where treatment T_1 (Control) demonstrated the maximum boron content in leaves, measuring 70.50 ppm at nominal with T_3, and these was substantial higher than all the other treatments. Whereas, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] recorded the minimum boron content in leaves, measuring 41.87 ppm at nominal value with T_2, at the value 40.98 ppm.

Pooled data for the two years also registered similar trend for boron content in leaves. Maximum boron in leaves (69.18 ppm) was recorded under the treatment T_1 (Control). Lowest boron content in leaves (37.61 ppm) was recorded in treatment T_2 (nano-Zn(60ppm)) at nominal value with T_9 that was 38.84 ppm.

4.4.2 Zinc content in leaves (ppm)

Table no. 4.11 presents the data on zinc content in leaves throughout the two-year experiment (2022 and 2023), along with the pooled data and its graphical represented in figure no. 4.33.

In 2022, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] showed the maximum zinc content in leaves (90.90 ppm), it was substantial higher with other treatments. Hence, the treatment T_1 (Control) noted the lowermost zinc content in leaves, measuring 16.35 ppm at nominal value with T_4 and T_5 the values were 17.54 and 16.71 ppm respectively.

During the subsequent year (2023) of the experiment, similar pattern was observed regarding the zinc content in leaves among the treatments. Treatment T_9, involving the application of nano-Zn_2(60ppm) + Cu_2(30ppm), displayed the maximum zinc content in leaves, measuring 28.50 ppm at nominal with T_8 and T_{10} the values were 27.98 and 27.40 ppm respectively, this was substantially maximum than rest of the treatments. Alternatively, T_1 registered the lowest zinc content in leaves (15.30 ppm) this at nominal then T_5 with a value of 16.04 ppm.

Two-year pooled data (2022 and 2023) further confirmed a similar trend in the zinc content of leaves across the treatments. Treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] demonstrated the superior zinc content in leaves, measuring 59.70 ppm, which was substantially higher with rest of the treatments. Meanwhile, treatment T_1 displayed the minimum zinc content in leaves, measuring 15.83 ppm this was at nominal value with treatment $T_{5,}$ value was 16.38 ppm.

4.4.3 Copper content in leaves (ppm)

Table no. 4.11 presents the data on copper content in leaves throughout the two-year experiment (2022 and 2023), along with the pooled data, graphically presented in figure no.4.34.

In the initial year (2022) of experimentation, the treatment T_5 (Cu_2(30ppm)) showed the maximum copper content in leaves, measuring 13.93 ppm, it was substantially maximum with all the treatments. Conversely, the T_1 (Control) recorded the minimum copper content in leaves, measuring 6.58 ppm this at nominal with $T_{2,}$ T_3 and T_{10} ranging from 7.03 to 7.83 ppm.

During the subsequent year (2023) of the experiment, observation recorded regarding the copper content in leaves among the treatments. Treatment T_9, involving the application of nano-Zn_2(60ppm) + Cu_2(30ppm) displayed the maximum copper content in leaves, measuring 15.53

Table no. 4.11: Effect of nano-Zn and nano-Cu on leaf nutrient content (ppm) Boron, Zinc, and Copper of guava.

Treatments	Leaf nutrient (ppm)								
	B			Zn			Cu		
	2022	2023	Pool	2022	2023	Pool	2022	2023	Pool
T_1	67.85±0.5^{d}	70.50±1.1^{e}	69.18±0.7^{f}	16.35±0.5^{a}	15.30±0.5^{a}	15.83±0.5^{a}	6.58±0.5^{a}	5.81±0.5^{a}	6.20±0.2^{a}
T_2	34.24±0.5^{a}	40.98±1.1^{a}	37.61±0.5^{a}	28.26±0.5^{c}	23.06±0.5^{c}	25.66±0.5^{d}	7.34±0.005^{a}	8.14±0.5^{b}	7.74±0.2^{b}
T_3	66.72±0.5^{d}	67.70±1.1^{de}	67.21±0.5^{e}	30.89±0.5^{e}	26.48±0.5^{d}	29.19±0.2^{ef}	7.03±0.005^{a}	7.76±0.5^{b}	7.40±0.2^{b}
T_4	61.90±0.5^{b}	62.49±1.1^{bc}	62.20±0.7^{bc}	17.54±0.5^{a}	18.09±0.5^{b}	17.82±0.2^{b}	11.59±0.5^{c}	12.10±0.5^{cd}	11.85±0.5^{d}
T_5	64.90±0.5^{c}	62.28±1.1^{bc}	63.59±0.7^{cd}	16.71±0.5^{a}	16.04±0.5^{a}	16.38±0.0^{a}	13.93±0.5^{d}	13.36±0.5^{d}	13.65±0.2^{f}
T_6	67.63±0.5^{d}	60.04±1.1^{b}	63.84±0.5^{cd}	23.59±0.5^{b}	23.82±0.5^{c}	23.71±0.5^{c}	10.3±0.5^{1b}	11.34±0.5^{c}	10.83±0.2^{c}
T_7	60.68±0.5^{b}	64.50±1.1^{cd}	62.59±0.5^{bc}	23.31±0.5^{b}	22.39±0.5^{c}	22.85±0.2^{c}	12.22±0.5^{c}	13.13±0.5^{d}	12.68±0.2^{de}
T_8	66.29±0.5^{cd}	63.50±1.1^{bc}	64.90±0.5^{d}	29.90±0.5^{cd}	27.98±0.5^{de}	28.94^{e}±0.2^{f}	11.92±0.005^{c}	12.72±0.5^{d}	12.32±0.2^{d}
T_9	35.80±0.5^{a}	41.87±1.1^{a}	38.84±0.2^{a}	30.90±0.5^{de}	28.50±0.5^{e}	29.70±0.2^{f}	11.47±0.005^{bc}	15.53±0.5^{e}	13.50±0.2^{e}
T_{10}	61.64±0.5^{b}	60.80±1.1^{bc}	61.22±0.5^{b}	29.25±0.5^{cd}	27.40±0.5^{de}	28.33±0.5^{e}	7.83±0.07^{a}	12.39±0.5^{cd}	10.11±0.3^{c}
S. Em (±)	2.2	1.7	1.9	1.0	0.8	0.9	0.4	0.5	0.4

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(nano-Cu_1(20ppm)], T_5 [nano-Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ nano-Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ nano-Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ nano-Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ nano-Cu_2(30ppm)], T_{10} [$ZnSO_4$]

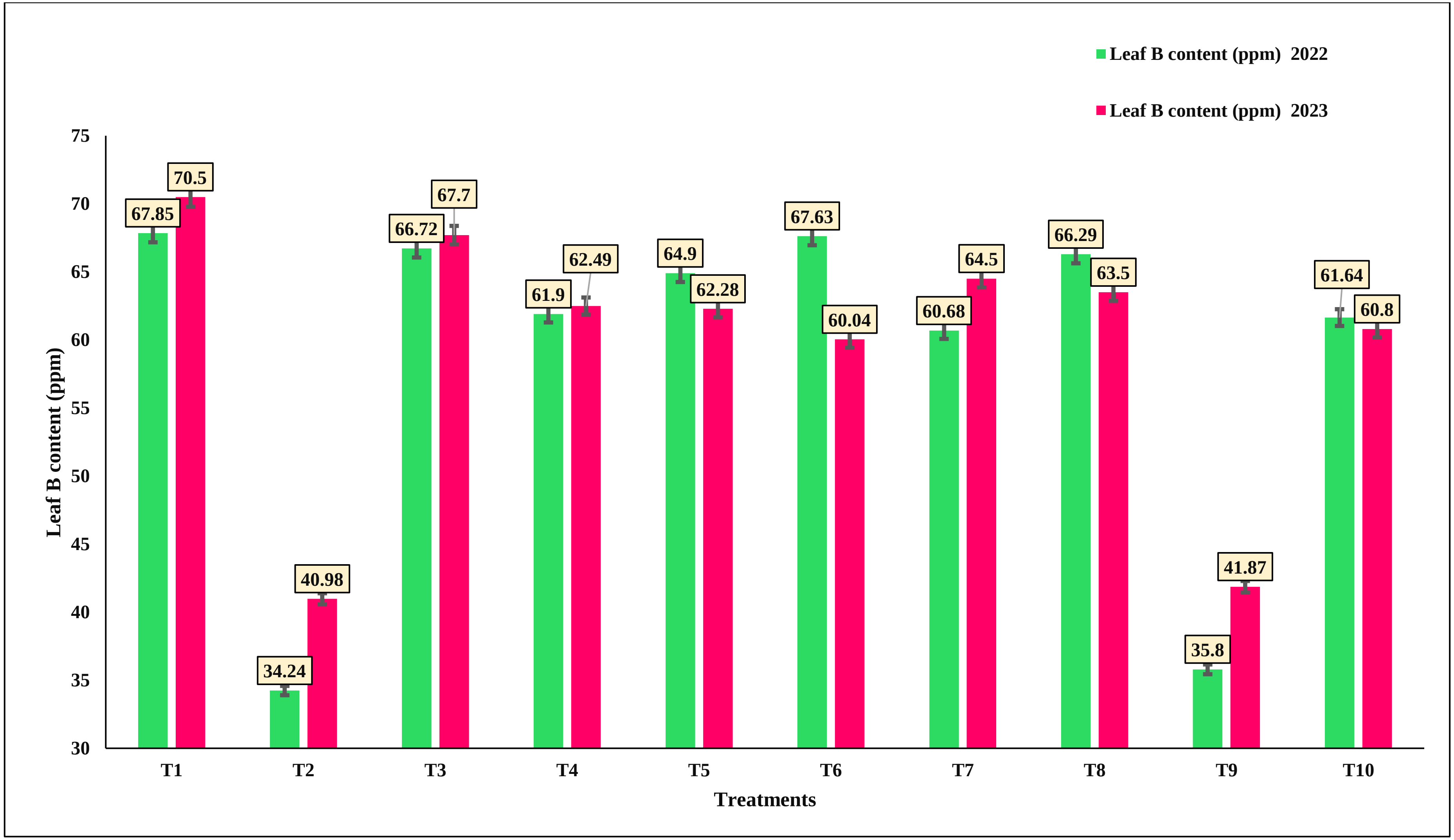

Fig. 4.31: Effect of nano-Zn and nano-Cu on leaf B content (ppm) in guava

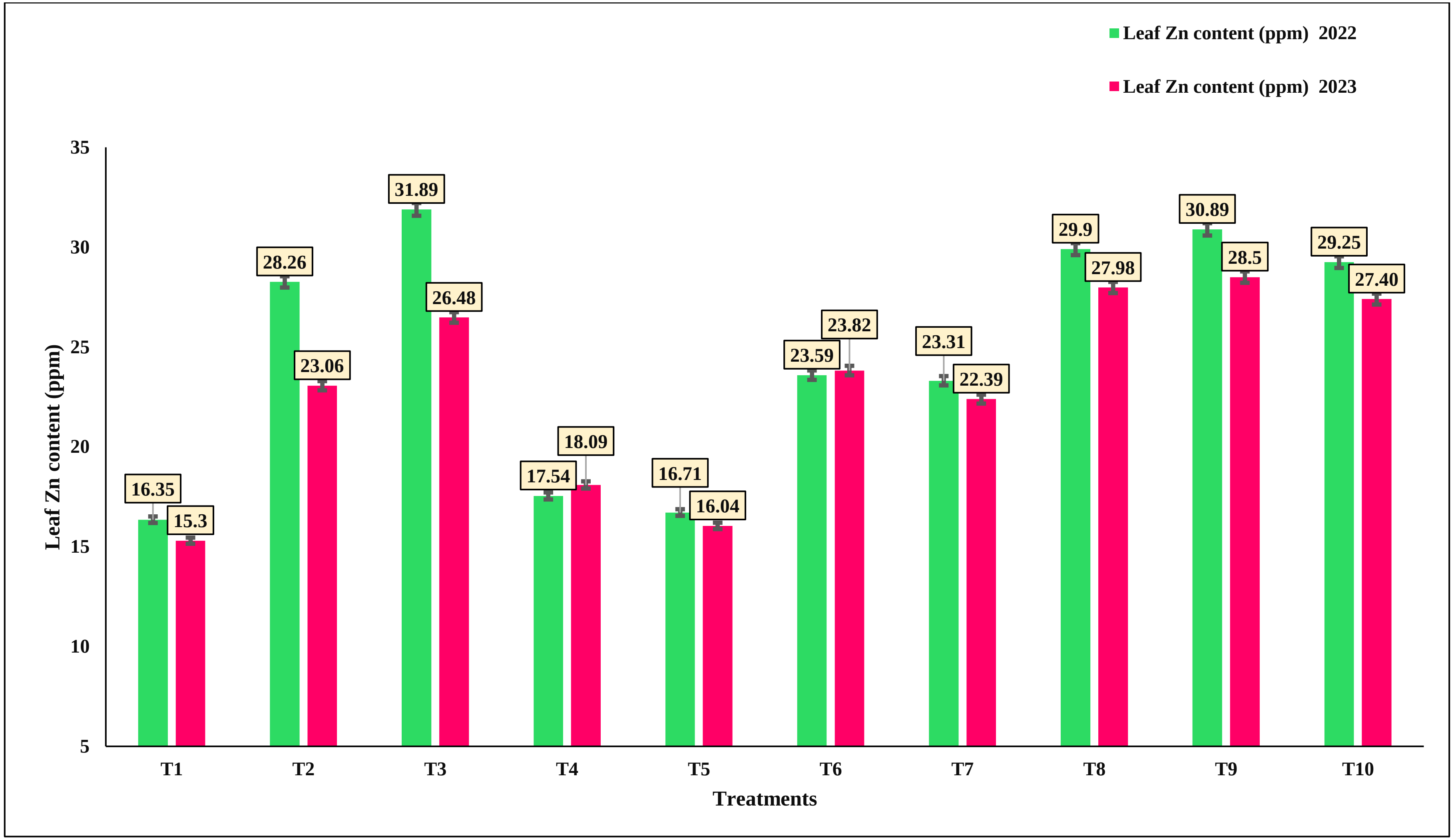

Fig. 4.32: Effect of nano-Zn and nano-Cu on leaf Zn content (ppm) in guava

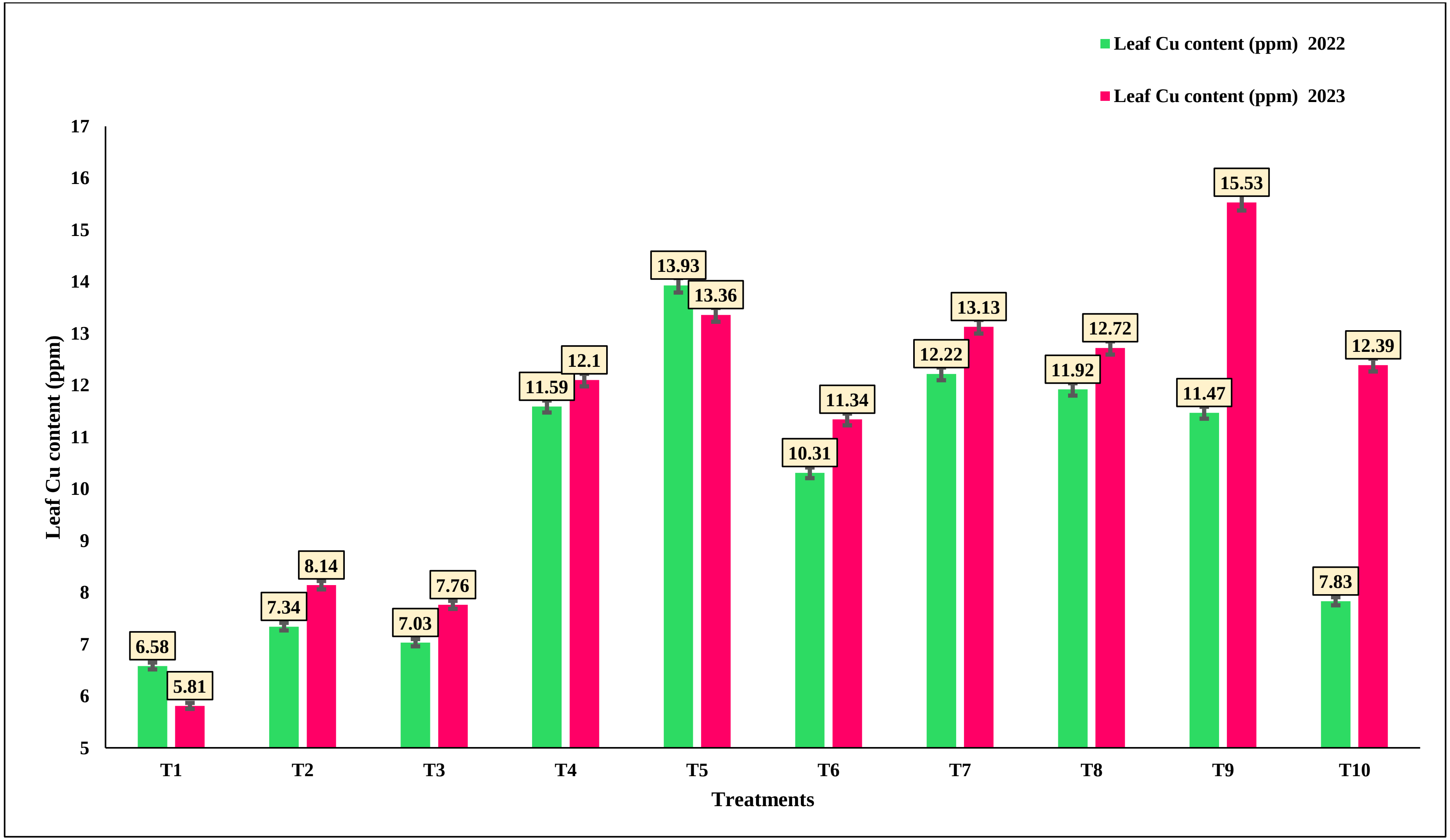

Fig. 4.34: Effect of nano-Zn and nano-Cu on leaf Cu content (ppm) in guava

ppm which was substantially superior than rest the of other treatments. Furthermore, treatment T_1 registered the minimum copper content in leaves, recording 5.81 ppm.

Two-year pooled data (2022 and 2023) observed in the copper content of leaves across the treatments. Treatment T_5 [Cu_2(30ppm)] demonstrated the maximum copper content in leaves, measuring 13.65 ppm, this was substantially maximum with the rest the treatments. Meanwhile, treatment T_1 displayed the minimum copper content in leaves, measuring 6.20 ppm.

4.4.4 Iron content in leaves (ppm)

Table no.4.12 shows the data of Iron in leaves during the two years of the experiment (2022 and 2023) along with the pooled data its graphically representation in figure no.4.35.

In the first year (2022) experimentation, treatment T_1 (Control) exhibited the maximum iron content in leaves, measuring 180.40 ppm, which was substantially maximum than remaining treatments. Conversely, T_{10} [$ZnSO_4$] showed the lowest iron content in leaves, measuring 120.10 ppm.

Similar observations were made during the second year of experimentation (2023), where treatment T_1 (Control) demonstrated the maximum iron content in leaves, measuring 173.50 ppm which was maximum than rest of the treatments. Whereas, T_{10} [$ZnSO_4$] resulted the minimum iron content in leaves, measuring 124.00 ppm at nominal with T_3 and T_8 with a value of 125.00 and 124.90 ppm respectively.

Pooled data for the two years also registered similar trend for iron content in leaves. Maximum iron in leaves (176.95 ppm) was recorded under the treatment T_1 (Control). Lowest boron content in leaves (122.05 ppm) was recorded in treatment T_{10} ($ZnSO_4$).

4.4.5 Calcium content in leaves (ppm)

Table no. 4.12 presents the data on calcium content in leaves throughout the two-year experiment (2022 and 2023), along with the pooled data, graphically presented in figure no.4.36.

In the initial year (2022) of experimentation, the treatment T_2 (nano-Zn_1(40ppm)) showed the maximum calcium content in leaves, measuring 22266.00 ppm, it was substantially superior with rest of the treatments. Hence, the treatment T_1 resulted the lowest calcium content in leaves, measuring 12930.00 ppm.

During the subsequent year (2023) of the experiment, observation recorded regarding the calcium content in leaves among the treatments. Treatment T_2, involving the application of nano-Zn_1(40ppm) displayed the maximum calcium content in leaves, measuring 21890.00 ppm which was substantially maximum than rest of the treatments. Alternatively, treatment T_1 registered the lowest calcium content in leaves, recorded 14720.00 ppm.

Two-year pooled data (2022 and 2023) observed in the calcium content of leaves across the treatments. Treatment T_2 [Cu_1(40ppm)] demonstrated the maximum calcium content in leaves, measuring 22078.00 ppm, it is substantially higher with the rest of treatments. Meanwhile, treatment T_1 displayed the lowest calcium content in leaves, measuring 13825.00 ppm.

4.2.6 Nitrogen content in leaves (ppm)

Table no. 4.12 presents the leaf nitrogen content data over the two-year period of the experiment (2022 and 2023) graphically presented in figure no.4.37.

In the experiment's first year (2022), maximum nitrogen content in leaves was observed in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] with 17000 ppm recorded, it is substantially maximum than rest of the treatments. Lowermost leaf nitrogen content (9100 ppm) was observed in treatment T_1 (Control).

Experiment conducted in 2023, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] once again displayed the maximum leaf nitrogen content (17450.00 ppm). Statistically, it is substantially superior from rest of the treatments. T_1 (Control) discovered the lowermost leaf nitrogen content (10150.00 ppm).

Aggregated data from the two-year experiment (2022 and 2023), showed that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] observed the maximum nitrogen content in leaves (17225.00 ppm). These records substantially different from rest of the treatments. Conversely, T_1 (control) displayed the minimum nitrogen in leaves (9625.00 ppm).

Table no. 4.12: Effect of nano-Zn and nano-Cu on leaf nutrient content (ppm) Iron, Calcium, and Nitrogen of guava.

Treatments	Leaf Nutrient %								
	Fe			Ca			N		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	180.40±0.5^{g}	173.50±0.8^{f}	176.95±0.3^{h}	12930.00±5.7^{a}	14720.00±86.6^{a}	13825.00±40.4^{a}	9100.00±28.8^{a}	10150.00±28.8^{a}	9625.00±14.4^{a}
T_2	132.00±1.1^{e}	139.20±0.8^{e}	135.60±0.5^{f}	22266.00±28.8^{f}	21890.00±86.6^{i}	22078.00±28.8^{f}	14000.00±57.7^{e}	14640.00±57.7^{cd}	14320.00±28.8^{d}
T_3	122.50±0.5^{b}	125.00±0.8^{ab}	123.75±0.3^{b}	17910.00±57.7^{d}	16730.00±86.6^{c}	17320.00±38.1^{c}	14833.33±33.3^{f}	14550.00±57.7^{cd}	14691.67±16.6^{e}
T_4	136.80±0.5^{f}	139.00±0.8^{e}	137.90±0.6^{g}	17690.00±577.3^{d}	17710.00±86.6^{f}	17700.00±245.3^{d}	11900.00±57.7^{c}	13440.00±577.3^{b}	12670.00±304.1^{b}
T_5	131.40±0.5^{e}	133.40±0.8^{d}	132.40±0.3^{e}	21400.00±57.7^{e}	21370.00±86.6^{h}	21385.00±38.1^{e}	13300.00±57.7^{d}	14360.00±57.7^{c}	13830.00±50.0^{c}
T_6	129.20±0.5^{d}	130.10±0.8^{c}	129.65±0.6^{d}	16740.00±577.3^{c}	17473.00±86.6^{e}	17106.50±269.6^{c}	10500.00±57.7^{b}	14280.00±57.7^{c}	12390.00±0.0^{b}
T_7	127.70±0.5^{d}	128.90±0.8^{c}	128.30±0.3^{cd}	17850.00±57.7^{d}	17853.00±86.6^{g}	17851.50±14.4^{d}	14800.00±57.7^{f}	15060.00±57.7^{d}	14930.00±50.0^{e}
T_8	124.80±0.5^{c}	124.90±0.8^{ab}	124.85±0.6^{b}	15380.00±57.7^{b}	15730.00±86.6^{b}	15555.00±38.1^{b}	14700.00±57.7^{f}	16850.00±57.7^{e}	15775.00±50.0^{f}
T_9	127.70±0.5^{d}	127.50±0.8^{bc}	127.60±0.6^{c}	17340.00±57.7^{cd}	17200.00±86.6^{d}	17270.00±38.1^{c}	17000.00±57.7^{h}	17450.00±57.7^{f}	17225.00±±57.7^{g}
T_{10}	120.10±0.5^{a}	124.00±0.8^{a}	122.05±0.3^{a}	17240.00±57.7^{cd}	17390.00±86.6^{de}	17315.00±62.9^{c}	16800.00±57.7^{g}	15000.00±57.7^{d}	15900.00±50.0^{f}
S. Em (±)	3.0	2.6	2.8	474.7	394.7	429.4	450.8	350.2	381.3

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(nano-Cu_1(20ppm)], T_5 [nano-Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ nano-Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ nano-Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ nano-Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ nano-Cu_2(30ppm)], T_{10} [$ZnSO_4$]

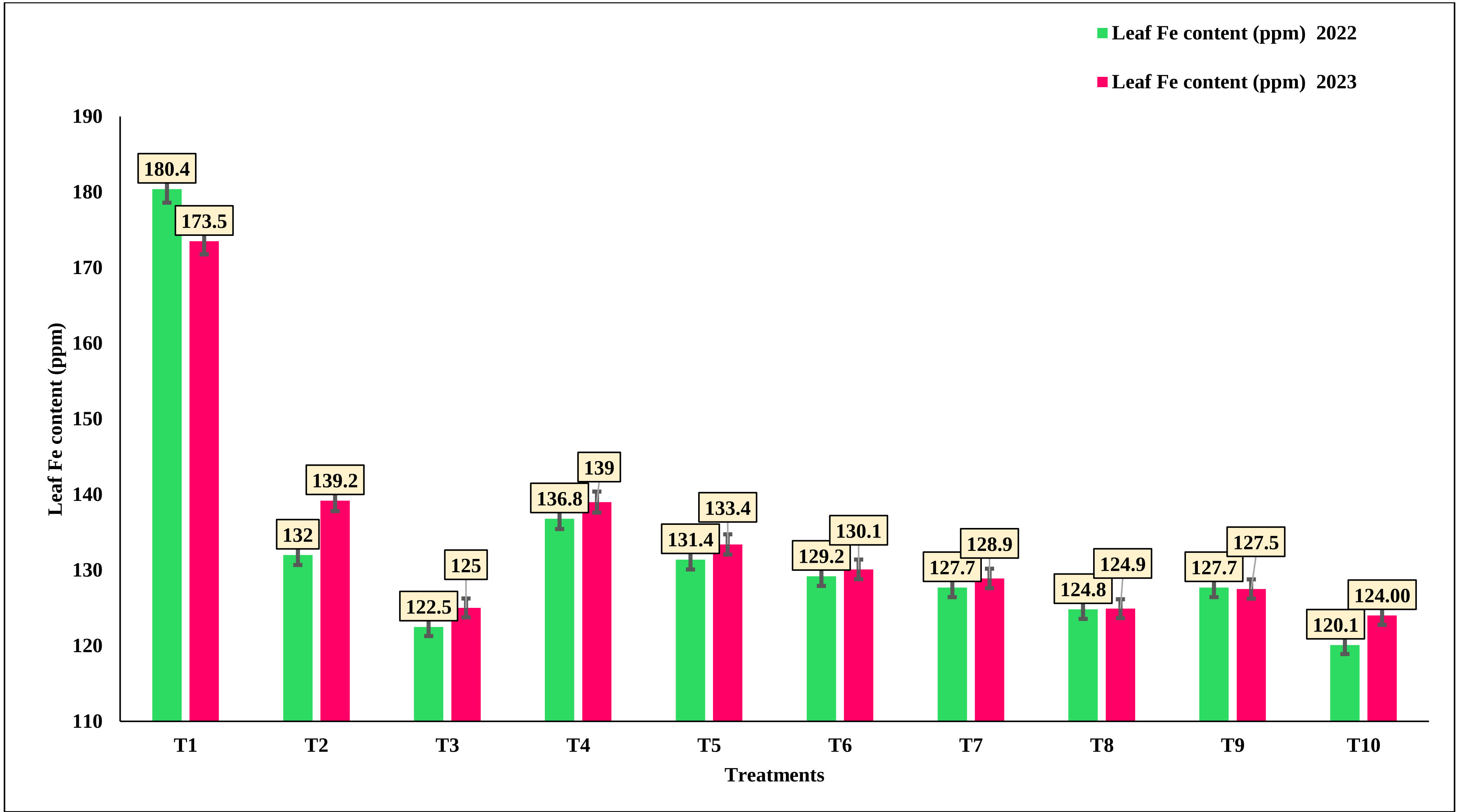

Fig. 4.35: Effect of nano-Zn and nano-Cu on leaf Fe content (ppm) in guava

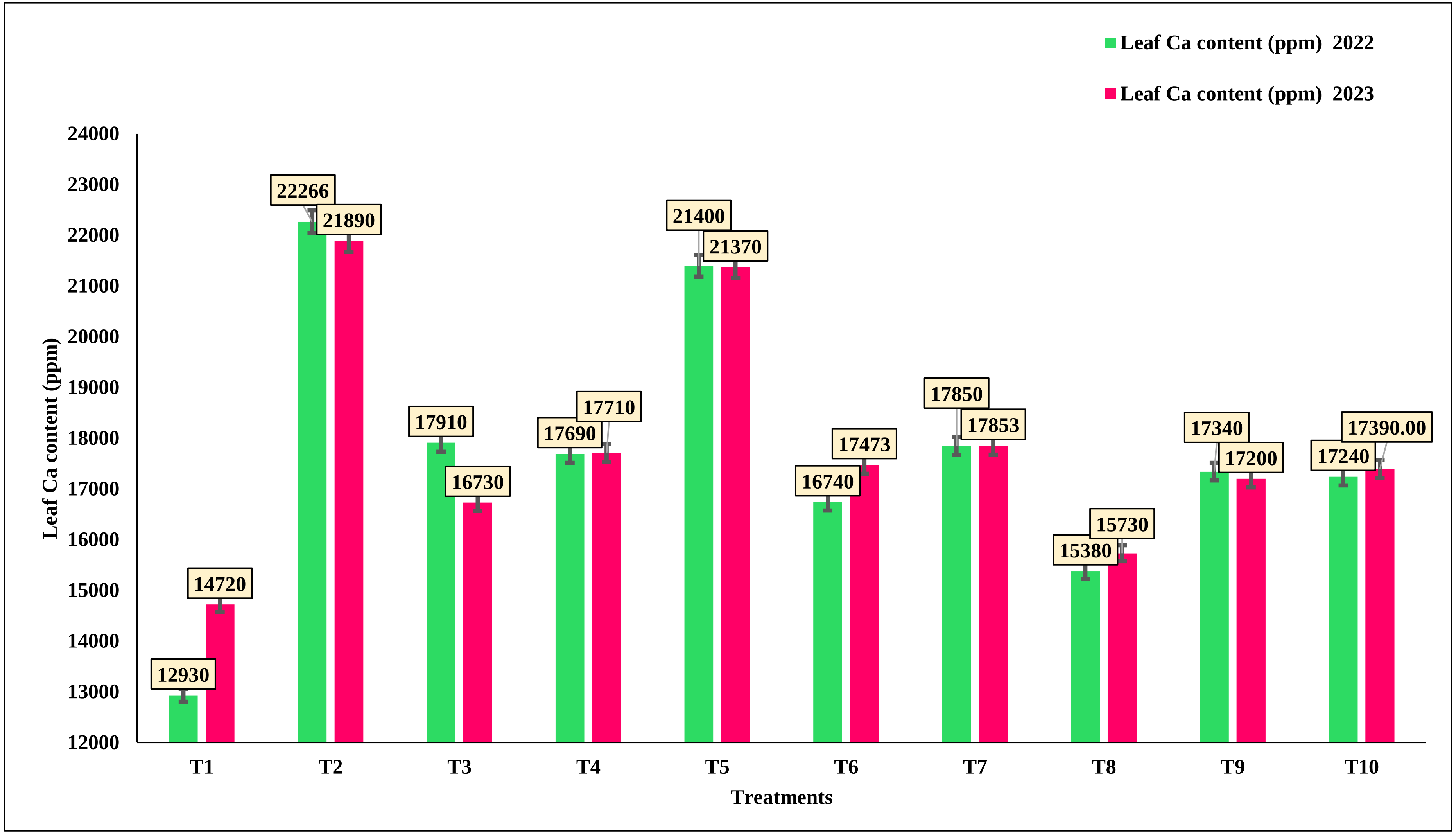

Fig. 4.36: Effect of nano-Zn and nano-Cu on leaf Ca content (ppm) in guava

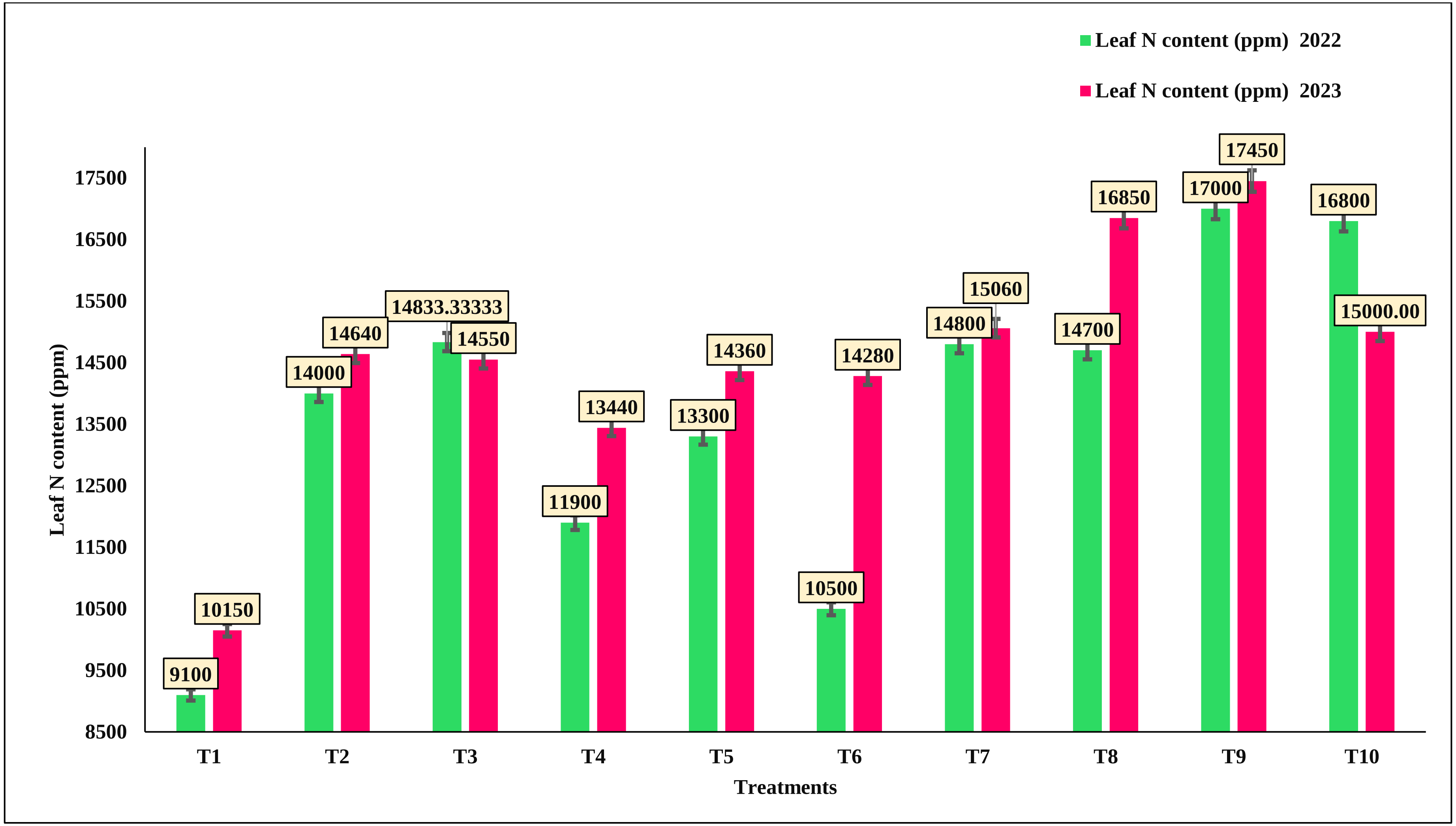

Fig. 4.37: Effect of nano-Zn and nano-Cu on leaf N content (ppm) in guava

4.4.7 Phosphorous content in leaves (ppm)

Table no. 4.13 shows the data pertaining to the phosphorous content in leaves during the two years of the experiment (2022 and 2023) along with the pooled data it is graphically presented in figure no.4.38.

In 2022 trial, the treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] resulted in the maximum phosphorous content in leaves, measuring 1557.00 ppm it is gradually maximum with rest of the treatments. Conversely, the T_1 (Control) displayed the minimum phosphorous content in leaves, measuring 1008.00 ppm this was at nominal with treatment T_4 value was 1053.00 ppm.

In an experiment performed in 2023, treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] exhibited the maximum phosphorous content in leaves, measuring 1553.00 ppm it is substantially maximum than other treatments. T_1 (Control) recorded the lowest phosphorous content in leaves, measuring 1044.00 ppm, at nominal with T_2, T_4, T_6, and T_{10} ranging from 1057.00 to 1160.00 ppm.

Two-year aggregated data also recorded that the treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] exhibited the maximum phosphorous content in leaves, measuring 1251.00 ppm. Moreover, the treatment T_1 (Control) recorded the lowest phosphorous content in leaves, measuring 1026.00 ppm at nominal with T_4, measuring 1055.00 ppm.

4.2.8 Potassium content in leaves (ppm)

The potassium in leaves during two-year experiment (2022 and 2023) was in Table 4.13 and graphically presented in figure no.4.39.

The experiment conducted in 2022, results were obtained regarding the potassium content in leaves. Treatment T_5 [Cu(30ppm)] showed the maximum potassium content, measuring 6808.00 ppm, it is substantially maximum from other treatments. In contrast, treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] exhibited the minimum potassium content in leaves, measuring 5019.00 ppm, it was at nominal with treatment T_7 (5047.00 ppm).

In the year 2023, treatment T1 (control) displayed the maximum potassium content in leaves, measuring 6592.00 ppm it is substantially maximum from other treatments. However, treatments T_5 [Cu(30ppm)] showed the lowest potassium content in leaves, measuring 5093.00 ppm.

Table no. 4.13: Effect of nano-Zn and nano-Cu on leaf nutrient content (ppm) Phosphorus and Potassium of guava.

Treatments	Leaf Nutrient (ppm)					
	P			K		
	2022	2023	Pooled	2022	2023	Pooled
T_1	1008.00±1.7^{a}	1044.00±1.1^{a}	1026.00±1.2^{a}	5205.00±2.8^{b}	6592.00±57.7^{e}	5898.50±2704^{f}
T_2	1182.00±57.7^{bcde}	1141.33±23.3^{ab}	1161.67±36.2^{bc}	6135.00±20.2^{f}	5388.00±57.7^{b}	5761.50±25.3^{e}
T_3	1300.00±28.8^{ef}	1383.00±57.7^{c}	1341.50±38.1^{d}	5380.00±17.3^{cd}	6140.00±57.7^{d}	5760.00±37.5^{e}
T_4	1053.00±28.8^{ab}	1057.00±2.3^{a}	1055.00±15.0^{ab}	5851.00±29.4^{e}	5309.00±57.7^{b}	5580.00±25.0^{d}
T_5	1245.00±57.7^{cdef}	1269.00±57.7^{bc}	1257.00±50.0^{cd}	6808.00±57.7^{g}	5093.00±57.7^{a}	5950.50±50.0^{f}
T_6	1140.00±57.7^{bc}	1160.00±57.7^{ab}	1150.00±0.0^{bc}	5368.00±57.7^{cd}	5937.00±57.7^{c}	5652.50±50.0^{de}
T_7	1277.00±57.7^{def}	1225.00±57.7^{b}	1251.00±57.7^{cd}	5047.00±57.7^{a}	5272.00±57.7^{b}	5159.50±28.8^{a}
T_8	1557.00±32.9^{g}	1553.00±57.7^{d}	1555.00±39.7^{e}	5019.00±57.7^{a}	5224.00±57.7^{ab}	5121.50±50.0^{a}
T_9	1341.00±23.6^{f}	1373.00±57.7^{c}	1357.00±36.2^{d}	5504.00±57.7^{d}	5411.00±57.7^{b}	5457.50±50.0^{c}
T_{10}	1149.00±28.2^{bcd}	1158.00±1.7^{ab}	1153.50±14.5^{bc}	5297.00±57.7^{bc}	5299.00±57.7^{b}	5298.00±50.0^{b}
S. Em (±)	29.8	30.6	29.2	98.9	87.2	53.2

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ Cu_2(30ppm)], T_{10} [$ZnSO_4$]

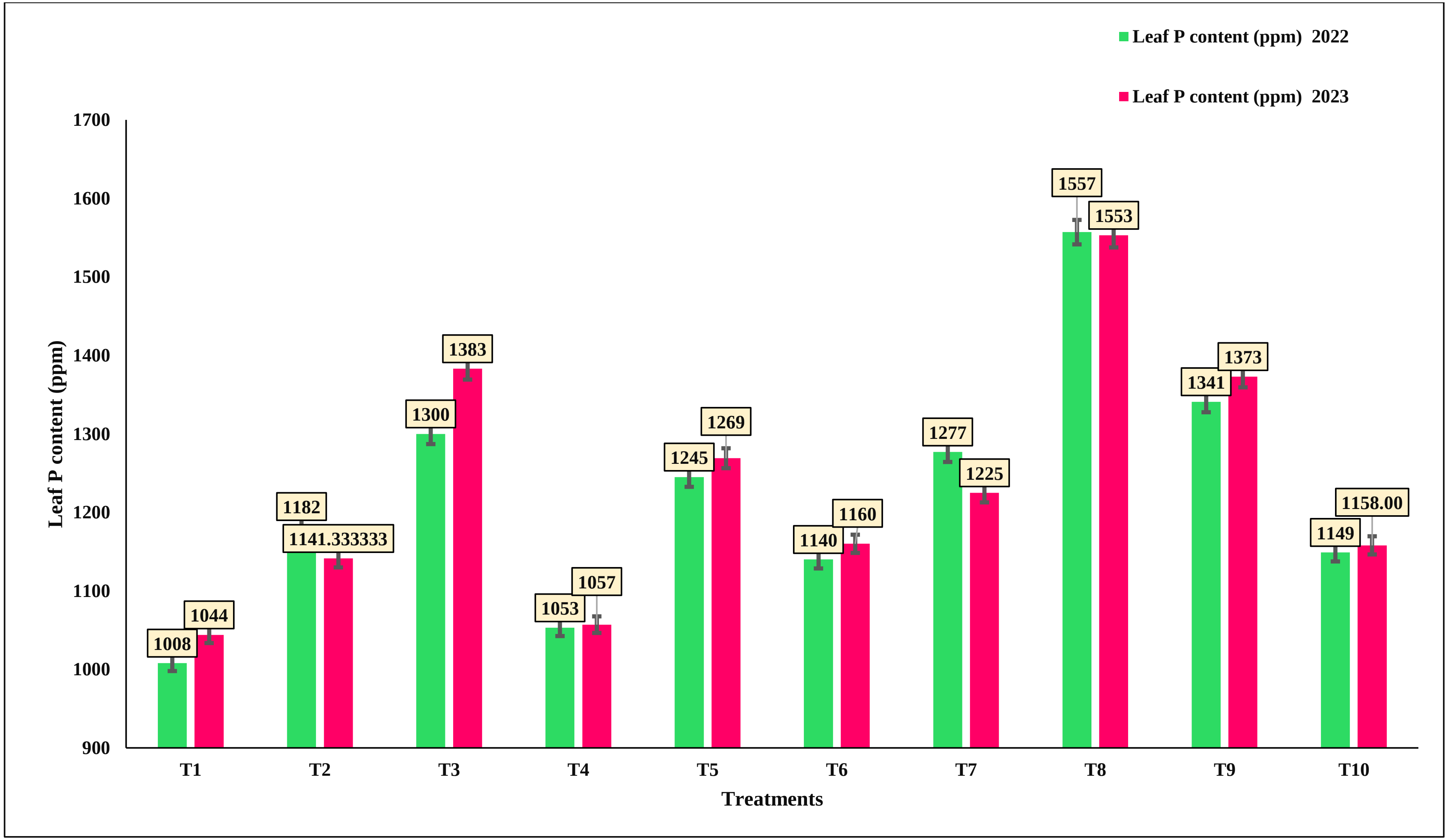

Fig. 4.38: Effect of nano-Zn and nano-Cu on leaf P content (ppm) in guava

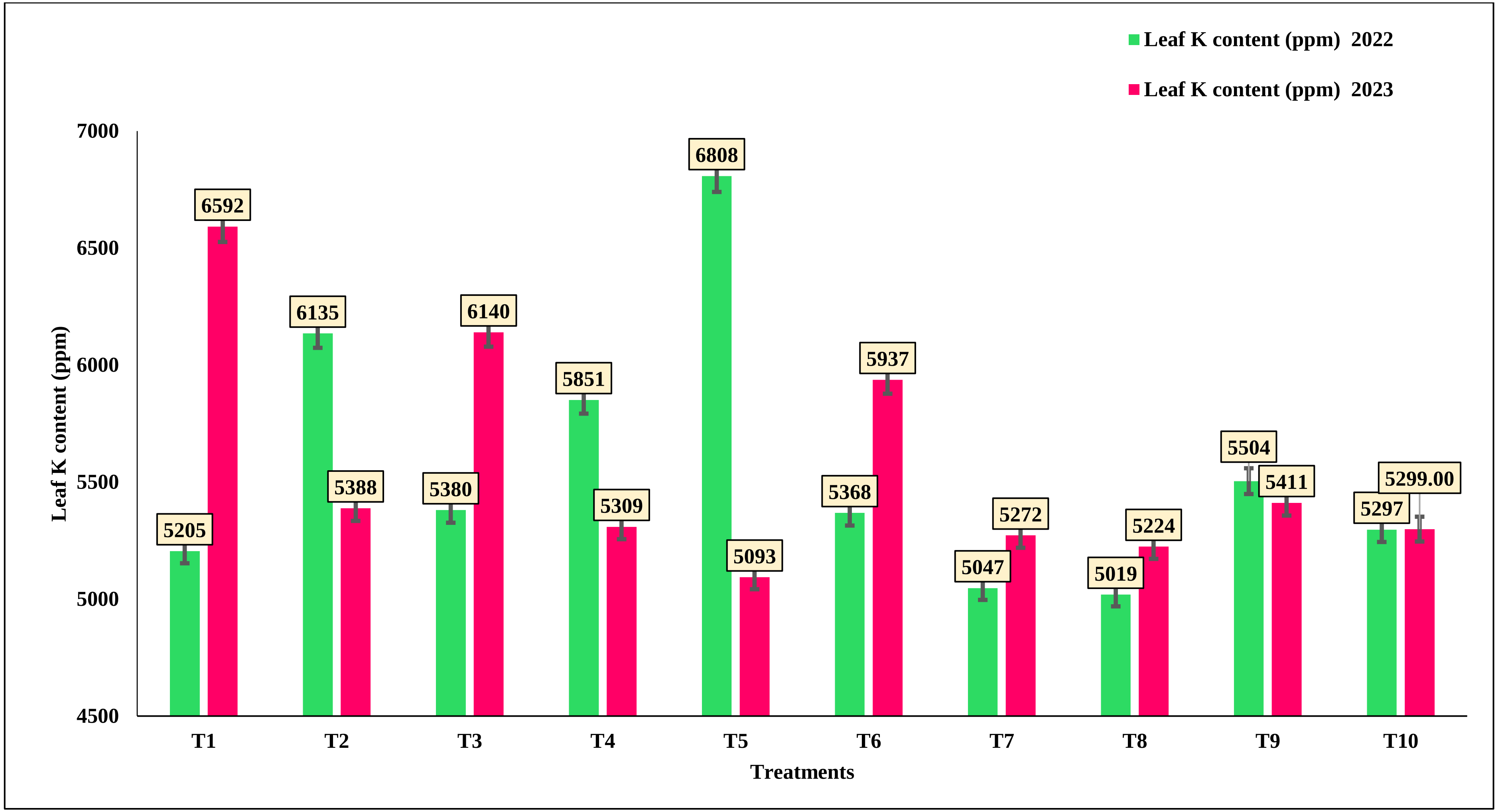

Fig. 4.39: Effect of nano-Zn and nano-Cu on leaf K content (ppm) in guava

The combined data from the two years (2022 and 2023) resulted that treatment T_5 [Cu_2(30ppm)] observed the maximum potassium content in leaves, measuring 5950.50 ppm, which was at nominal with the K (potassium) content recorded in T_1 (control) measuring 5898.50 ppm. Instead, treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] recorded the minimum potassium content in leaves, measuring 5121.50 ppm at nominal with T_7 measuring 5159.50 ppm.

4.5 Qualitative studies

4.5.1 Total sugars (%)

Table no. 4.14 shows the data on the variation in the total sugars %, during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments have a positive impact on total sugars (%) in guava during the experiment, graphically presented in figure no.4.40.

During 2022, the highest total sugars (%) stage was under treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 8.74% were recorded which was gradually different from all the treatments. The minimum total sugars, 8.12% was observed in treatment T_1 (Control).

In the second trial year (2023), statistically, treatments made a substantial impact on the total sugars (%) of guava fruits. The Maximum total sugars % (8.93) was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] it is substantially maximum from other treatments. The lowermost total sugars, 8.20 % was in T_1 (Control).

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the maximum total sugars, the value of 8.84 % it is substantially maximum other treatments. In contrast, treatment T_1 had the lowest total sugars %, with a value of 8.16 %.

4.5.2 Reducing sugars (%)

Table no. 4.14 presents the data on the variation in reducing sugars (%) during the two-year experiment (2022 and 2023). A detailed analysis of the data reveals a substantial impact of various nano-micronutrient treatments on the reducing sugars of the guava during both years of the experiment, graphically presented in figure no.4.41.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was recorded with the maximum reducing sugars % was 5.46 % it is substantially maximum from other treatments. Lowest value reducing sugars % were 4.95 % recorded in treatment T_1 (Control).

In 2023, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum reducing sugars %, which was 5.28% it is substantially maximum from other treatments. Rest of the treatments showed substantial differences in reducing sugars%. Treatment T_1 (Control) recorded the lowest reducing sugars % was 4.87 % at nominal with T_2 (nano-Zn (40ppm)) with a value of 4.89 %.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum reducing sugars %, value of 5.37% it is substantially maximum from other treatments. Instead, the T_1 (Control) was observed with the lowest reducing sugars %, a value of 4.91%.

4.5.3 Non-reducing sugars (%)

Table no. 4.14 provides information about the variation in non-reducing sugars % observed throughout the two years of the experiment (2022 and 2023). Nano-micronutrients on non-reducing sugars % in guava fruit during both the years of the experiment, graphically presented in figure no.4.42.

During the first year of the experiment (2022), the highest non-reducing sugars % was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 3.32 % this was at nominal with treatment T_8 with the value of 3.29 %. The minimum non-reducing sugars were observed in treatment T_1 with a value of 3.06 %.

In the second year of the trial (2023), The highest non-reducing sugars % were recorded in treatment T_9, using nano-Zn_2(60ppm) + Cu_2(30ppm) that was 3.64 % at nominal with T_8 (nano-Zn_2(60ppm) + Cu_1(20ppm)) with the same value of 3.64 %. Instead, treatment T_1 (Control) recorded the minimum non-reducing sugars 3.33 %.

Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum non-reducing sugars, 3.48 %. This was at nominal with treatment T_8 (nano-Zn_2(60ppm) + Cu_1(20ppm) with the value of 3.47 %. Instead, treatment T_1 (Control) resulted in the lowest non-reducing sugars %, measuring 3.20 %. Statistically, all the treatments made a substantial impact on the non-reducing sugars of the guava plants.

The application of zinc, which is crucial for redox processes and sugar metabolism, plays a role in the metabolism of nucleic acids and starches and affects various enzymes. When zinc is used alongside copper, there is a positive correlation with the soluble solids content and total sugars in guava fruits. A similar study on Aonla (*Phyllanthus emblica*) cv. Banarasi found that foliar sprays of Zn, Cu, and B, and their individual levels, significantly influenced sugar content. Notable improvements in both reducing and non-reducing sugar contents were observed following the application of Zn, Cu, and B (Singh *et al*., 2012).

4.5.4 TSS (^{0}B)

Table no. 4.14 shows the data on the variation in the TSS (^{0}B) during the two years of the experiment (2022 and 2023) along with the pooled data. A keen perusal of the data indicates that there was a substantial effect of different nano-micronutrient treatments on TSS (^{0}B) in Guava during both the years of the experiment, graphically presented in figure no.4.43.

During the first year of the experiment (2022), the maximum TSS (^{0}B) was under treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 9.89°B at nominal with T_5, T_7, and T_{10} ranging from 9.84 to 9.87°B. The minimum TSS value on the zero day was 9.68 °B was recorded in treatment T_1 (Control).

In the second trial year (2023), statistically, treatments made a substantial impact on the TSS (^{0}B) on the zero day of guava fruit storage. The maximum TSS on the zero day was 10.10°B recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] at nominal with T_5, T_7, T_8, and T_{10} ranging from 10.00 to 10.07°B. The lowest TSS was 9.84°B in T_1 (Control) it is at nominal with T_2, T_3, and T_4 ranging from 9.90 to 9.92°B.

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the maximum TSS, a value of 10.00°B at nominal with T_5, T_7, and T_{10} ranging from 9.94 to 9.97°B. In contrast, treatment T_1 (control) had the lowest TSS, a value of 9.76°B at nominal with treatments T_2, T_3, and T_4 ranging from 9.82 to 9.84°B.

Table no. 4.14: Effect of nano-Zn and nano-Cu on total sugars (%), reducing sugars (%), non-reducing sugars (%) and TSS (^{0}B) of guava.

Treatments	Quality of guava fruit											
No. of days	Total sugars (%)			Reducing sugars (%)			Non-reducing sugars (%)			TSS (^{0}B)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	8.12±0.01^{a}	8.20±0.01^{a}	8.16±0.01^{a}	4.95±0.01^{a}	4.87±0.01^{a}	4.91±0.01^{a}	3.06±0.01^{a}	3.33±0.01^{a}	3.20±0.01^{a}	9.68±0.01^{a}	9.84±0.01^{a}	9.76±0.012^{a}
T_2	8.20±0.008^{b}	8.35±0.005^{b}	8.28±0.00^{b}	5.03±0.008^{b}	4.89±0.01^{a}	4.96±0.008^{b}	3.12±0.02^{b}	3.46±0.01^{b}	3.29±0.008^{c}	9.75±0.02^{bc}	9.90±0.01^{ab}	9.83±0.017^{ab}
T_3	8.24±0.01^{bc}	8.39±0.008^{b}	8.32±0.005^{bc}	5.08±0.008^{c}	4.95±0.02^{b}	5.02±0.01^{c}	3.16±0.005^{bc}	3.44±0.01^{b}	3.30±0.006^{c}	9.72±0.01^{ab}	9.92±0.03^{abcd}	9.82±0.012^{ab}
T_4	8.25±0.02^{bc}	8.39±0.02^{b}	8.32±0.02^{c}	5.12±0.008^{d}	4.99±0.005^{b}	5.06±0.005^{d}	3.17±0.017^{bc}	3.40±0.03^{b}	3.29±0.01^{bc}	9.77±0.01^{bcd}	9.91±0.01^{abcd}	9.84±0.011^{ab}
T_5	8.35±0.02^{d}	8.47±0.01^{c}	8.41±0.01^{d}	5.19±0.01^{e}	5.07±0.02^{cd}	5.14±0.02^{e}	3.22±0.008^{de}	3.40±0.03^{b}	3.31±0.01^{c}	9.84±0.003^{efg}	10.04±0.03^{def}	9.94±0.020^{cde}
T_6	8.26±0.01^{c}	8.36±0.02^{b}	8.31±0.01^{bc}	5.15±0.01^{d}	5.05±0.003^{c}	5.10±0.006^{e}	3.2±0.011^{cd}	3.31±0.01^{a}	3.25±0.01^{b}	9.79±0.01^{cde}	9.97±0.04^{bcde}	9.88±0.027^{bc}
T_7	8.47±0.01^{e}	8.61±0.01^{d}	8.54±0.008^{e}	5.20±0.003^{e}	5.07±0.017^{cd}	5.14±0.008^{e}	3.25±0.005^{ef}	3.54±0.006^{c}	3.39±0.006^{d}	9.87±0.02^{fg}	10.07±0.07^{ef}	9.97±0.049^{de}
T_8	8.64±0.02^{g}	8.82±0.003^{f}	8.73±0.008^{g}	5.34±0.008^{g}	5.18±0.02^{e}	5.26±0.01^{g}	3.29±0.012^{gh}	3.64±0.03^{d}	3.47±0.01^{e}	9.82±0.01^{def}	10.00±0.04^{bcdef}	9.91±0.028^{cd}
T_9	8.74±0.008^{h}	8.93±0.01^{g}	8.84±0.01^{h}	5.46±0.008^{h}	5.28±0.006^{f}	5.37±0.003^{h}	3.32±0.017^{h}	3.64±0.01^{d}	3.48±0.01^{e}	9.89±0.03^{g}	10.10±0.01^{f}	10.00±0.005^{e}
T_{10}	8.54±0.02^{f}	8.690.01^{e}	8.62±0.01^{f}	5.26±0.01^{f}	5.11±0.02^{d}	5.19±0.01^{f}	3.27±0.008^{fg}	3.58±0.01^{c}	3.43±0.003^{d}	9.85±0.01^{fg}	10.02±0.02^{cdef}	9.94±0.015^{cde}
S. Em (±)	0.036	0.041	0.038	0.02	0.023	0.024	0.146	0.022	0.017	0.012	0.017	0.014

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)], T_4[(nano-Cu_1(20ppm)], T_5 [nano-Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ nano-Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ nano-Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ nano-Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ nano-Cu_2(30ppm)], T_{10} [$ZnSO_4$]

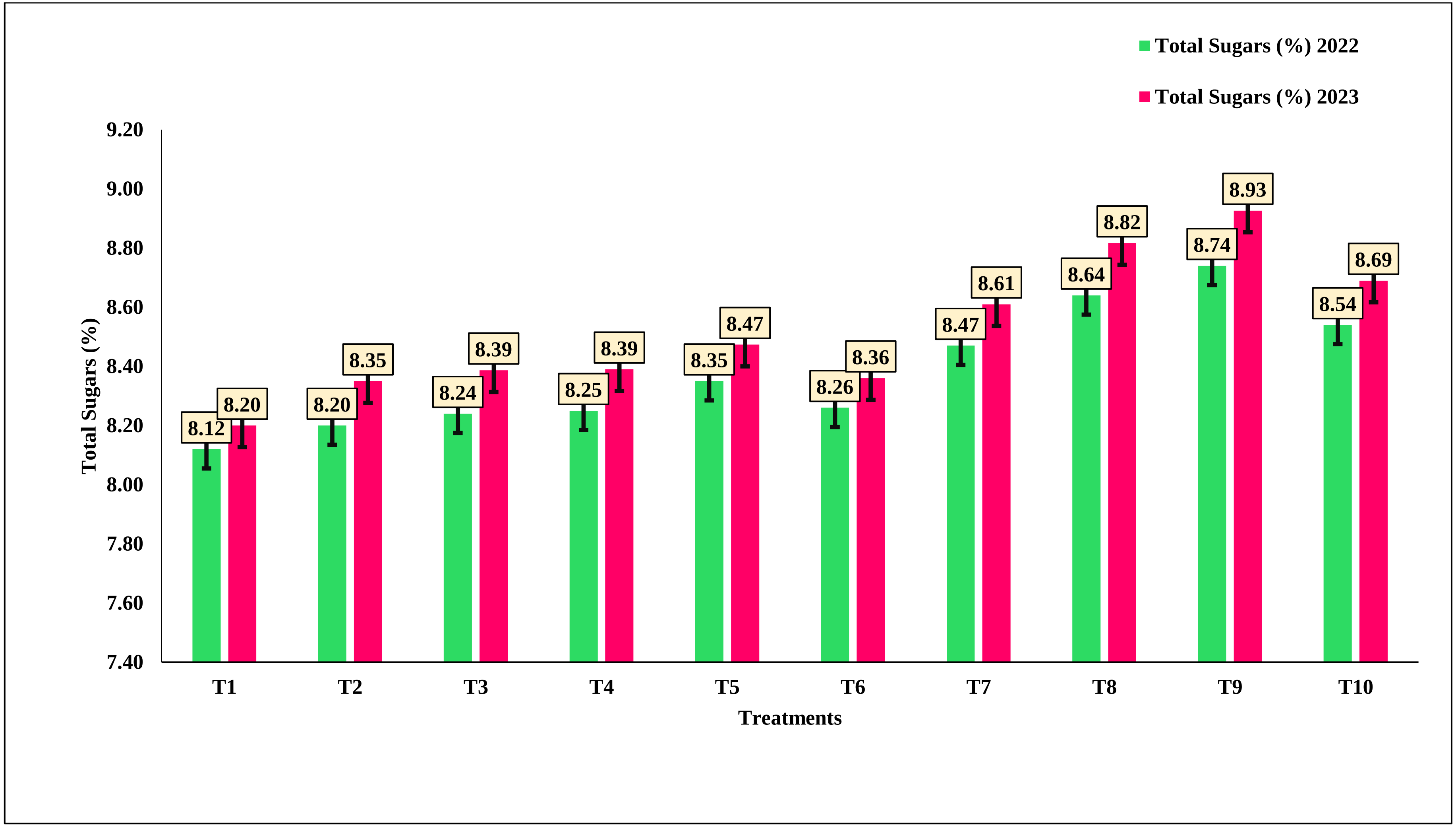

Fig. :4.40 Effect of nano-Zn and nano-Cu on total sugars % in guava

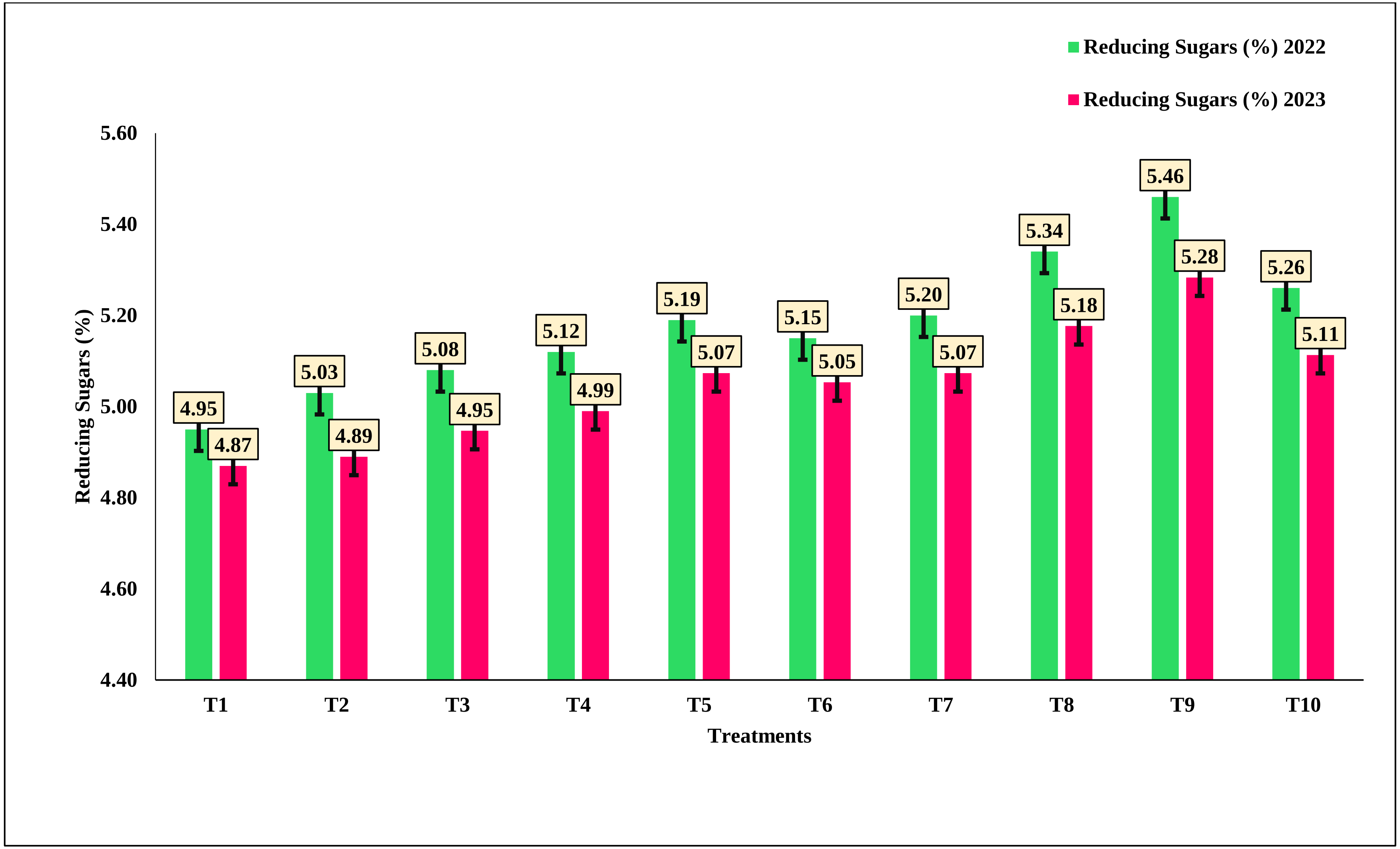

Fig. 4.41: Effect of nano-Zn and nano-Cu on reducing sugars % in guava

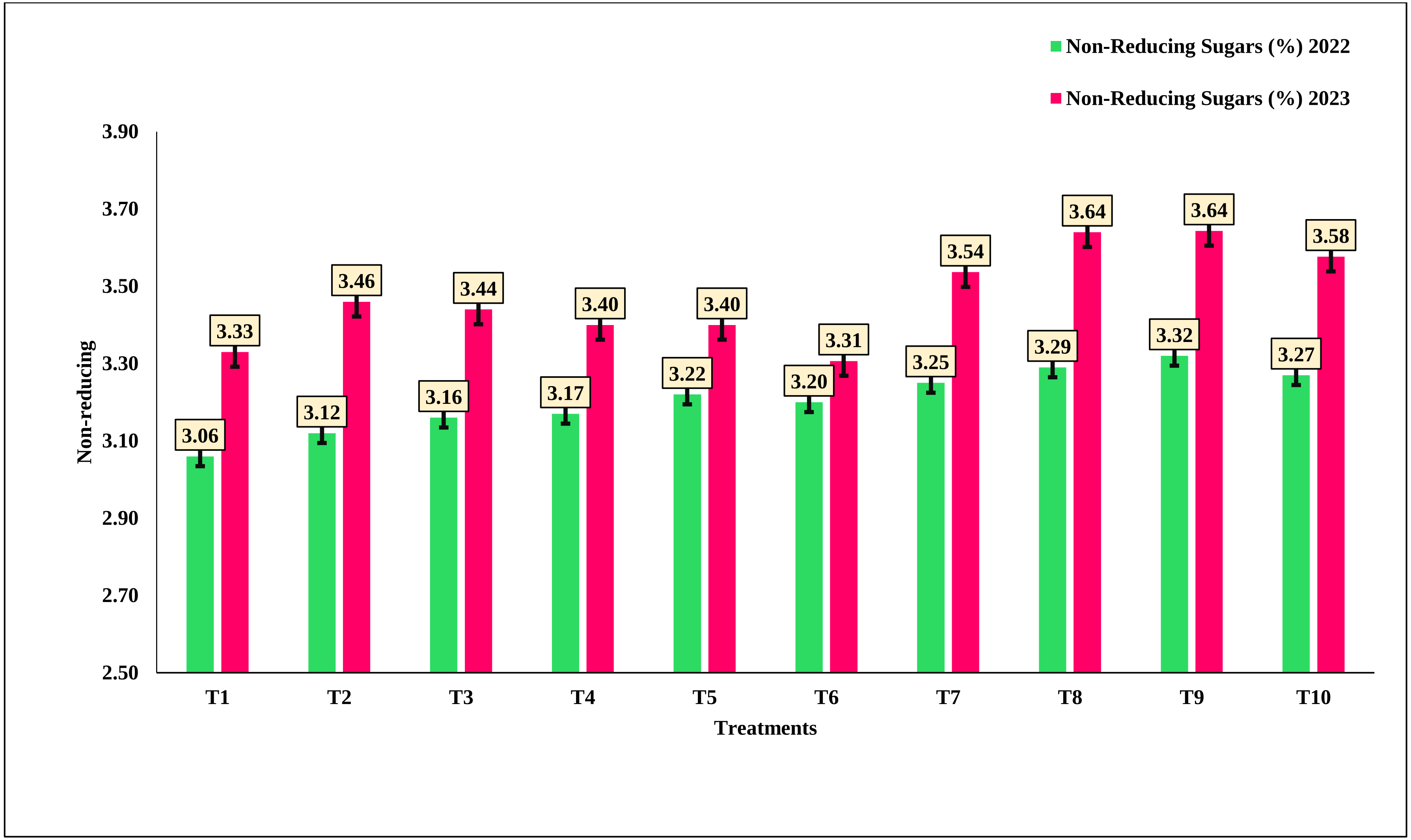

Fig. 4.42: Effect of nano-Zn and nano-Cu on non-reducing sugars % in guava

Fig. :4.43 Effect of nano-Zn and nano-Cu on TSS (°B) in guava

4.5.5 Titratable acidity (%)

Table no. 4.15 provides information about the variation in titratable acidity (%) observed throughout the two years of the experiment (2022 and 2023). A keen perusal of the data indicates there was a substantial effect of pre-harvest application of nano-micronutrients on titratable acidity (%) in guava fruit during both the years of the experiment, graphically presented in figure no.4.44.

During the first year of the experiment (2022), the maximum titratable acidity (%) was recorded in treatment T_1 (control) which was 1.23 % this was at nominal with treatment T_2, and T_3 with the value of 1.23 and 1.23 % respectively. The minimum titratable acidity (%) were observed in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] with a value of 0.98 %.

In the second year of the trial (2023), The maximum titratable acidity (%) was recorded in treatment T_3 (nano-Zn_2(60ppm)) was 1.40 % at nominal with T_1 and T_2 with the same value of 1.37 and 1.40 % respectively. Instead, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] recorded the minimum titratable acidity (%) 1.05 %.

Data combined for two years (2022 and 2023) showed that treatment T_2 (nano-Zn_1(40ppm)) had the maximum titratable acidity (%) 1.32 %. This was at nominal with treatments T_1 and T_3 with the values of 1.30 and 1.31 % respectively. Instead, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the lowest titratable acidity (%) percentage, measuring 1.05 %. Statistically, all the treatments made a substantial impact on the titratable acidity (%) of the guava plants.

4.5.6 TSS: Acid ratio

Table no. 4.15 provides information about the variation in the TSS: Acid ratio observed throughout the two years of the experiment (2022 and 2023). Nano-micronutrients on the Total Soluble Solids: Acid ratio in Guava fruit during both the years of the experiment, graphically presented in figure no.4.45.

During the first year of the experiment (2022), the maximum TSS: Acid ratio was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 10.06 substantially different from other treatments. The lowermost TSS: Acid ratio was resulted in T_1 with a value of 7.82 at nominal with T_2 and T_3 with the value of 7.93 and 7.95 respectively.

In the second year of the trial (2023), The maximum TSS: Acid ratio was recorded in treatment T_9, using nano-Zn_2(60ppm) + Cu_2(30ppm) that was 9.13 substantially different from other treatments. Insted, treatment T_3 (nano-Zn_2 (60ppm)) recorded the minimum TSS: Acid ratio with a value of 7.07 at nominal with T_1, T_2, and T_4 ranging from 7.08 to 7.32.

Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum TSS: Acid ratio was 9.13 substantially different from other treatments. Instead, treatment T_2 (nano-Zn_1 (40ppm)) resulted in the lowest TSS: Acid ratio, measuring 7.50 at nominal with T_1 and T_3 with the value of 7.51 each. Statistically, all the treatments made a substantial impact on the TSS: Acid ratio of the guava fruit.

Nano-Zinc improves carbohydrate metabolism, increase sugar accumulation. While nano-Copper enhances enzymes activity, adding in sugar synthesis. Both nutrients contribute to elevated TSS levels and reduce acidity level. It justified by a study conducted on Aonla plant (*Phyllanthus emblica*) cv. Banarasi which resulted that The TSS of aonla fruits was improved significantly with the foliar application of Zn, Cu and B elements. The fruit acidity was significantly reduced by increasing concentrations of the Zn, Cu and B elements (Singh *et al.,*2012).

4.5.7 Ascorbic acid (mg/100g)

Table no. 4.15 presents the data on the variation in ascorbic acid (mg/100g) during the two-year experiment (2022 and 2023). Nano-micronutrient treatments impact on the ascorbic acid (Vit-C) of the guava fruit during both years of the experiment, graphically presented in figure no.4.46.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was recorded with the highest ascorbic acid (Vit-C) was 268.90mg/100g substantially maximum from other treatments. The lowest ascorbic acid (Vit-C) was 246.14 recorded in treatment T_1 (Control).

In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum ascorbic acid (Vit-C), which was 271.12 mg/100g substantially maximum from other treatments. Rest of the treatments showed substantial differences in ascorbic acid. Treatment T_1 (Control) recorded the lowest ascorbic acid (Vit-C) was 247.64 mg/100g.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the superior ascorbic acid (Vit-C), a value of 270.01 mg/100g substantially maximum from other treatments. Instead, the treatment T_1 was noted with the lowest ascorbic acid (Vit-C), a value of 246.89 mg/100g.

Table no. 4.15: Effect of nano-Zn and nano-Cu on titratable acidity (%), TSS:Acid ratio and ascorbic acid (mg/100g) of guava.

Treatments	Quality of guava fruit (at harvest stage)								
	Titratable acidity (%)			TSS: Acid ratio			Ascorbic acid (mg/100g)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	1.23±0.003^{f}	1.37±0.02^{def}	1.30±0.020^{ef}	7.82±0.032^{a}	7.19±0.113^{ab}	7.51±0.072^{a}	246.14±0.864^{a}	247.64±1.214^{a}	246.89±1.039^{a}
T_2	1.23±0.005^{ef}	1.40±0.02^{ef}	1.32±0.025^{f}	7.93±0.052^{ab}	7.08±0.112^{a}	7.50±0.068^{a}	252.32±0.518^{b}	253.80±0.443^{b}	253.07±0.454^{b}
T_3	1.22±0.008^{ef}	1.40±0.008^{f}	1.31±0.005^{f}	7.95±0.063^{ab}	7.07±0.063^{a}	7.51±0.034^{a}	251.89±1.108^{b}	253.76±1.401^{b}	252.83±1.252^{b}
T_4	1.20±0.003^{e}	1.35±0.02^{de}	1.28±0.020^{e}	8.09±0.017^{b}	7.32±0.098^{ab}	7.71±0.051^{b}	253.17±0.468^{b}	254.31±0.468^{b}	253.74±0.468^{b}
T_5	1.17±0.003^{d}	1.28±0.01^{c}	1.23±0.010^{d}	8.38±0.020^{c}	7.84±0.066^{c}	8.12±0.031^{c}	259.12±0.505^{c}	260.98±0.565^{c}	260.05±0.505^{c}
T_6	1.20±0.003^{e}	1.350.01^{d}	1.28±0.011^{e}	8.13±0.033^{b}	7.41±0.088^{b}	7.77±0.040^{b}	257.22±1.419^{c}	258.73±1.145^{c}	257.98±1.282^{c}
T_7	1.15±0.012^{d}	1.30±0.01^{c}	1.23±0.020^{d}	8.53±0.083^{c}	7.77±0.073^{c}	8.15±0.070^{c}	264.13±1.945^{d}	265.67±2.064^{d}	264.90±1.999^{d}
T_8	1.07±0.011^{b}	1.21±0.01^{b}	1.14±0.020^{b}	9.17±0.086^{e}	8.29±0.075^{d}	8.74±0.080^{e}	258.46±0.562^{c}	260.32±0.904^{c}	259.39±0.733^{c}
T_9	0.98±0.014^{a}	1.11±0.003^{a}	1.05±0.015^{a}	10.06±0.173^{f}	9.130.020^{e}	9.60±0.089^{f}	268.90±0.406^{e}	271.12±0.367^{e}	270.01±0.385^{e}
T_{10}	1.12±0.011^{c}	1.22±0.003^{b}	1.17±0.010^{c}	8.80±0.101^{d}	8.24±0.015^{d}	8.52±0.055^{d}	263.510.518^{d}	264.71±0.552^{d}	264.12±0.536^{d}
S. Em (±)	0.014	0.017	0.086	0.124	0.118	0.120	1.229	1.25	1.241

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(nano-Cu_1(20ppm)], T_5 [nano-Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ nano-Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ nano-Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ nano-Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ nano-Cu_2(30ppm)], T_{10} [$ZnSO_4$]

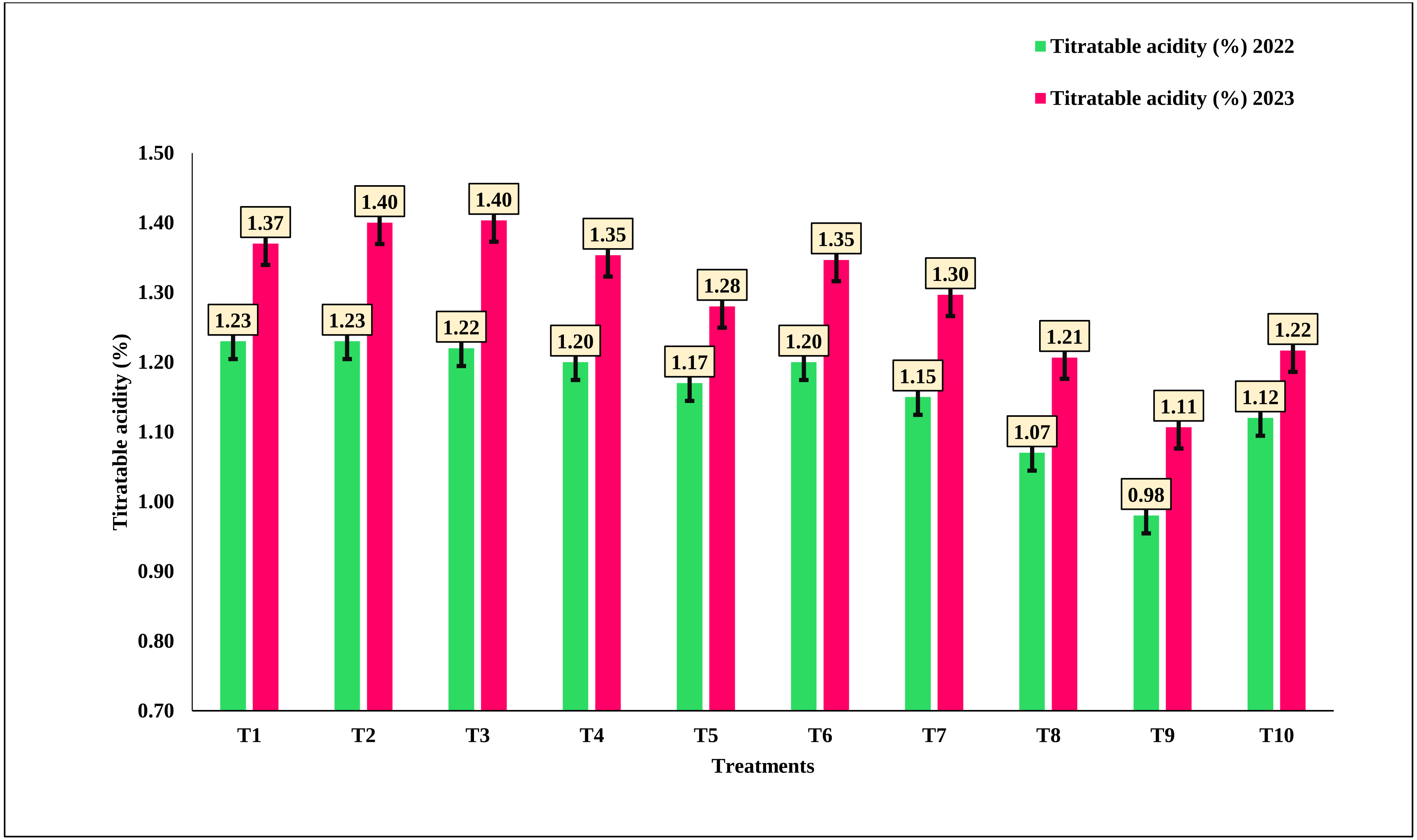

Fig. 4.44: Effect of nano-Zn and nano-Cu on titratable acidity in guava

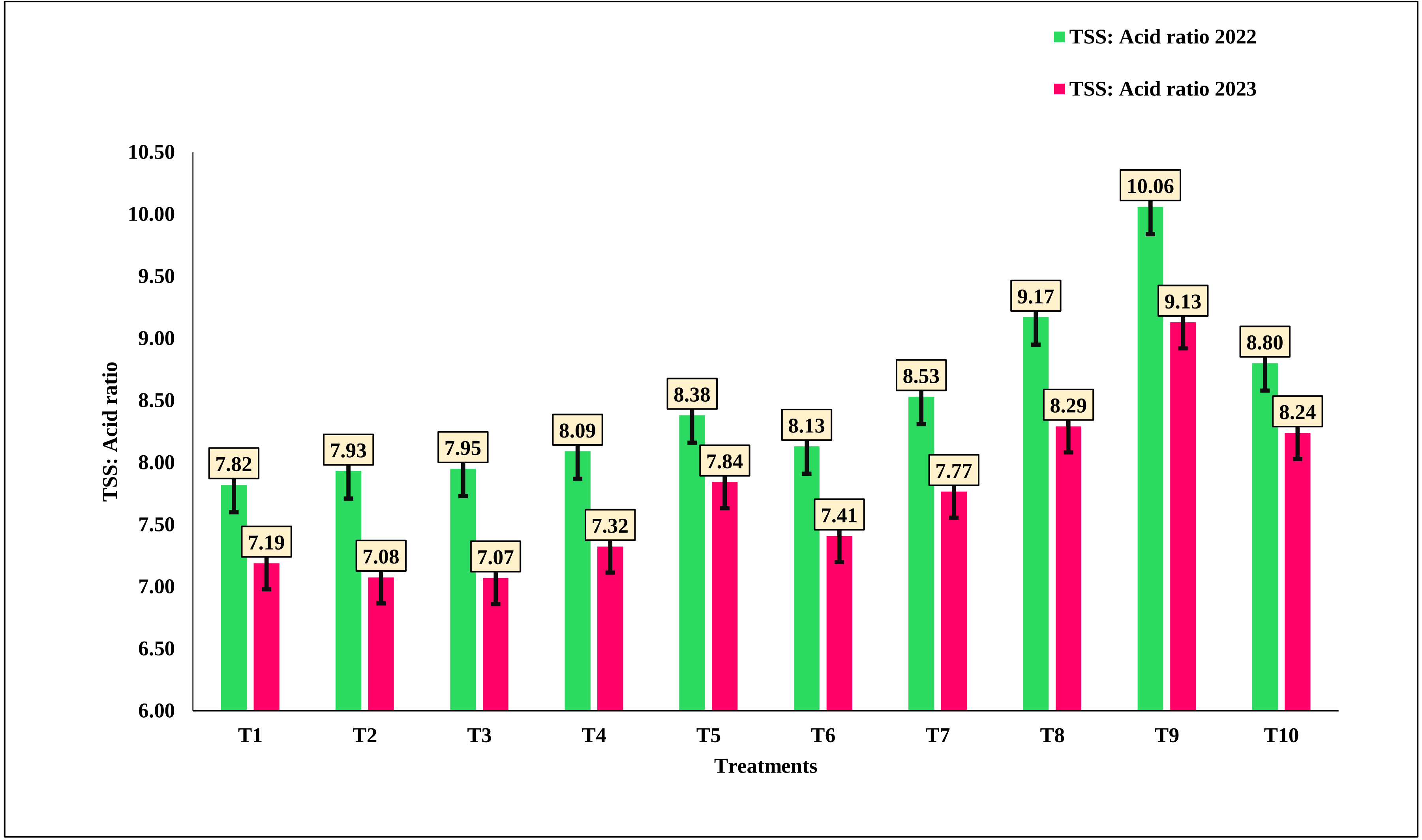

Fig. :4.45 Effect of nano-Zn and nano-Cu on TSS: Acid ratio in guava

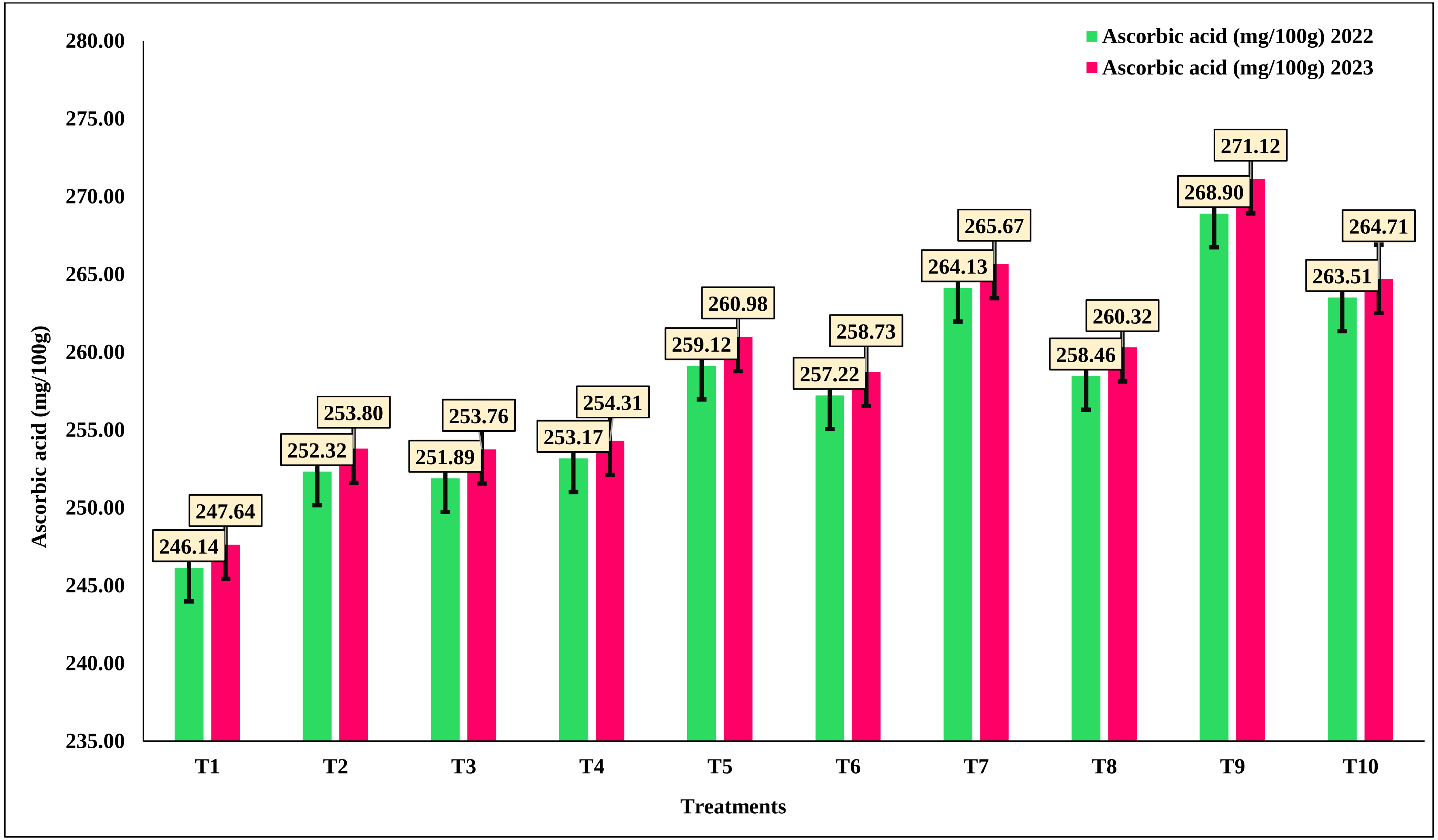

Fig. 4.46: Effect of nano-Zn and nano-Cu on ascorbic acid (mg/100g) in guava

4.5.8 Antioxidants DPPH (%)

Table no. 4.16 shows the data on the variation in the antioxidants (%) during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments impact at antioxidants (%) in guava during both the years of the experiment, graphically presented in figure no.4.47.

During the first year of the experiment (2022), the superior antioxidants (%) was under treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 48.35% were noted at nominal with T_7 with value of 48.17%. The minimum antioxidants, 39.58 % was recorded in treatment T_1 (Control).

In the second trial year (2023), statistically, treatments made a substantial impact on the antioxidants (%) on the zero day of guava fruit storage. The maximum antioxidant (%) on the zero day was 49.31 % was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] it is substantially superior from other treatments. The lowest antioxidants (%) was 40.00 % in treatment T_1 (Control).

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the superior antioxidants (%), with a value of 48.84 % which was substantially superior from other treatments. Insted, treatment T_1 had the lowest value of antioxidants, 39.79 %.

4.5.9 Firmness (kg/in^2)

Table no. 4.16 provides information about the variation in firmness (kg/in^2) observed throughout the two years of the experiment (2022 and 2023). Nano-micronutrients treatment impact on firmness (kg/in^2) in guava fruit during both the years of the experiment, graphically presented in figure no.4.48.

During the first year of the experiment (2022), the superior firmness (kg/in^2) was noted in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] and T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] which was 5.71 kg/in^2. This was no substantial difference. The lowest firmness (kg/in^2) was ensued in treatment T_1 with a value of 5.00 kg/in^2.

In the second year of the trial (2023), The superior firmness (kg/in^2) was noted in treatments T_5 and T_7, with the same value of 5.95 kg/in^2 at nominal with T_6, T_8, T_9 and T_{10} ranging from 5.54 to 5.90. Instead, treatment T_1 (Control) noted the minimum firmness was 5.00 kg/in^2 at nominal with T_2 with a value of 5.33 kg/in^2.

Data combined for two years (2022 and 2023) showed that treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] had the maximum firmness (kg/in^2) was 5.80 kg/in^2. This was at nominal with treatments T_2, T_3, T_4, T_5, T_6, T_7, T_9, and T_{10} ranging from 5.25 to 5.76 kg/in^2. Instead, treatment T_1 ensued in the lowest firmness (kg/in^2), measuring 5.00 kg/in^2 at nominal with T_2, T_3, T_4, T_6, and T_7 ranging from 5.25 to 5.74 kg/in^2.

4.5.10 Pectin content (%)

Table no. 4.16 presents the data on the variation in pectin content (%) during the two-year experiment (2022 and 2023). Nano-micronutrient treatments impact on the pectin content (%) of the guava during both years of the experiment, graphically presented in figure no.4.49.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was noted with the superior pectin content (%) was 2.13 % this was superior among the treatments. The lowest pectin content (%) was 1.47 % noted in treatment T_1 (Control) which was at nominal with the treatment T_2 with a value of 1.57%.

In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the superior pectin content (%), which was 2.31 % it is substantially superior from other treatments. Rest of the treatments showed substantial differences in pectin content (%). Treatment T_1 (Control) noted the lowest pectin content (%) was 1.55 %.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] ensued in the superior pectin content (%), with a value of 2.22 % it is substantially superior from other treatments. Instead, the treatment T_1 was noted with the lowest pectin content (%), a value of 1.51%.

The application of copper nanoparticles resulted in firmer fruits, as well as an increase in Vitamin C, lycopene, and ABTS antioxidant capacity compared to the control group. Additionally, there was a reduction in the enzymatic activities of ascorbate peroxidase (APX) and glutathione peroxidase (GPX), while the activities of superoxide dismutase (SOD) and catalase (CAT) significantly increased. The use of Cu nanoparticles led to a higher accumulation of bioactive compounds in tomato fruits (López-Vargas *et al.,* 2018). Similarly, a study on sweet oranges revealed that the treatment with Zn (0.5%), B (0.3%), and Cu (0.7%) produced the best results in terms of juice percentage (28.16%), total soluble solids (10.49°B), ascorbic acid (38.52 mg/100 ml), reducing sugar (4.95%), non-reducing sugar (1.95%), total sugar (6.90%), and minimal titratable acidity (0.89%). This micronutrient treatment proved most effective in enhancing the quality attributes of sweet orange fruits.

Table no. 4.16: Effect of nano-Zn and nano-Cu on antioxidants (%), firmness (kg/in^2) and pectin content (%) of guava.

Treatments	Quality of guava fruit (at harvest stage)								
	Antioxidants (%)			Firmness (kg/in^2)			Pectin content (%)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pool
T_1	39.58±0.017^{a}	40.00±0.036^{a}	39.79±0.176^{a}	5.00±0.013^{a}	5.00±0.046^{a}	5.00±0.078^{a}	1.47±0.012^{a}	1.55±0.014^{a}	1.51±0.01^{a}
T_2	45.60±0.191^{bc}	45.98±0.202^{c}	45.79±0.198^{bc}	5.17±0.02^{a}	5.33±0.035^{ab}	5.25±0.033^{ab}	1.57±0.026^{ab}	1.72±0.037^{b}	1.65±0.032^{b}
T_3	45.43±0.115^{b}	45.72±0.094^{b}	45.58±0.105^{b}	5.31±0.33^{a}	5.46±0.33^{bc}	5.39±0.33^{ab}	1.60±0.058^{b}	1.74±0.075^{b}	1.67±0.06^{b}
T_4	45.76±0.015^{cd}	46.21±0.030^{c}	45.99±0.020^{cd}	5.38±0.29^{a}	5.47±0.014^{bc}	5.42±0.14^{ab}	1.65±0.02^{b}	1.79±0.017^{b}	1.72±0.02^{b}
T_5	45.76±0.011^{cd}	46.06±0.016^{c}	45.91±0.003^{c}	5.49±0.14^{a}	5.95±0.021^{d}	5.72±0.065^{b}	1.78±0.05^{cd}	1.91±0.040^{c}	1.85±0.04^{c}
T_6	45.85±0.014^{d}	46.50±0.017^{d}	46.18±0.015^{d}	5.39±0.24^{a}	5.66±0.020^{bcd}	5.53±0.11^{ab}	1.68±0.032^{bc}	1.78±0.023^{b}	1.74±0.027^{b}
T_7	48.17±0.014^{fg}	48.62±0.018^{f}	48.40±0.012^{f}	5.52±0.31^{a}	5.95±0.032d	5.74±0.176^{ab}	1.81±0.043^{d}	1.95±0.025^{cd}	1.88±0.033^{c}
T_8	46.20±0.008^{e}	47.14±0.020^{e}	46.67±0.014^{e}	5.71±0.10^{a}	5.90±0.24^{cd}	5.80±0.24^{b}	1.96±0.34^{e}	2.13±0.025^{e}	2.05±0.027^{d}
T_9	48.35±0.066^{g}	49.31±0.078^{h}	48.84±0.072^{g}	5.71±0.10^{a}	5.80±0.014^{cd}	5.76±0.06^{b}	2.13±0.03^{f}	2.31±0.031^{f}	2.22±0.032^{e}
T_{10}	48.06±0.017^{f}	48.91±0.020^{g}	48.49±0.018^{f}	5.59±0.22^{a}	5.54±0.035^{bcd}	5.57^{b}±0.12	1.89±0.045^{de}	2.04±0.037^{de}	1.96±0.040^{cd}
S. Em (±)	0.440	0.463	0.451	0.070	0.064	0.062	0.036	0.040	0.038

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(nano-Cu_1(20ppm)], T_5 [nano-Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ nano-Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ nano-Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ nano-Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ nano-Cu_2(30ppm)], T_{10} [$ZnSO_4$]

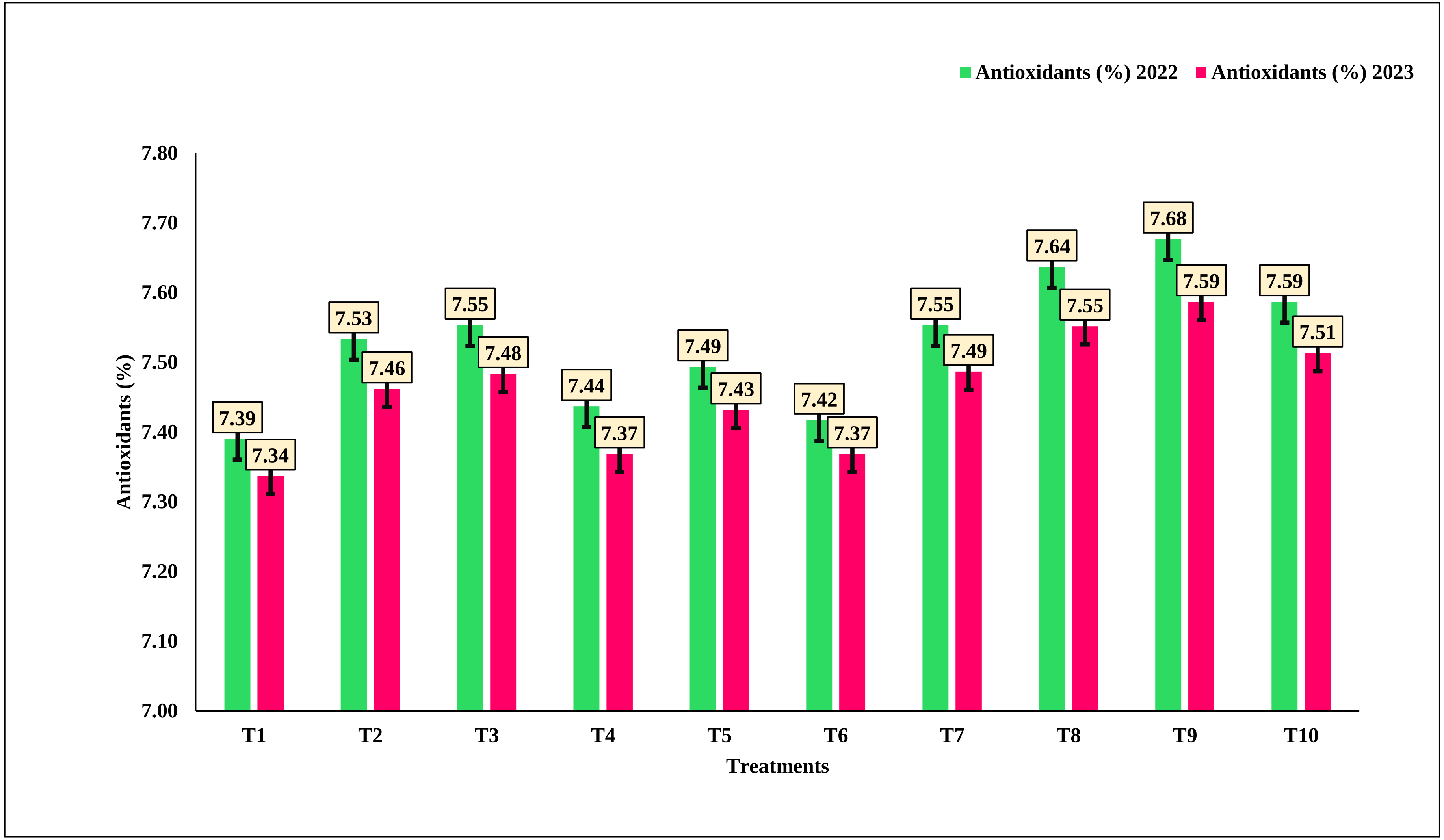

Fig. 4.47: Effect of nano-Zn and nano-Cu on antioxidants (%) in guava

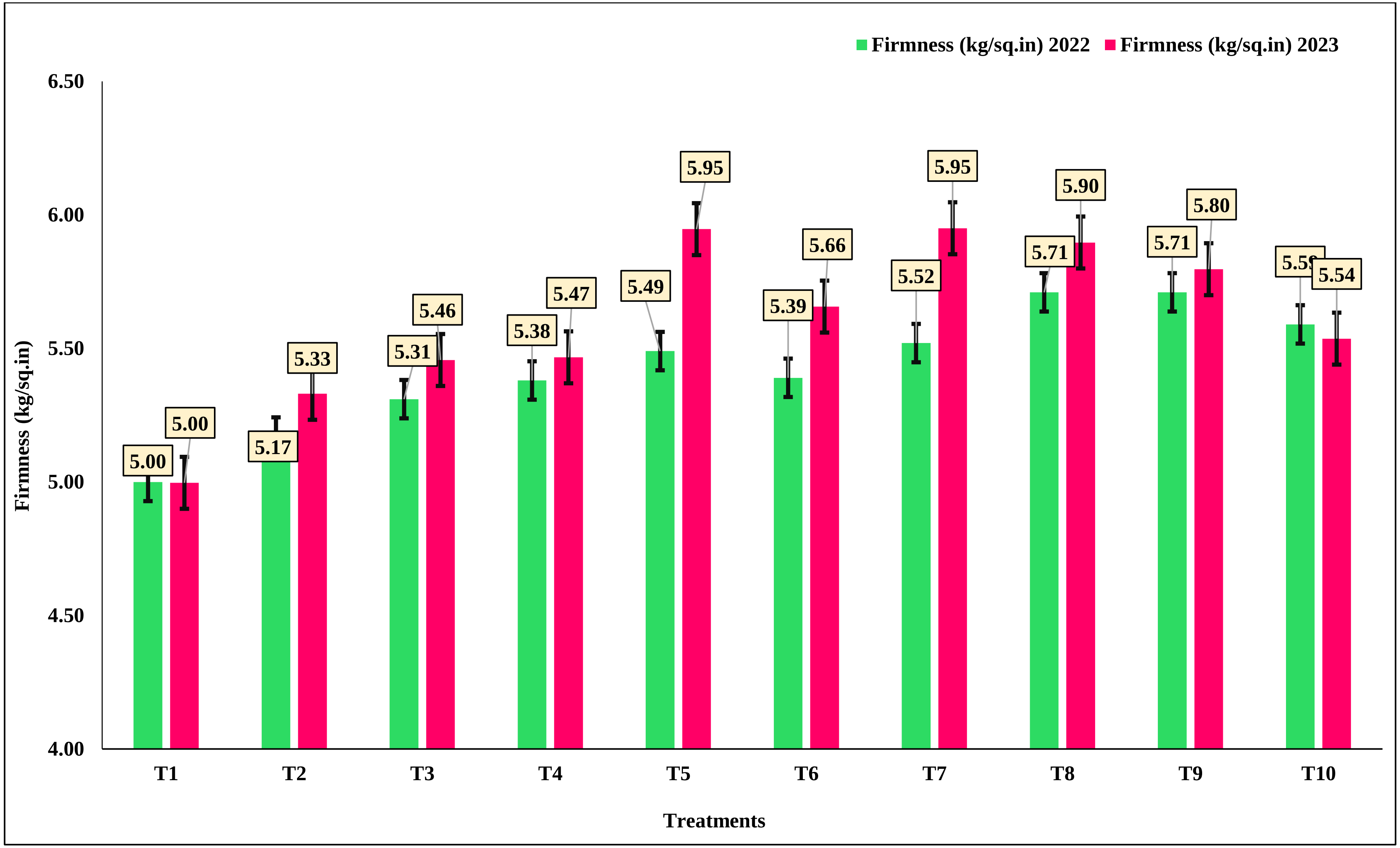

Fig. 4.48: Effect of nano-Zn and nano-Cu on firmness (kg/in^2) in guava

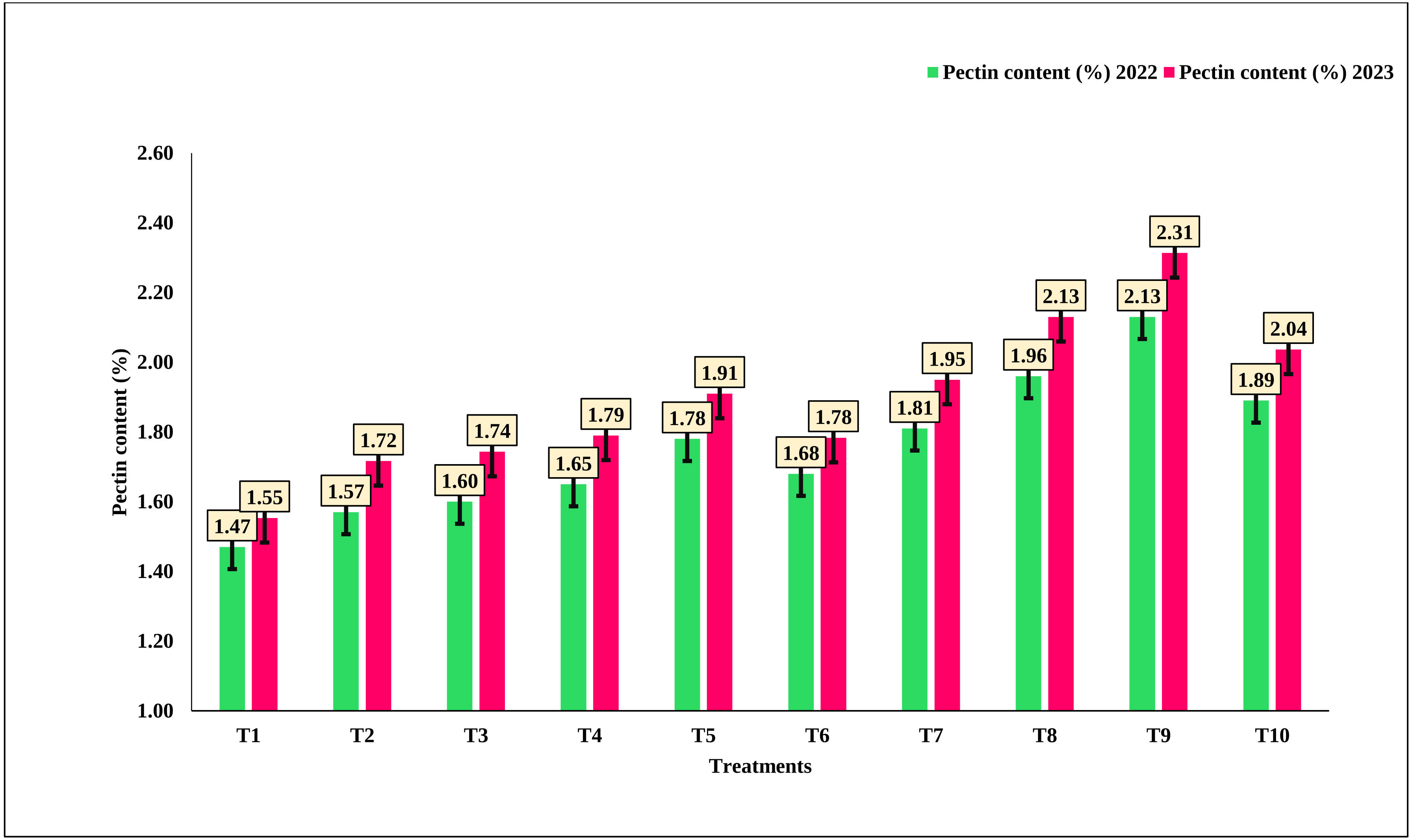

Fig. 4.49: Effect of nano-Zn and nano-Cu on pectin content (%) in guava

4.6 Impact of nano zinc and nano copper on shelf life of guava fruits

4.6.1 Total Sugars (%) (0 DAS)

Table no. 4.17 shows the data on the variation in the total sugars % on the zero day of storage during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments have positive impact on total sugars (%) on the zero day in guava during the experiment, graphically presented in figure no.4.50.

During 2022, the highest total sugars (%) on the zero day was under treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 8.74% were recorded which was gradually different from all the treatments. The minimum total sugars on the zero day 8.12% was observed in treatment T_1 (Control).

In the second trial year (2023), statistically, treatments made a substantial impact on the total sugars (%) at the zero day of guava fruits storage. The maximum total sugars at zero day 8.93 % was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] it is substantially maximum from other treatments. The lowermost total sugars at the zero day 8.20 % was in T_1 (Control).

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the maximum total sugars at the zero day, the value of 8.84 % it is substantially maximum other treatments. In contrast, treatment T_1 had the lowest total sugars at the zero day, with a value of 8.16 %.

4.6.2 Total sugars (%) (4 DAS)

Table 4.17 shows the data on the variation in the total sugars (%) on the fourth day of storage during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments impact on total sugars (%) on the fourth day in guava during experimental trials, graphically presented in figure no.4.51.

During 2022, higher total sugars (%) on the fourth day of storage was under T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 8.90 % were recorded which was gradually more than all the treatments. The minimum total sugars on the fourth day of storage (8.32 %) were recorded in treatment T_1 (Control) which was at nominal with T_2, T_3, and T_4 with the values 8.34, 8.34, and 8.34 percent respectively.

In the second years trial year (2023), statistically, treatments made a substantial impact on the total sugars percent on the fourth day of guava fruits storage. The highest total sugars % on the fourth day was in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 9.08 % it was substantially maximum from other treatments. The lowest total sugars on the fourth day of storage 8.40 % was in T_1 (Control).

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the maximum total sugars on the fourth day, value 8.99 % it is substantially maximum from other treatments. In contrast, treatment T_1 had the lowest total sugars on the fourth day, with a value of 8.36 %.

4.6.3 Total sugars (%) (8 DAS)

Table no. 4.17 shows the data on the variation in the total sugars (%) on the eight day of storage during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments impact on total sugars (%) on the eighth day of storage in guava during both years of the experiment, graphically presented in figure no.4.52.

During 2022, the higher total sugars (%) on the eighth day of storage was under T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 9.29 % were recorded which was gradually more than all the treatments. The minimum total sugars on the eighth day of storage were 8.84 % which was noticed in treatment T_1 (Control).

In 2023, statistically, treatments made a substantial impact on the total sugars (%) on the eighth day of guava fruit storage. The Maximum total sugars on the eighth day of storage were recorded on treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 9.48 % with substantially higher than all the treatments. The lowest total sugars on the eighth day were 8.92 % in treatment T_1 (Control).

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the maximum total sugars on the eighth day, value of 9.39 % it is substantially maximum from the other treatments. In contrast, treatment T_1 had the lowest total sugars on the eighth day, with a value of 8.88 %.

4.6.4 Total sugars (%) (12 DAS)

Table 4.17 shows the data on the variation in the total sugars (%) on the twelfth day of storage during the two years of the experiment (2022 and 2023) along with the pooled data. A keen perusal of the data indicates that there is a substantial consequence of different nano-

Table no. 4.17: Effect of nano-Zn and nano-Cu on total sugars (%) at 0 DAS, 4 DAS, 8 DAS, and 12 DAS of guava.

No. of days	Total sugars (%)											
	0 (DAS)			4 (DAS)			8 (DAS)			12 (DAS)		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_1	8.12±0.01^{a}	8.20±0.01^{a}	8.16±0.01^{a}	8.32±0.01^{a}	8.40±0.01^{a}	8.36±0.01^{a}	8.84±0.01^{a}	8.92±0.02^{a}	8.88±0.01^{a}	8.48±0.03^{a}	9.12±0.06^{a}	8.80±0.01^{a}
T_2	8.20±0.008^{b}	8.35±0.005^{b}	8.28±0.00^{b}	8.34±0.01^{ab}	8.48±0.02^{b}	8.41±0.01^{b}	8.88±0.003^{b}	9.03±0.01^{b}	8.96±0.005^{b}	9.92±0.01^{b}	10.04±0.03^{b}	9.98±0.01^{b}
T_3	8.24±0.01^{bc}	8.39±0.008^{b}	8.32±0.005^{bc}	8.34±0.003^{ab}	8.48±0.01^{b}	8.41±0.006^{b}	8.89±0.008^{b}	9.04±0.02^{b}	8.97±0.01^{b}	9.94±0.008^{bc}	10.08±0.01^{bc}	10.01±0.008^{b}
T_4	8.25±0.02^{bc}	8.39±0.02^{b}	8.32±0.02^{c}	8.34±0.003^{ab}	8.48±0.003^{b}	8.42±0.003^{b}	8.93±0.005^{c}	9.07±0.008^{bc}	9.00±0.005^{bc}	9.95±0.01^{bc}	10.09±0.01^{bc}	10.03±0.01^{b}
T_5	8.35±0.02^{d}	8.47±0.01^{c}	8.41±0.01^{d}	8.43±0.01^{c}	8.55±0.006^{c}	8.49±0.008^{c}	8.96±0.008^{d}	9.09±0.01^{bc}	9.03±0.01^{cd}	10.02±0.01^{d}	10.15±0.02^{cd}	10.09±0.01^{c}
T_6	8.26±0.01^{c}	8.36±0.02^{b}	8.31±0.01^{bc}	8.35±0.01^{b}	8.45±0.01^{b}	8.41±0.00^{ab}	8.93±0.003^{c}	9.03±0.008^{b}	8.99±0.003^{bc}	9.98±0.01^{cd}	10.08±0.01^{bc}	10.03±0.01^{b}
T_7	8.47±0.01^{e}	8.61±0.01^{d}	8.54±0.008^{e}	8.60±0.008^{d}	8.74±0.01^{d}	8.67±0.01^{d}	8.97±0.01^{d}	9.11±0.02^{c}	9.04±0.01^{d}	10.07±0.01^{e}	10.21±0.02^{d}	10.14±0.01^{d}
T_8	8.64±0.02^{g}	8.82±0.003^{f}	8.73±0.008^{g}	8.77±0.01^{f}	8.94±0.02^{f}	8.86±0.02^{f}	9.17±0.01^{f}	9.35±0.03^{e}	9.26±0.02^{f}	10.17±0.01^{f}	10.34±0.02^{e}	10.26±0.01^{e}
T_9	8.74±0.008^{h}	8.93±0.01^{g}	8.84±0.01^{h}	8.9±0.005^{g}	9.08±0.01^{g}	8.99±0.006^{g}	9.29±0.008^{g}	9.48±0.02^{f}	9.39±0.01^{g}	10.42±0.01^{g}	10.61±0.02^{f}	10.52±0.02^{f}
T_{10}	8.54±0.02^{f}	8.690.01^{e}	8.62±0.01^{f}	8.67±0.008^{e}	8.82±0.01^{e}	8.75±0.003^{e}	9.04±0.008^{e}	9.19±0.02^{d}	9.12±0.01^{e}	10.16±0.02^{f}	10.31±0.01^{e}	10.23±0.01^{e}
S. Em (±)	0.03681	0.04105	0.03882	0.03752	0.04178	0.03983	0.02505	0.02971	0.02728	0.09	0.06828	0.08002

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ Cu_2(30ppm)], T_{10} [$ZnSO_4$]

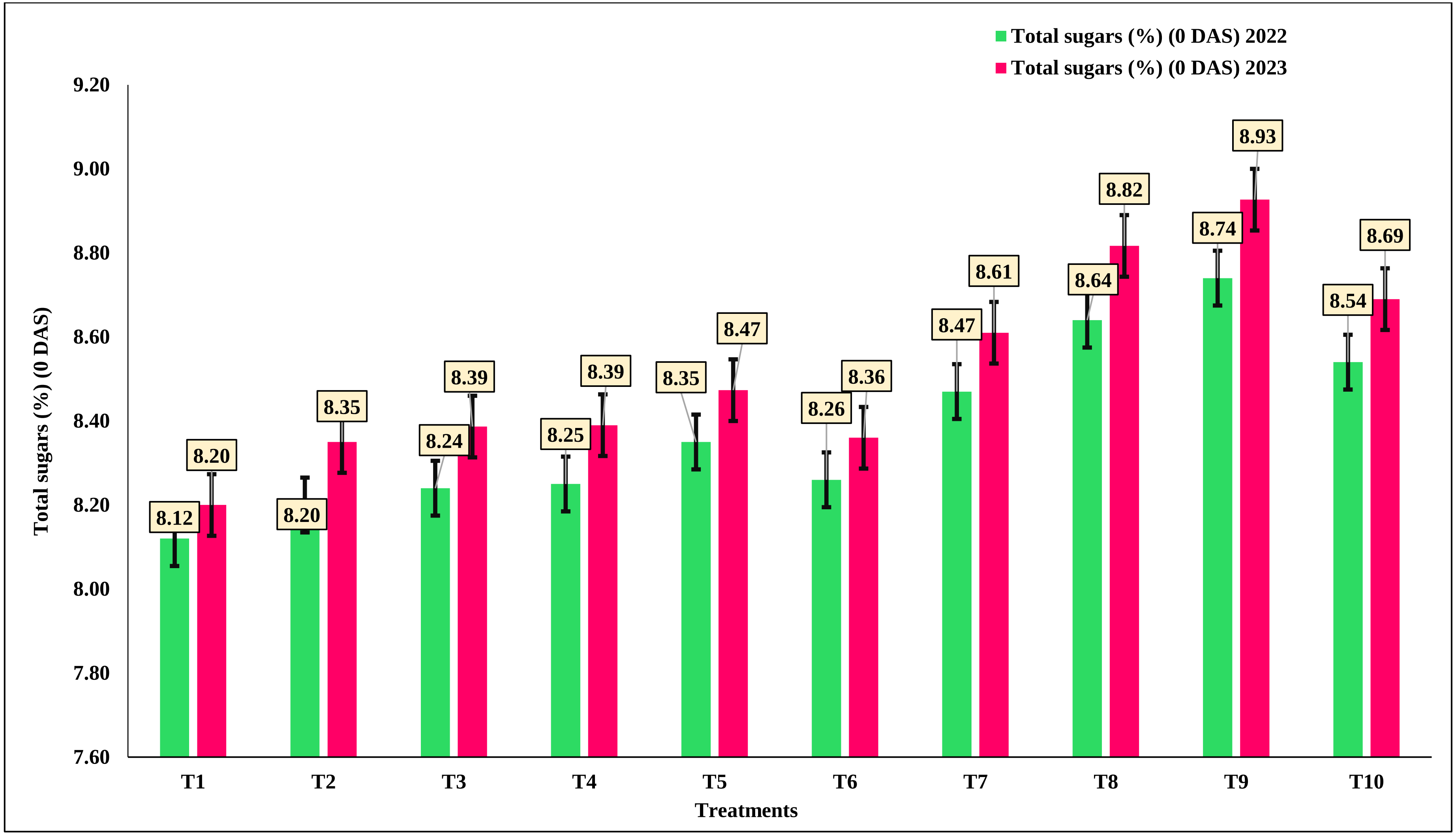

Fig. 4.50: Effect of nano-Zn and nano-Cu on total sugars % (0 DAS) in guava

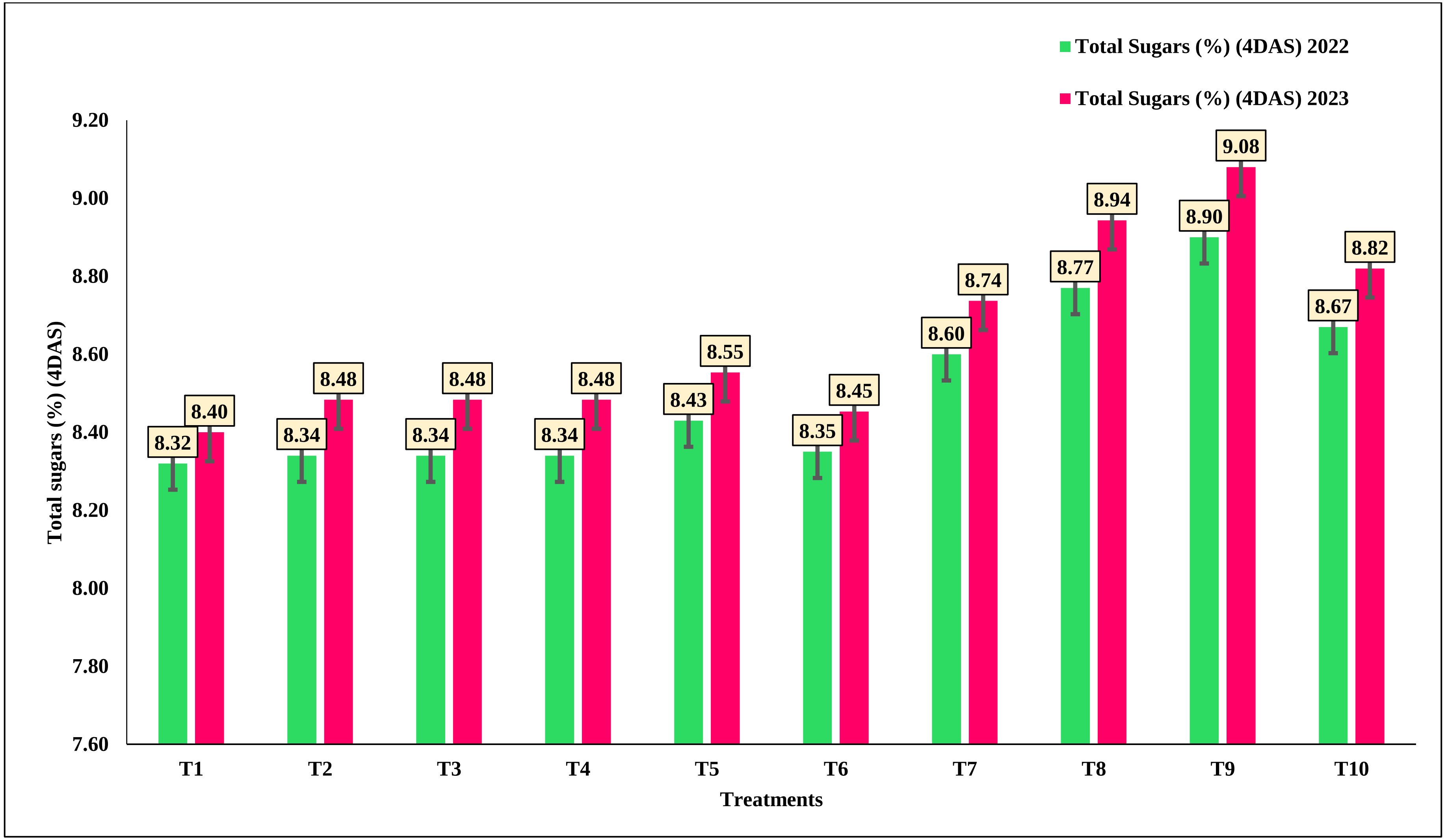

Fig. 4.51: Effect of nano-Zn and nano-Cu on total sugars % (4 DAS) in guava

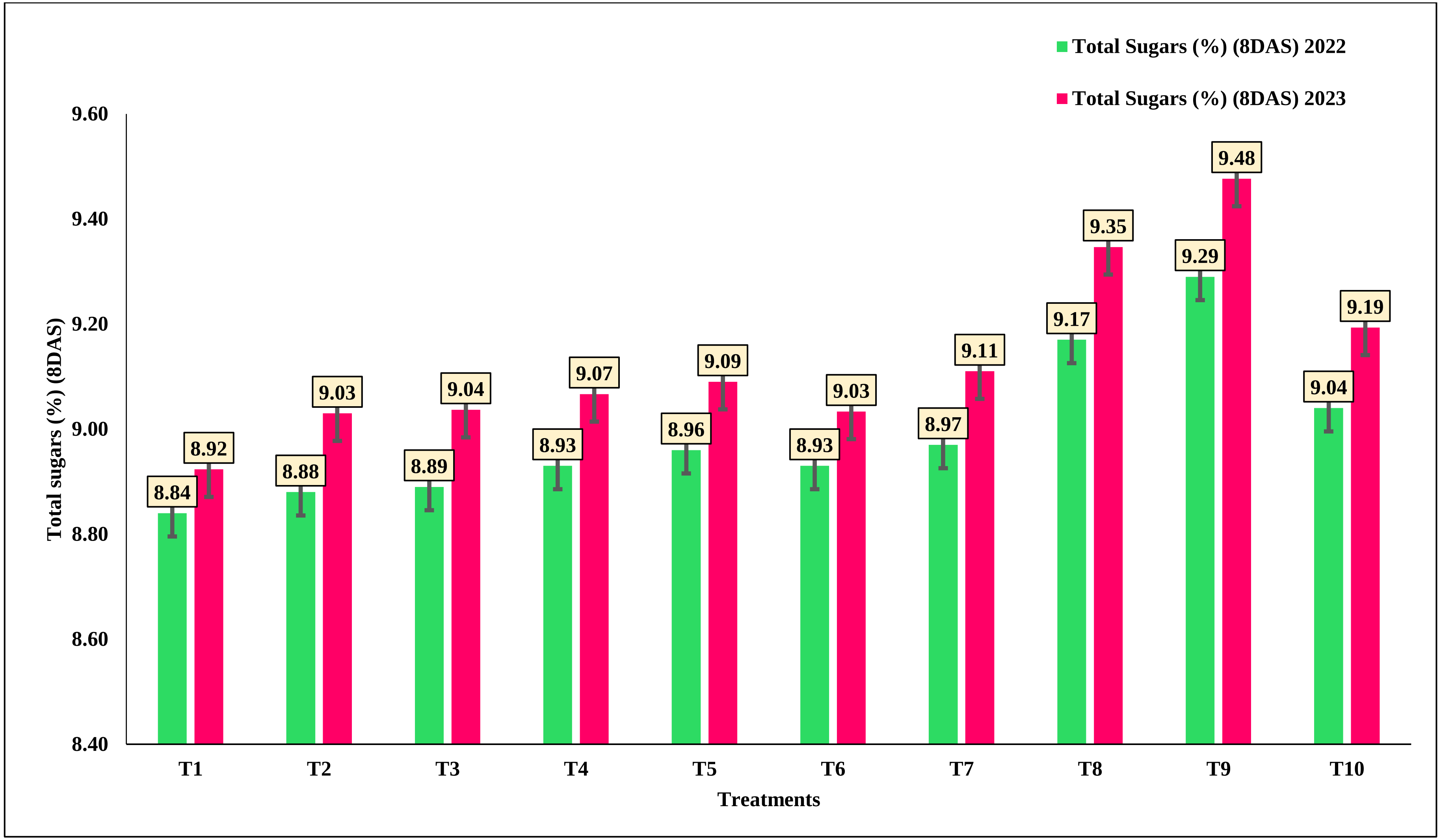

Fig. 4.52: Effect of nano-Zn and nano-Cu on total sugars % (8 DAS) in guava

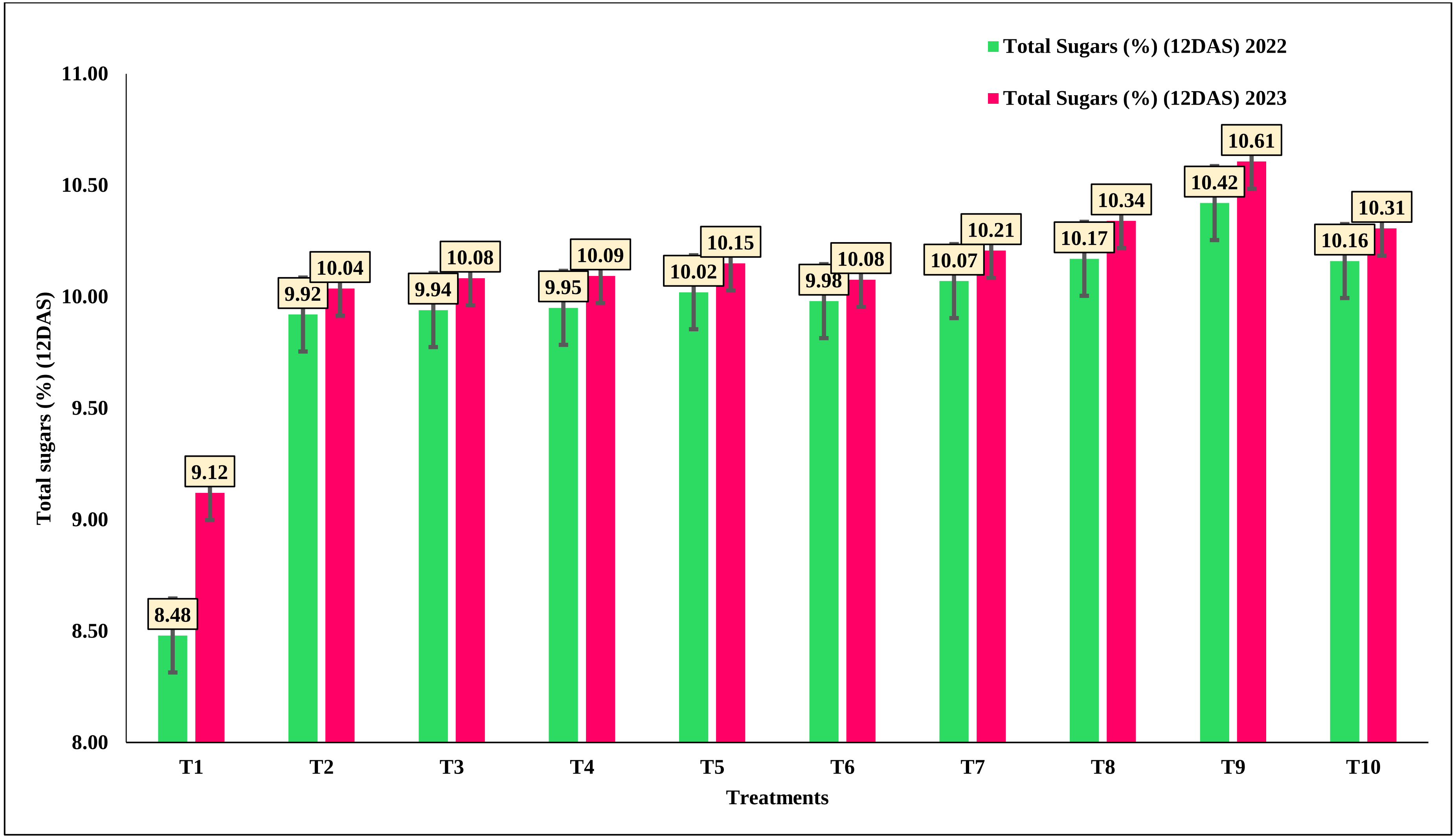

Fig. 4.53: Effect of nano-Zn and nano-Cu on total sugars % (12 DAS) in guava

micronutrient treatments on total sugars (%) on the twelfth day of storage in guava during both years of the experiment, graphically presented in figure no.4.53.

During 2022, the higher total sugars (%) on the twelfth day of storage was under T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 10.42 % were recorded which was gradually more than all the treatments. The minimum total sugars on the twelfth day of storage were 8.48 % which was noticed in treatment T_1 (Control).

In 2023, statistically, treatments made a substantial impact on the total sugars % on the twelfth day of guava fruit storage. The Maximum total sugars on the twelfth day of storage were recorded on treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 10.61 % substantially higher than all the treatments. The lowest total sugars on the twelfth day were 9.12 % in treatment T_1 (Control).

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the maximum total sugars on the twelfth day, value of 10.52 % it is substantially maximum from other treatments. In contrast, treatment T_1 had the lowest total sugars on the twelfth day, with a value of 8.80 %.

4.6.5 Reducing sugars (%) (0 DAS)

Table no. 4.18 presents the data on the variation in reducing sugars (%) during the two-year experiment (2022 and 2023). A detailed analysis of the data reveals a substantial impact of various nano-micronutrient treatments on the reducing sugars of the guava during both years of the experiment, graphically presented in figure no.4.54.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was recorded with the maximum reducing sugars % on the zero day of storage was 5.46 % it is substantially maximum from other treatments. Lowest value reducing sugars % on the zero day of storage were 4.95 % recorded in treatment T_1 (Control).

In 2023, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum reducing sugars % on the zero day of storage, which was 5.28% it is substantially maximum from other treatments. Rest of the treatments showed substantial differences in reducing sugars on the zero day of storage. Treatment T_1 (Control) recorded the lowest reducing sugars on the zero day of storage was 4.87 % at nominal with T_2 (nano-Zn (40ppm)) with a value of 4.89 %.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum reducing sugars on the zero day of storage, value of 5.37% it is substantially maximum from other treatments. Instead, the T_1 (Control) was observed with the lowest reducing sugars % on the zero day of storage, a value of 4.91%.

4.6.6 Reducing sugars (%) (4 DAS)

Table no. 4.18 presents the data on the variation in reducing sugars % on the fourth day of storage during the two-year experiment (2022 and 2023). A detailed analysis of the data reveals a substantial impact of various nano-micronutrient treatments on the fruit-reducing sugars % on the fourth day of storage of the guava during both years of the experiment, graphically presented in figure no.4.55.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was recorded with the maximum reducing sugars % on the fourth day of storage was 5.57 % it is substantially maximum from other treatments. Lowermost reducing sugars % on the fourth day of storage were 5.08 % recorded in treatment T_1 (Control).

In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum reducing sugars % on the fourth day of storage, which was 5.39 % it is substantially maximum from other treatments. Rest of the treatments showed substantial differences in reducing sugars on the fourth day of storage. Treatment T_1 (Control) recorded the lowest reducing sugars % on the fourth day of storage was 5.00 % at nominal with T_2 (nano-Zn_1 (40ppm)) with a value of 5.00 %.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] ensued in the superior reducing sugars % on the fourth day of storage, with a value of 5.48 % it was substantially superior from other treatments. Instead, treatment T_1 (Control) was observed with the lowest reducing sugars % on the fourth day of storage, value of 5.04 % at nominal with treatment T_2 (nano-Zn (40ppm)) with a value of 5.07 %.

4.6.7 Reducing sugars (%) (8 DAS)

Table no. 4.18 presents the data on the variation in reducing sugars (%) on the eighth day of storage during the two-year experiment (2022 and 2023). A detailed analysis of the data reveals a substantial impact of nano-micronutrient treatments on the reducing sugars on the eighth day of storage of the guava during both years of the experiment, graphically presented in figure no.4.56.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was recorded with the highest reducing sugars on the eighth day of storage was 5.68 % it is substantially maximum from other treatment. Lowermost reducing sugars % on the eighth day of storage were 5.17 % recorded in treatment T_1 (Control).

In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum reducing sugars on the eighth day of storage, which was 5.50 % it is substantially maximum from other treatments. Rest of treatments showed substantial differences in reducing sugars on the eighth day of storage. Treatment T_2 (nano-Zn (40ppm)) recorded the lowest reducing sugars on the eighth day of storage was 5.08 % at nominal with T_1 (Control) with a value of 5.09 %.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum reducing sugars on the eighth day of storage, value of 5.59 % it is substantially maximum from other treatments. Instead, treatment T_1 (Control) was experiential with the lowermost reducing sugars on the eighth day of selflife study, value of 5.13 % at nominal with T_2 (nano-Zn (40ppm)) with a value of 5.15 %.

4.6.8 Reducing sugars (%) (12 DAS)

Table no. 4.18 presents the data on the variation in reducing sugars (%) on the twelfth day of storage during the two-year experiment (2022 and 2023). A detailed analysis of the data reveals a substantial impact of various nano-micronutrient treatments on the reducing sugars on the twelfth day of storage of the guava during both years of the experiment graphically presented in figure no.4.57.

In 2022, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was noted with the superior reducing sugars % on the twelfth day of self-life study was 6.16 % it is substantially superior from other treatments. Instead, lowermost reducing sugars % on the twelfth day of self-life studies were 5.05 % noted in treatment T_1.

In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the highest reducing sugars % on the twelfth day of self-life studies, which was 5.99 % it is substantially maximum from other treatments. Rest of the treatments showed substantial differences in reducing sugars % on the twelfth day of storage. Treatment T_1 (Control) recorded the lowest reducing sugars % on the twelfth day of storage was 5.12 %.

Table no. 4.18: Effect of nano-Zn and nano-Cu on reducing sugars (%) at 0 DAS, 4 DAS, 8 DAS, and 12 DAS of guava.

Treatments	Reducing sugars (%)											
	1 (DAS)			4 (DAS)			8 (DAS)			12 (DAS)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	4.95±0.01^{a}	4.87±0.01^{a}	4.91±0.01^{a}	5.08±0.01^{a}	5.00±0.005^{a}	5.04±0.006^{a}	5.17±0.005^{a}	5.09±0.01^{a}	5.13±0.008^{a}	5.05±0.01^{a}	5.12±0.02^{a}	5.09±0.01^{a}
T_2	5.03±0.008^{b}	4.89±0.01^{a}	4.96±0.008^{b}	5.14±0.01^{b}	5.00±0.01^{a}	5.07±0.001^{a}	5.22±0.01^{b}	5.08±0.01^{a}	5.15±0.01^{a}	5.45±0.008^{b}	5.32±0.01^{b}	5.39±0.01^{b}
T_3	5.08±0.008^{c}	4.95±0.02^{b}	5.02±0.01^{c}	5.21±0.003^{c}	5.08±0.01^{b}	5.15±0.01^{b}	5.31±0.008^{c}	5.17±0.02^{b}	5.24±0.01^{b}	5.49±0.01^{b}	5.35±0.02^{b}	5.42±0.01^{b}
T_4	5.12±0.008^{d}	4.99±0.005^{b}	5.06±0.005^{d}	5.24±0.008^{cd}	5.11±0.01^{b}	5.18±0.01^{b}	5.31±0.14^{c}	5.18±0.01^{b}	5.25±0.01^{b}	5.56±0.01^{c}	5.43±0.008^{c}	5.50±0.008^{c}
T_5	5.19±0.01^{e}	5.07±0.02^{cd}	5.14±0.02^{e}	5.28±0.006^{ef}	5.16±0.01^{c}	5.22±0.008^{c}	5.35±0.008^{d}	5.23±0.01^{c}	5.30±0.008^{c}	5.71±0.01^{d}	5.59±0.01^{d}	5.65±0.01^{d}
T_6	5.15±0.01^{d}	5.05±0.003^{c}	5.10±0.006^{e}	5.26±0.01^{de}	5.16±0.006^{c}	5.21±0.008^{c}	5.33±0.01^{cd}	5.24±0.006^{c}	5.29±0.008^{c}	5.68±0.01^{d}	5.59±0.02^{d}	5.64±0.01^{d}
T_7	5.20±0.003^{e}	5.07±0.017^{cd}	5.14±0.008^{e}	5.30±0.008^{f}	5.17±0.02^{c}	5.24±0.01^{c}	5.40±0.008^{e}	5.27±0.01^{c}	5.34±0.01^{d}	5.85±0.02^{e}	5.72±0.01^{e}	5.79±0.01^{e}
T_8	5.34±0.008^{g}	5.18±0.02^{e}	5.26±0.01^{g}	5.48±0.008^{h}	5.32±0.02^{e}	5.40±0.01^{e}	5.61±0.008^{g}	5.44±0.02^{e}	5.53±0.01^{f}	6.07±0.03^{g}	5.90±0.05^{g}	5.99±0.04^{g}
T_9	5.46±0.008^{h}	5.28±0.006^{f}	5.37±0.003^{h}	5.57±0.01^{i}	5.39±0.008^{f}	5.48±0.008^{f}	5.68±0.008^{h}	5.50±0.02^{f}	5.59±0.01^{g}	6.16±0.01^{h}	5.99±0.02^{h}	6.08±0.01^{h}
T_{10}	5.26±0.01^{f}	5.11±0.02^{d}	5.19±0.01^{f}	5.37±0.005^{g}	5.22±0.01^{d}	5.30±0.008^{d}	5.48±0.006^{f}	5.34±0.01^{d}	5.41±0.01^{e}	5.94±0.01^{f}	5.79±0.02^{f}	5.87±0.01^{f}
S. Em (±)	0.02	0.02307	0.02466	0.02	0.02266	0.02434	0.02	0.02503	0.02673	0.05	0.04319	0.05351

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm) + Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm) + Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)], T_{10} [$ZnSO_4$]

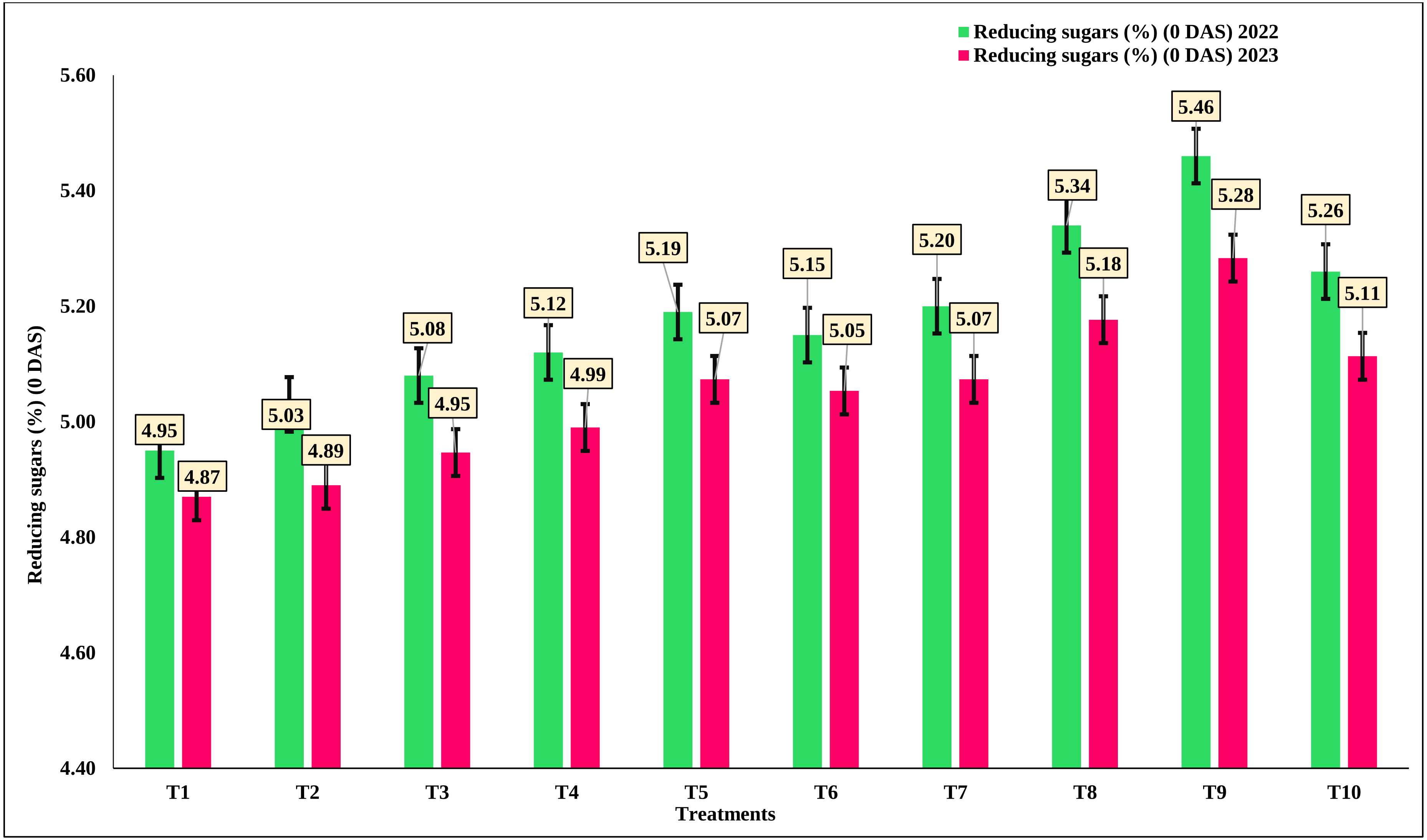

Fig. 4.54: Effect of nano-Zn and nano-Cu on reducing sugars % (0 DAS) in guava

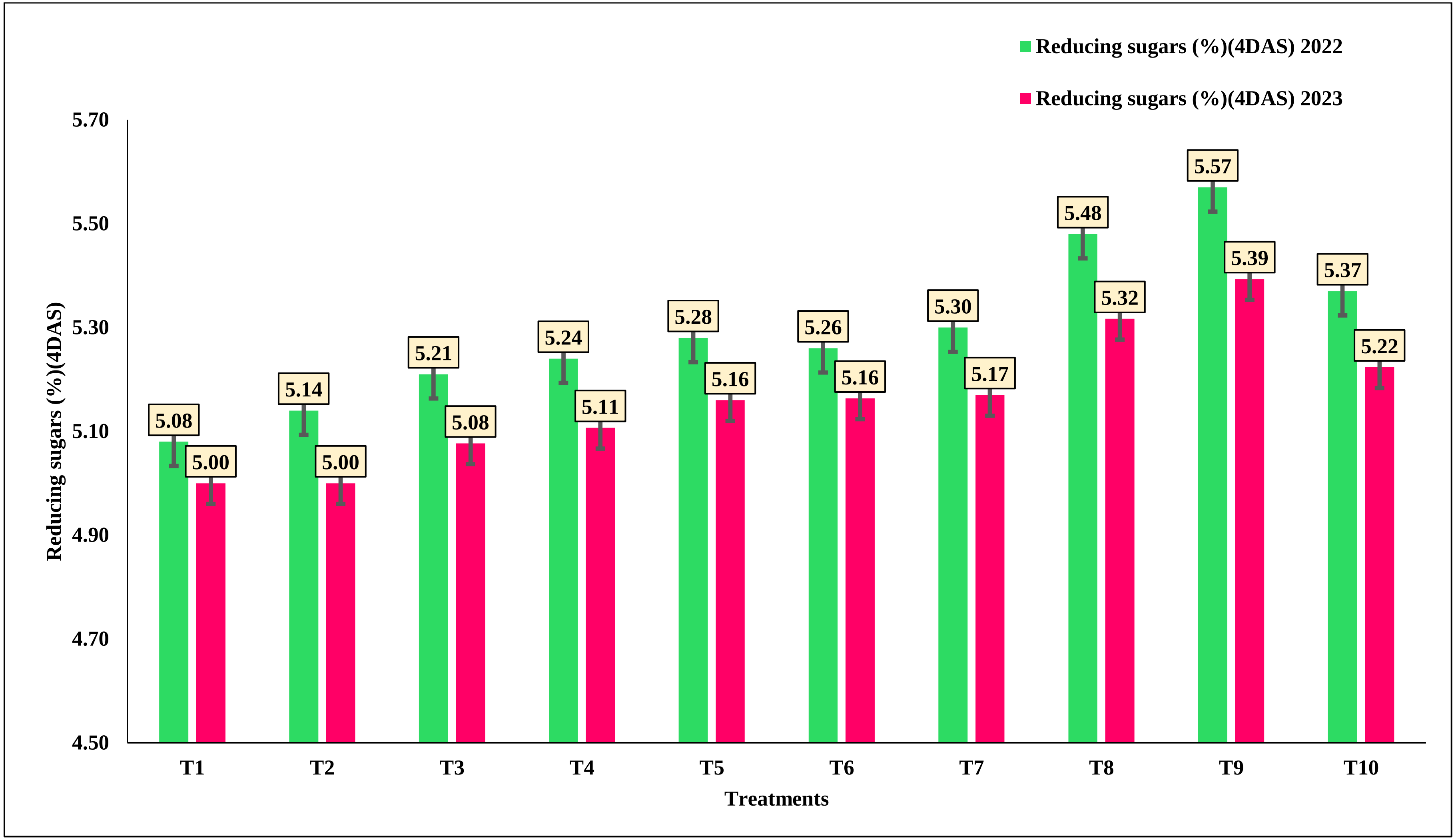

Fig. 4.55: Effect of nano-Zn and nano-Cu on reducing sugars % (4 DAS) in guava

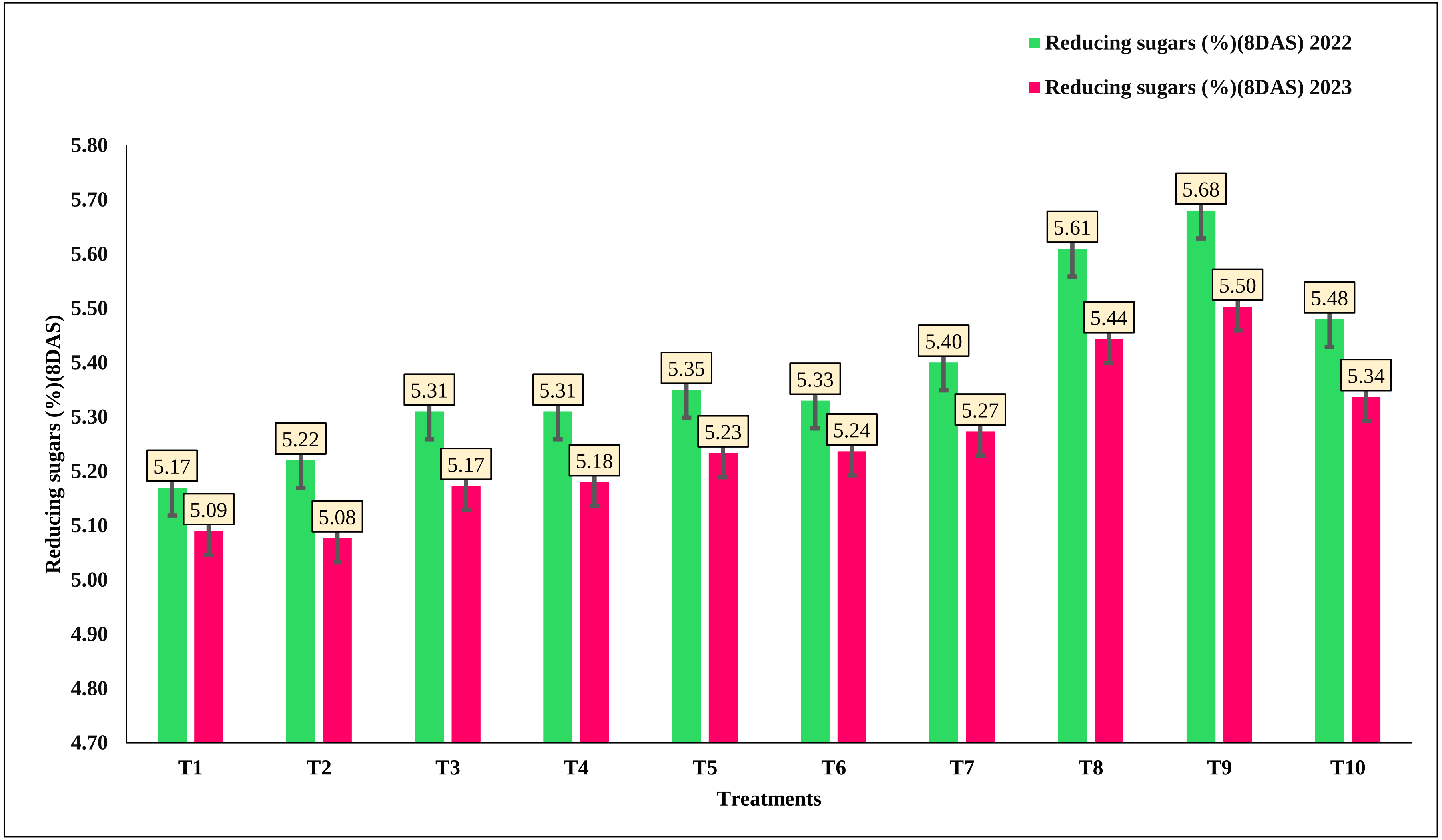

Fig. 4.56: Effect of nano-Zn and nano-Cu on reducing sugars % (8 DAS) in guava

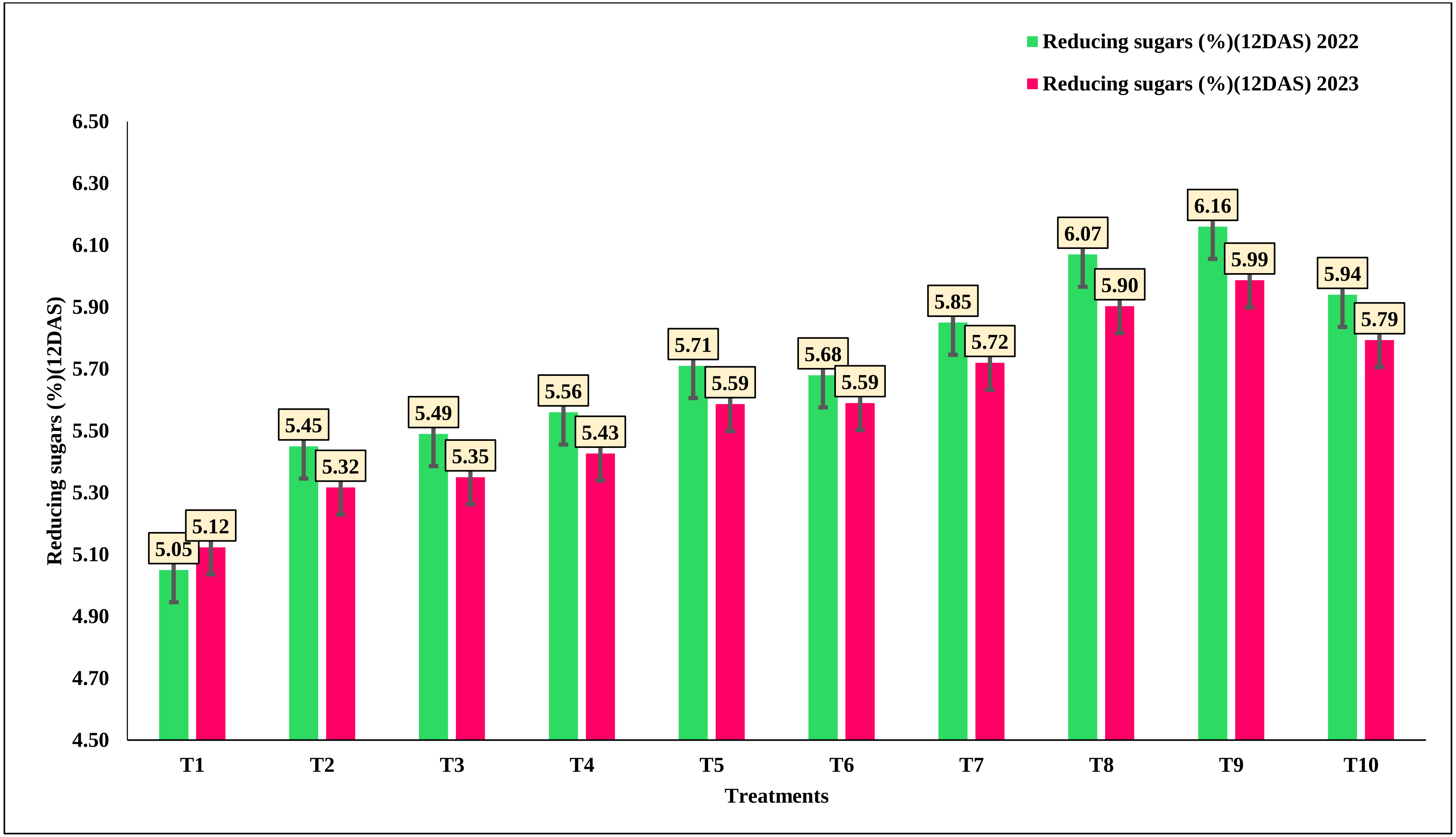

Fig. 4.57: Effect of nano-Zn and nano-Cu on reducing sugars % (12 DAS) in guava

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] ensued in superior reducing sugars % on the twelfth day of shelf-life studies, value of 6.08 % it is substantially maximum from other treatments. Hence, treatment T_1, was noted with the lowest reducing sugars on the twelfth day of shelf-life studies, value of 5.09 %.

4.6.9 Non-reducing sugars (%) (0 DAS)

Table no. 4.19 provides information about the variation in non-reducing sugars on zero day of storage observed throughout the two years of the experiment (2022 and 2023). Nano-micronutrients on non-reducing sugars % on zero day of storage in guava fruit during both the years of the experiment, graphically presented in figure no.4.58.

During the first year of the experiment (2022), the highest non-reducing sugars % on the zero day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 3.32 % this was at nominal with treatment T_8 with the value of 3.29 %. The minimum non-reducing sugars were observed in treatment T_1 with a value of 3.06 %.

In the second year of the trial (2023), The highest non-reducing sugars % on the zero day of storage were recorded in treatment T_9, using nano-Zn_2(60ppm) + Cu_2(30ppm) that was 3.64 % at nominal with T_8 (nano-Zn_2(60ppm) + Cu_1(20ppm)) with the same value of 3.64 %. Instead, treatment T_1 (Control) recorded the minimum non-reducing sugars on zero day of storage 3.33 %.

Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum non-reducing sugars on zero day of storage 3.48 %. This was at nominal with treatment T_8 (nano-Zn_2(60ppm) + Cu_1(20ppm) with the value of 3.47 %. Instead, treatment T_1 (Control) resulted in the lowest non-reducing sugars % on the zero day of storage, measuring 3.20 %. Statistically, all the treatments made a substantial impact on the non-reducing sugars on the zero day of storage of the guava plants.

4.6.10 Non-reducing sugars (%) (4 DAS)

Table no. 4.19 provides information about the variation in non-reducing sugars on the fourth day of storage observed throughout the two years of the experiment (2022 and 2023). Effect of nano-micronutrients on non-reducing sugars at fourth day of storage, fruits during the trials of the experiment, graphically presented in figure no.4.59.

During the first year of the experiment (2022), the highest value of non-reducing sugar% on the fourth day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 3.32 % this was at nominal with treatment T_8 with the value of 3.30 %. The minimum non-reducing sugars were observed in treatment T_1 with a value of 3.07 % at nominal with T_2 (nano-Zn_1 (40ppm)) with a value of 3.08 %.

In the second year of the trial (2023), The highest non-reducing sugar % at the fourth day of storage were resulted in treatment T_9, using nano-Zn_2(60ppm) + Cu_2(30ppm) that was 3.69 % at nominal with T_8 (nano-Zn_2(60ppm) + Cu_1(20ppm)) with the value of 3.63 %. Instead, treatment T_6 (nano-Zn_1(40ppm) + Cu_1(20ppm))) recorded the lowest non-reducing sugars % at the fourth day of storage was 3.29 %.

Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum non-reducing sugars on the fourth day of storage at 3.51 %. Instead, treatment T_1 (Control) resulted in the lowest non-reducing sugar % at fourth day of storage, measuring 3.24 % which was at nominal with T_2, T_3, T_4, and T_6 ranging from 3.24 to 3.28%. Statistically, all the treatments made a substantial impact on the non-reducing sugar % on the fourth day of storage of the guava plants.

4.6.11 Non-reducing sugars (%) (8 DAS)

Table no. 4.19 provides information about the variation in non-reducing sugars on the eighth day of storage observed throughout the two years of the experiment (2022 and 2023). Nano-micronutrients on non-reducing sugars on the eighth day of storage in guava fruit during both the years of the experiment, graphically presented in figure no.4.60.

During the first year of the experiment (2022), the maximum non-reducing sugars on the eighth day of shelf-life studies was recorded in T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 3.68 % this was at nominal with treatment T_8, and T_{10} with the value of 3.67 and 3.66 percent respectively. The minimum non-reducing sugars were observed in treatment T_1 with a value of 3.45 %.

In the second year of the trial (2023), The maximum non-reducing sugars on the eighth day of storage were recorded in T_9, using nano-Zn_2(60ppm) + Cu_2(30ppm) that was 3.97 % it is at nominal with treatment T_8, and T_{10} with the value of 3.90 and 3.86 percent respectively. Insted, treatment T_6 (nano-Zn_1(40ppm) + Cu_1(20ppm))) noted the lowest non-reducing sugars on the eighth day of shelf-life studies was 3.80 % it is at nominal with T_1, T_2, T_5, T_7 and T_{10} ranging from 3.83 to 3.86 percent.

Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum non-reducing sugar on the eighth day of storage at 3.83 % at nominal with treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] with value 3.79 %. Instead, treatment T_1 (Control) resulted in the lowest non-reducing sugars % on the eighth day of storage, measuring 3.64 % at nominal with treatment T_6 with a value of 3.69 %. Statistically, all the treatments made a substantial impact on the non-reducing sugars on the eighth day of storage of the guava plants.

4.6.12 Non-reducing sugars (%) (12 DAS)

Table no. 4.19 provides information about the variation in non-reducing sugars on the twelfth day of storage observed throughout the two years of the experiment (2022 and 2023). Nano-micronutrients on non-reducing sugars on the twelfth day of storage in guava fruit during both the years of the experiment, graphically presented in figure no.4.61.

During the first year of the experiment (2022), the maximum non-reducing sugars on the twelfth day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 4.58 % this was at nominal with treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] which was 4.55 %. The minimum non-reducing sugars were observed in treatment T_1 with a value of 3.43 %.

In the second year of the trial (2023), The highest non-reducing sugars on the twelfth day of storage were recorded in treatment T_3, using nano-Zn_2(60ppm) that was 4.73 % at nominal with T_2, and T_4 with the value of 4.72 and 4.67 percent respectively. Instead, treatment T_1 (control) recorded the minimum non-reducing sugars on the twelfth day of storage was 4.00 %.

Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum non-reducing sugars on the twelfth day of storage at 4.60 %. Instead, treatment T_1 (Control) resulted in the lowest non-reducing sugars% on the twelfth day of storage, measuring 3.71 %. Statistically, all the treatments made a substantial impact on the non-reducing sugars on the twelfth day of storage of the guava plants.

Zinc significantly affects the levels of total sugars, reducing sugars, and non-reducing sugars in treated plants, playing a crucial role in oxidation-reduction processes and sugar metabolism. This influence is attributed to zinc's involvement in nucleic acid and starch metabolism and its effect on various enzymes related to these biochemical pathways. Additionally, when combined with zinc, copper has been found to positively correlate with the soluble solids content and total sugars in guava fruits. These findings align with those observed

Table no. 4.19: Effect of nano-Zn and nano-Cu on non-reducing sugars (%) at 0 DAS, 4 DAS, 8 DAS, and 12 DAS of guava.

Treatments	Non-reducing sugars (%)											
	1 (DAS)			4 (DAS)			8 (DAS)			12 (DAS)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	3.06±0.01^{a}	3.33±0.01^{a}	3.20±0.01^{a}	3.07±0.012^{a}	3.40±0.02^{b}	3.24±0.014^{a}	3.45±0.021^{a}	3.83±0.02^{ab}	3.64±0.017^{a}	3.43±0.052^{a}	4.00±0.05^{a}	3.71±0.17^{a}
T_2	3.12±0.02^{b}	3.46±0.01^{b}	3.29±0.008^{c}	3.08±0.020^{a}	3.48±0.03^{c}	3.28±0.008^{ab}	3.50±0.020^{b}	3.95±0.003^{cd}	3.73±0.011^{bc}	4.17±0.031^{b}	4.72±0.04^{fg}	4.45±0.020^{c}
T_3	3.16±0.005^{bc}	3.44±0.01^{b}	3.30±0.006^{c}	3.13±0.005^{b}	3.41±0.02^{b}	3.27±0.011^{ab}	3.54±0.020^{bc}	3.86±0.02^{ab}	3.70±0.021^{b}	4.22±0.005^{bc}	4.73±0.03^{g}	4.48±0.015^{c}
T_4	3.17±0.017^{bc}	3.40±0.03^{b}	3.29±0.01^{bc}	3.17±0.031^{c}	3.38±0.008^{b}	3.28±0.014^{ab}	3.55±0.003^{bcd}	3.89±0.02^{bc}	3.72±0.014^{bc}	4.260.030^{cd}	4.67±0.01^{efg}	4.46±0.023^{c}
T_5	3.22±0.008^{de}	3.40±0.03^{b}	3.31±0.01^{c}	3.22±0.017^{cd}	3.39±0.02^{b}	3.31±0.017^{b}	3.60±0.013^{de}	3.86±0.02^{ab}	3.73±0.008^{bc}	4.30±0.012^{d}	4.56±0.01^{cde}	4.43±0.006^{bc}
T_6	3.2±0.011^{cd}	3.31±0.01^{a}	3.25±0.01^{b}	3.18±0.008^{c}	3.29±0.01^{a}	3.24±0.012^{a}	3.58±0.020^{cde}	3.80±0.003^{a}	3.69±0.011^{ab}	4.27±0.015^{cd}	4.49±0.01^{bc}	4.38±0.005^{b}
T_7	3.25±0.005^{ef}	3.54±0.006^{c}	3.39±0.006^{d}	3.24±0.003^{de}	3.57±0.01^{d}	3.41±0.006^{c}	3.61±0.013^{ef}	3.84±0.02^{ab}	3.73±0.17^{bc}	4.38±0.015^{e}	4.49±0.01^{bc}	4.43±0.014^{bc}
T_8	3.29±0.012^{gh}	3.64±0.03^{d}	3.47±0.01^{e}	3.3±0.005^{fg}	3.63±0.04^{de}	3.46±0.010^{d}	3.67±0.020^{g}	3.90±0.02^{bcd}	3.79±0.21^{de}	4.55±0.023^{g}	4.44±0.06^{b}	4.50±0.028^{c}
T_9	3.32±0.017^{h}	3.64±0.01^{d}	3.48±0.01^{e}	3.32±0.16^{g}	3.69±0.003^{e}	3.51±0.016^{e}	3.68±0.008^{g}	3.97±0.02^{d}	3.83±0.15^{e}	4.58±0.021^{g}	4.62±0.04^{def}	4.60±0.024^{d}
T_{10}	3.27±0.008^{fg}	3.58±0.01^{c}	3.43±0.003^{d}	3.27±0.003^{ef}	3.60±0.01^{d}	3.44±0.003^{cd}	3.66±0.018^{fg}	3.86±0.03^{ab}	3.76±0.16^{cd}	4.46±0.018^{f}	4.51±0.01^{bcd}	4.49±0.016^{c}
S. Em (±)	0.146	0.022	0.017	0.160	0.023	0.017	0.014	0.011	0.010	0.057	0.038	0.043

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ Cu_2(30ppm)], T_{10} [$ZnSO_4$]

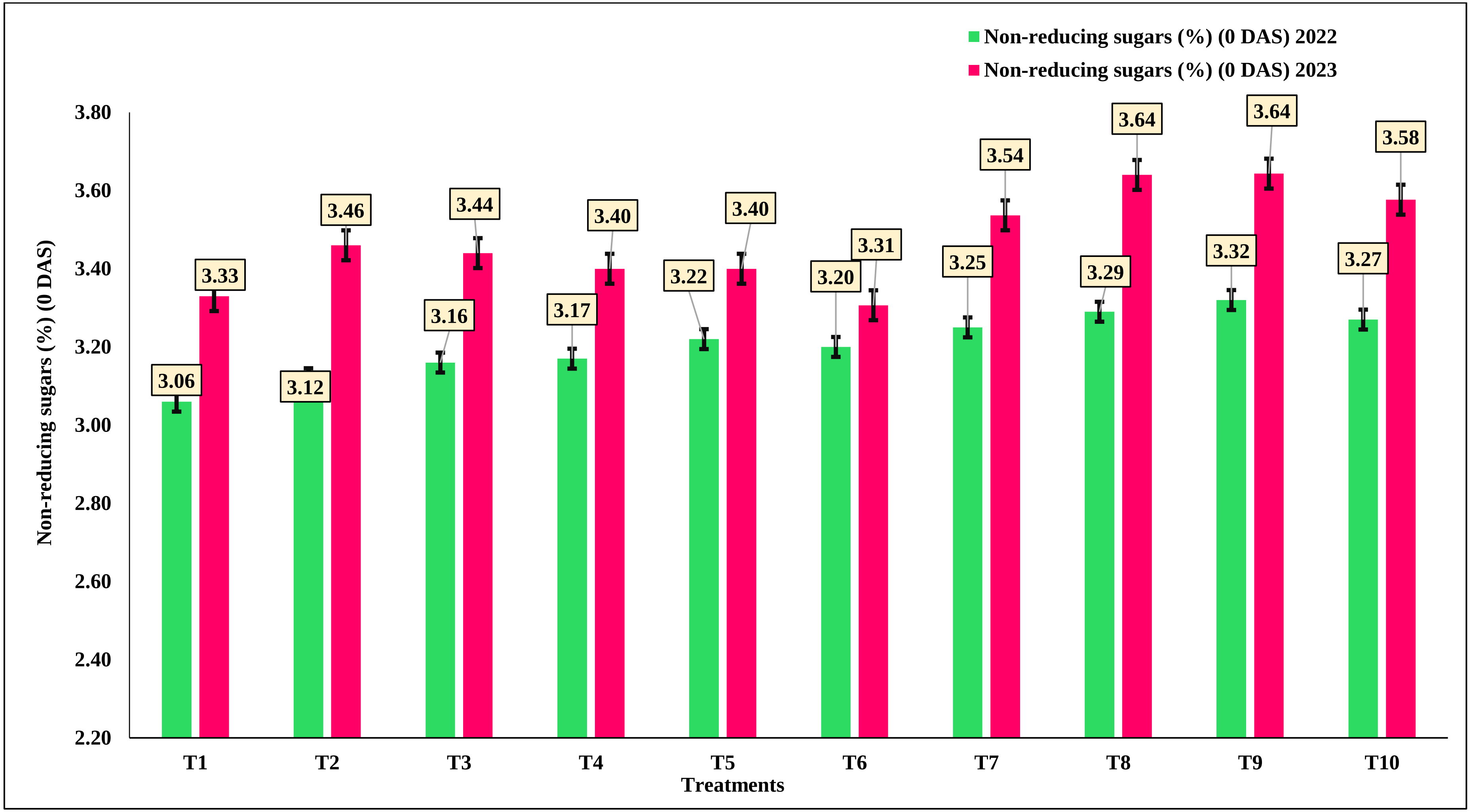

Fig. 4.58: Effect of nano-Zn and nano-Cu on non-reducing Sugars % (0 DAS) in guava

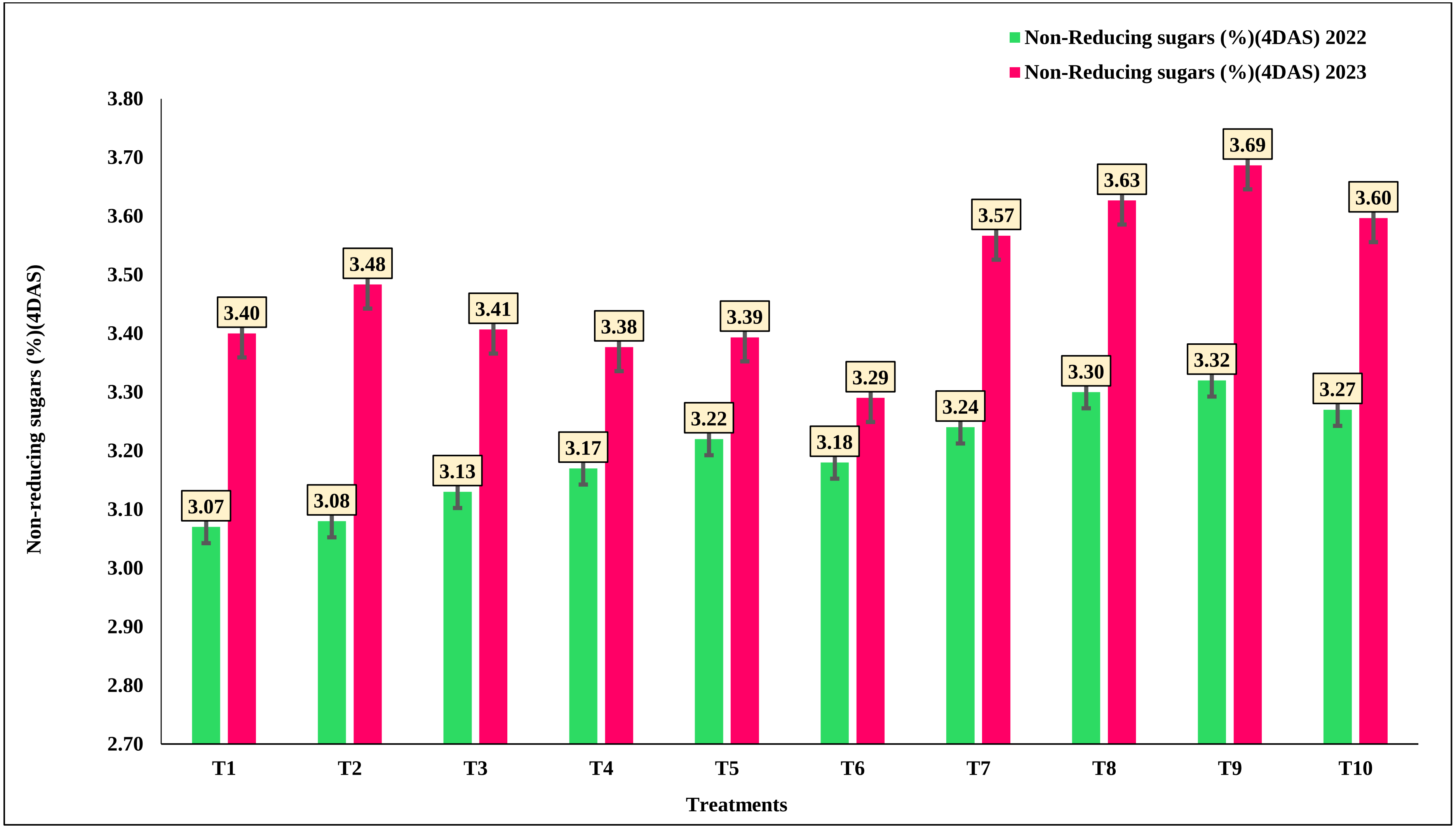

Fig. 4.59: Effect of nano-Zn and nano-Cu on non-reducing sugars % (4 DAS) in guava

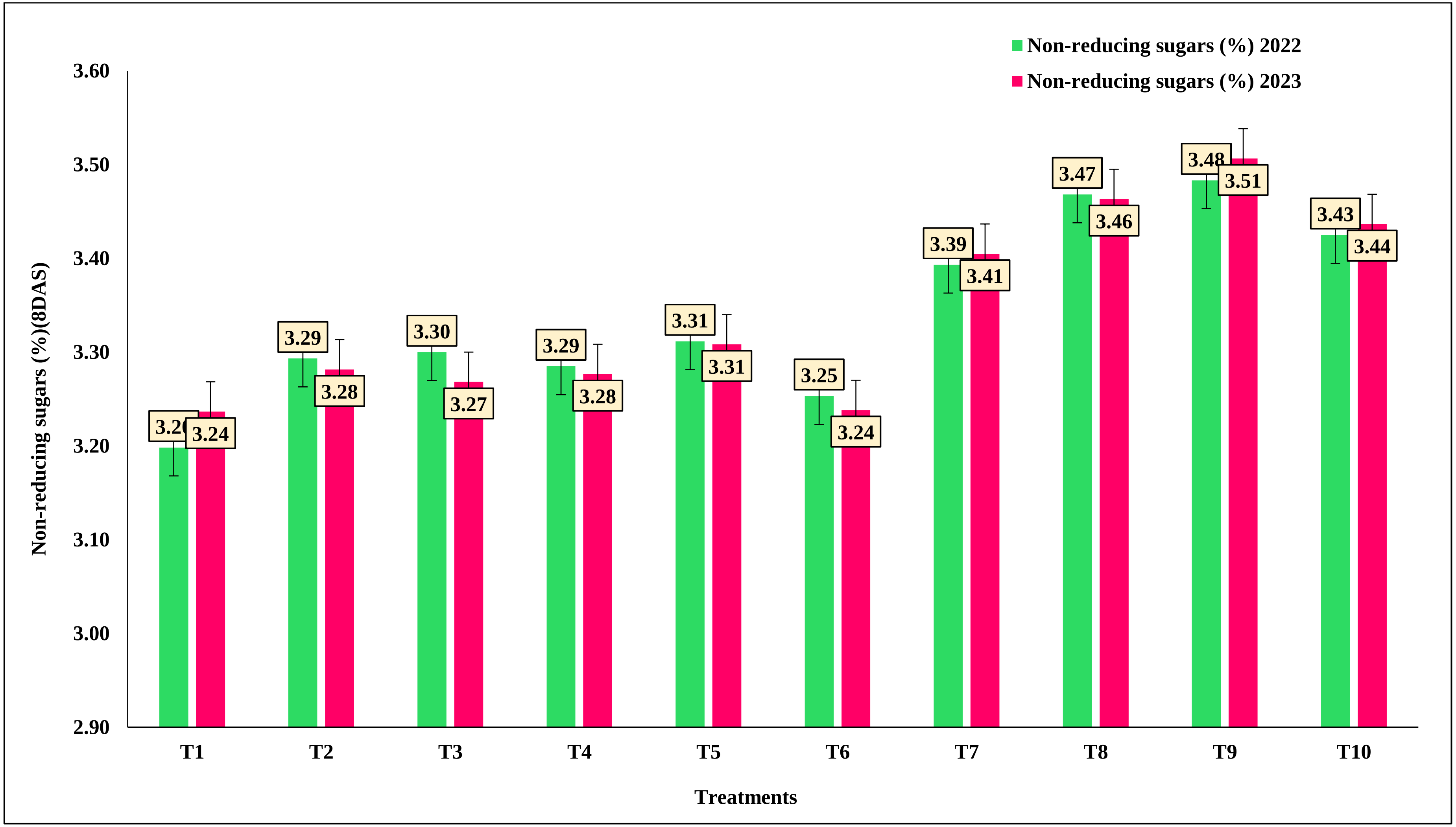

Fig. 4.60: Effect of nano-Zn and nano-Cu on non-reducing sugars % (8 DAS) in guava

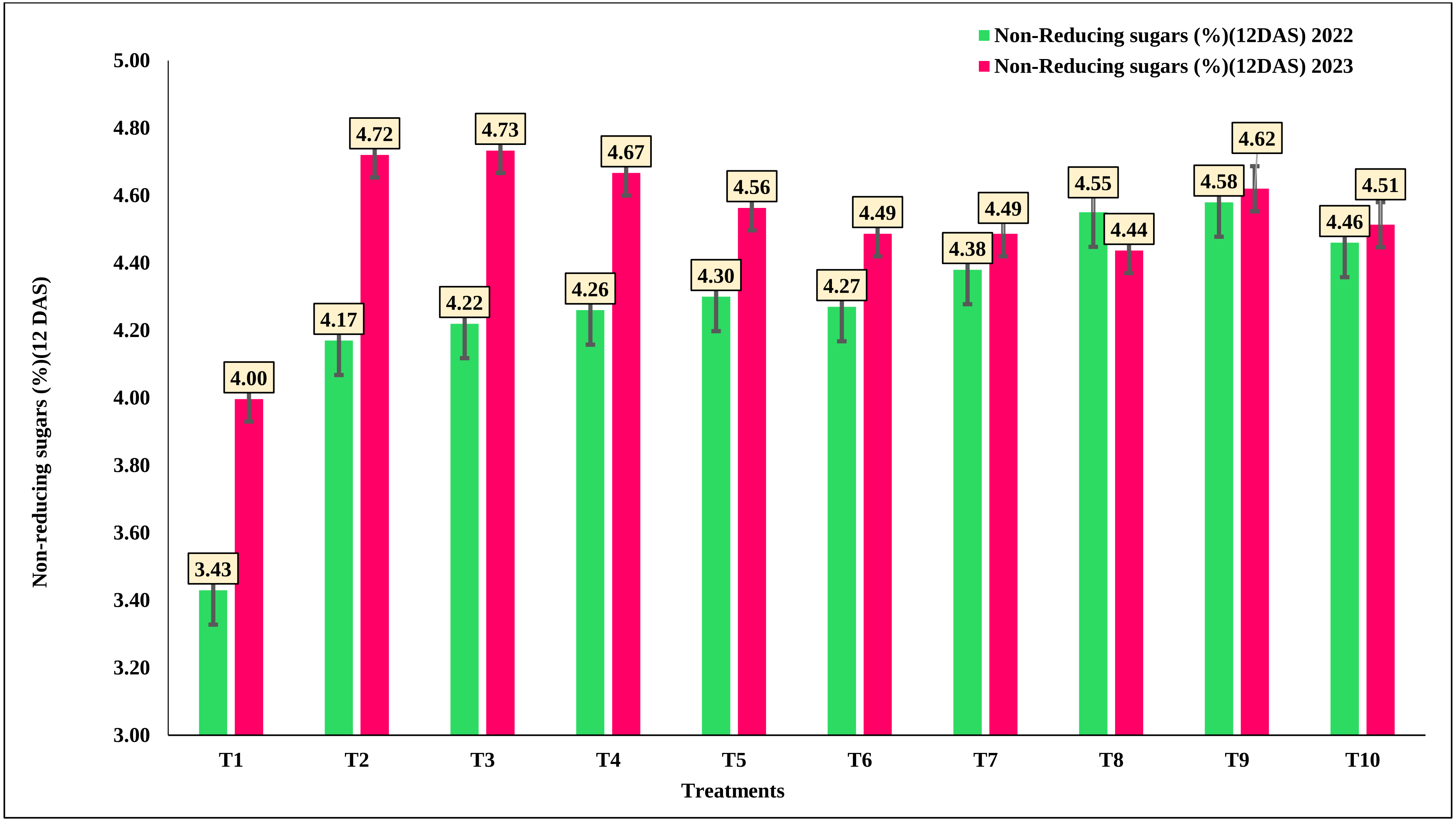

Fig. :4.61 Effect of nano-Zn and nano-Cu on non-reducing sugars % (12 DAS) in guava

in tomato fruits treated with 10 mg of Cu nanoparticles, as documented by Hernández *et al.* (2017).

The study offers an understanding of how plants can absorb nanoparticles (NPs). It is suggested that a key factor in NP absorption is their capacity to penetrate the stomata on leaf surfaces. Due to their minute size, NPs can influence plant physiology even at minimal concentration levels by interacting with membrane transport proteins and infiltrating plant cells. Newly developed leaves, which typically have a thinner wax coating and are often in an immature state, are particularly efficient at nutrient absorption (Ilyas *et al.,* 2015).

4.6.13 TSS (^{0}B) (0 DAS)

Table no. 4.20 shows the data on the variation in the TSS (^{0}B) on the zero day of storage during the two years of the experiment (2022 and 2023) along with the pooled data. A keen perusal of the data indicates that there was a substantial effect of different nano-micronutrient treatments on TSS (^{0}B) on the zero day in guava during both the years of the experiment, graphically presented in figure no.4.62.

During the first year of the experiment (2022), the maximum TSS (^{0}B) on the zero day was under treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 9.89°B at nominal with T_5, T_7, and T_{10} ranging from 9.84 to 9.87°B. The minimum TSS value on the zero day was 9.68 °B was recorded in treatment T_1 (Control).

In the second trial year (2023), statistically, treatments made a substantial impact on the TSS (^{0}B) on the zero day of guava fruit storage. The Maximum TSS on the zero day was 10.10°B recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] at nominal with T_5, T_7, T_8, and T_{10} ranging from 10.00 to 10.07°B. The lowest TSS on the zero day of storage was 9.84°B in T_1 (Control) it is at nominal with T_2, T_3, and T_4 ranging from 9.90 to 9.92°B.

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the maximum TSS on the zero day of shelf-life studies, a value of 10.00°B at nominal with T_5, T_7, and T_{10} ranging from 9.94 to 9.97°B. In contrast, treatment T_1 (control) had the lowest TSS on the zero day of shelf-life studies, a value of 9.76°B at nominal with treatments T_2, T_3, and T_4 ranging from 9.82 to 9.84°B.

4.6.14 TSS (^{0}B) (4 DAS)

Table no. 4.20 shows the data on the variation in the TSS (^{0}B) on the fourth day of storage during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments impact on TSS (^{0}B) on the fourth day of storage in guava during both years of the experiment graphically presented in figure no.4.63.

During the first year of the experiment (2022), the maximum TSS (^{0}B) on the fourth day of storage was under treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 10.81°B were recorded at nominal with T_7 with the value of 10.77°B. The minimum TSS (^{0}B) on the fourth day of storage was 10.54°B were resulted in T_1 at nominal with T_3 with the values 10.57°B.

In the second-year trial year (2023), statistically, treatments made a substantial impact on the TSS (^{0}B) on the fourth day of guava fruits storage. The maximum TSS on the fourth day was in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 11.02°B at nominal with T_5, T_7, T_8, and T_{10} ranging from 10.88 to 10.97°B. The lowest TSS on the fourth day of storage was 10.71°B in T_1 at nominal with T_2, T_3, T_4, and T_6 ranging from 10.73 to 10.85°B.

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the supreme TSS (^{0}B) on the fourth day of shelf-life studies, a value of 10.92°B at nominal with the T_5, T_7, and T_{10} ranging from 10.85 to 10.88°B. In contrast, treatment T_1 had the lowest TSS (^{0}B) on the fourth day of shelf-life studies, a value of 10.63°B at nominal with T_2, T_3, and T4 ranging from 10.66 to 10.70°B.

4.6.15 TSS (^{0}B) (8 DAS)

Table no. 4.20 shows the data on the variation in the TSS (^{0}B) on the eight day of shelf-life studies during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments impact on TSS (^{0}B) on the eight day of storage in guava during both years of the experiment, graphically presented in figure no.4.64.

During the first year of the experiment (2022), the maximum TSS (^{0}B) on the eight day of storage was under T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 11.74°B at nominal with T_7 and T_{10} which was 11.71 and 11.64°B respectively. The minimum TSS on the eight day of storage was 11.30°B which was resulted in T_1, at nominal with T_3 with the value of 11.35°B.

In the second trial year (2023), statistically, treatments made a substantial impact on the TSS on the eight day of guava fruit storage. The highest TSS on the eight day of storage was recorded on treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 11.95°B at nominal with the T_5, T_7, T_8, and T_{10} ranging from 11.80 to 11.91°B. The lowest TSS (^{0}B) on the eight day was 11.46°B in T_1 at nominal with T_2, and T_3 with the values of 11.58 and 11.55°B respectively.

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the maximum TSS on the eight day a value of 11.85°B at nominal with T_5, T_7, and T_{10} ranging from 11.73 to 11.81°B. In contrast, treatment T_1 had the lowest TSS on the eight day, with a value of 11.38°B at nominal with T_3 with the value of 11.45°B.

4.6.16 TSS (^{0}B) (12 DAS)

Table no. 4.20 shows the data on the variation in the TSS (^{0}B) on the twelfth day of storage during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments impact on TSS (^{0}B) on the twelfth day of storage in guava during both years of the experiment, graphically presented in figure no.4.65. During the first year of the experiment (2022), the maximum TSS (^{0}B) on the twelfth day of storage was under T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] this was 12.86°B resulted substantially maximum from the treatments. The lowest TSS on the twelfth day of storage was 11.27°B, which was recorded in treatment T_1 (Control). In the second trial year (2023), statistically, treatments made a substantial impact on the TSS (^{0}B) on the twelfth day of guava fruit shelf-life studies. The Maximum TSS (^{0}B) on the twelfth day of shelf-life studies was noted on treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 13.07°B substantially maximum from other treatments. The lowermost TSS on the twelfth day were 11.31°B in treatment T_1 (Control). Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the maximum TSS (^{0}B) on the twelfth day, a value of 12.97°B substantially maximum from other treatments. In contrast, treatment T_1 had the lowest TSS (^{0}B) on the twelfth day, with a value of 11.29°B. Foliar application of nano Zn and nano Cu enhances Total Soluble Solids (TSS) in plants. Nano Zn improves carbohydrate metabolism, increasing sugar accumulation, while nano Cu enhances enzyme activity, aiding in sugar synthesis. Both nanoparticles contribute to elevated TSS levels, promoting plant growth and quality yield. Related outcomes noted by Rawat *et al*. (2010) in their study of micronutrients, particularly ZnSO4 at the dose of 0.4g/L concentration, substantially improved Total Soluble Solids (TSS) in guava cv. Lucknow-49. This treatment led to a notable decrease in acidity and a substantial enhancement in biochemical traits (Total soluble solids, sugars, TSS:acid ratio). It also confirmed by Giram *et al*. (2021) that foliar application of micronutrients, particularly treatment T11 containing zinc sulfate, boron, copper sulfate, and magnesium sulfate, substantially increased Total Soluble Solids (TSS) in Mrig bahar guava. The treatment recorded in the maximum TSS value of 12.67 ^{0}B, indicating improved fruit quality.

Table no. 4.20: Effect of nano-Zn and nano-Cu on TSS (°B) at 0 DAS, 4 DAS, 8 DAS, and 12 DAS of guava.

	TSS (^{0}B)											
Intervals	**0 (DAS)**			**4 (DAS)**			**8 (DAS)**			**12 (DAS)**		
Treatments	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_1	9.68 ± 0.01^{a}	9.84 ± 0.01^{a}	9.76 ± 0.012^{a}	10.54 ± 0.008^{a}	10.71 ± 0.02^{a}	10.63 ± 0.017^{a}	$11.30.03^{a}$	11.46 ± 0.04^{a}	11.38 ± 0.038^{a}	11.27 ± 0.03^{a}	11.31 ± 0.05^{a}	11.29 ± 0.020^{a}
T_2	9.75 ± 0.02^{bc}	9.90 ± 0.01^{ab}	9.83 ± 0.017^{ab}	10.59 ± 0.005^{bc}	10.73 ± 0.01^{a}	10.66 ± 0.006^{a}	11.44 ± 0.01^{bc}	11.58 ± 0.02^{ab}	11.51 ± 0.20^{bc}	12.44 ± 0.01^{c}	12.56 ± 0.02^{bc}	12.50 ± 0.023^{c}
T_3	9.72 ± 0.01^{ab}	9.92 ± 0.03^{abcd}	9.82 ± 0.012^{ab}	10.57 ± 0.01^{ab}	10.77 ± 0.04^{ab}	10.67 ± 0.027^{ab}	11.35 ± 0.05^{ab}	11.55 ± 0.04^{ab}	11.45 ± 0.49^{ab}	12.29 ± 0.01^{b}	12.48 ± 0.02^{b}	12.39 ± 0.010^{b}
T_4	9.77 ± 0.01^{bcd}	9.91 ± 0.01^{abcd}	9.84 ± 0.011^{ab}	10.62 ± 0.003^{c}	10.76 ± 0.006^{ab}	10.70 ± 0.003^{ab}	11.52 ± 0.05^{cd}	11.66 ± 0.05^{bc}	11.59 ± 0.055^{cd}	12.46 ± 0.01^{cd}	12.60 ± 0.01^{cd}	12.53 ± 0.014^{c}
T_5	9.84 ± 0.003^{efg}	10.04 ± 0.03^{def}	9.94 ± 0.020^{cde}	10.75 ± 0.01^{e}	10.94 ± 0.04^{cd}	10.85 ± 0.031^{de}	11.63 ± 0.01^{ef}	11.82 ± 0.01^{cde}	11.73 ± 0.003^{efg}	12.59 ± 0.008^{e}	12.79 ± 0.04^{ef}	12.69 ± 0.025^{e}
T_6	9.79 ± 0.01^{cde}	9.97 ± 0.04^{bcde}	9.88 ± 0.027^{bc}	10.66 ± 0.01^{d}	10.85 ± 0.05^{abc}	10.76 ± 0.036^{bc}	11.53 ± 0.02^{cde}	11.71 ± 0.05^{bcd}	11.62 ± 0.040^{cde}	12.51 ± 0.01^{d}	12.69 ± 0.03^{de}	12.60 ± 0.017^{d}
T_7	9.87 ± 0.02^{fg}	10.07 ± 0.07^{ef}	9.97 ± 0.049^{de}	10.77 ± 0.008^{ef}	10.97 ± 0.05^{cd}	10.88 ± 0.023^{de}	11.71 ± 0.01^{fg}	11.91 ± 0.07^{e}	11.81 ± 0.044^{fg}	12.72 ± 0.02^{f}	12.92 ± 0.04^{g}	12.83 ± 0.023^{f}
T_8	9.82 ± 0.01^{def}	10.00 ± 0.04^{bcdef}	9.91 ± 0.028^{cd}	10.7 ± 0.005^{d}	10.88 ± 0.03^{bcd}	10.79 ± 0.024^{cd}	11.61 ± 0.02^{def}	11.80 ± 0.05^{cde}	11.71 ± 0.037^{def}	12.58 ± 0.01^{e}	12.76 ± 0.02^{ef}	$12.670.012^{e}$
T_9	9.89 ± 0.03^{g}	10.10 ± 0.01^{f}	10.00 ± 0.005^{e}	10.81 ± 0.01^{f}	11.02 ± 0.06^{d}	10.92 ± 0.040^{e}	11.74 ± 0.01^{g}	11.95 ± 0.06^{e}	11.85 ± 0.041^{g}	12.86 ± 0.01^{g}	13.07 ± 0.03^{h}	12.97 ± 0.011^{g}
T_{10}	9.85 ± 0.01^{fg}	10.02 ± 0.02^{cdef}	9.94 ± 0.015^{cde}	10.75 ± 0.02^{e}	10.95 ± 0.05^{cd}	10.86 ± 0.039^{de}	11.64 ± 0.02^{fg}	11.84 ± 0.06^{de}	11.74 ± 0.016^{efg}	12.63 ± 0.01^{e}	12.83 ± 0.04^{fg}	12.73 ± 0.029^{e}
S. Em (±)	0.012	0.017	0.014	0.016	0.022	0.019	0.027	0.031	0.029	0.077	0.086	0.081

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ Cu_2(30ppm)], T_{10} [$ZnSO_4$]

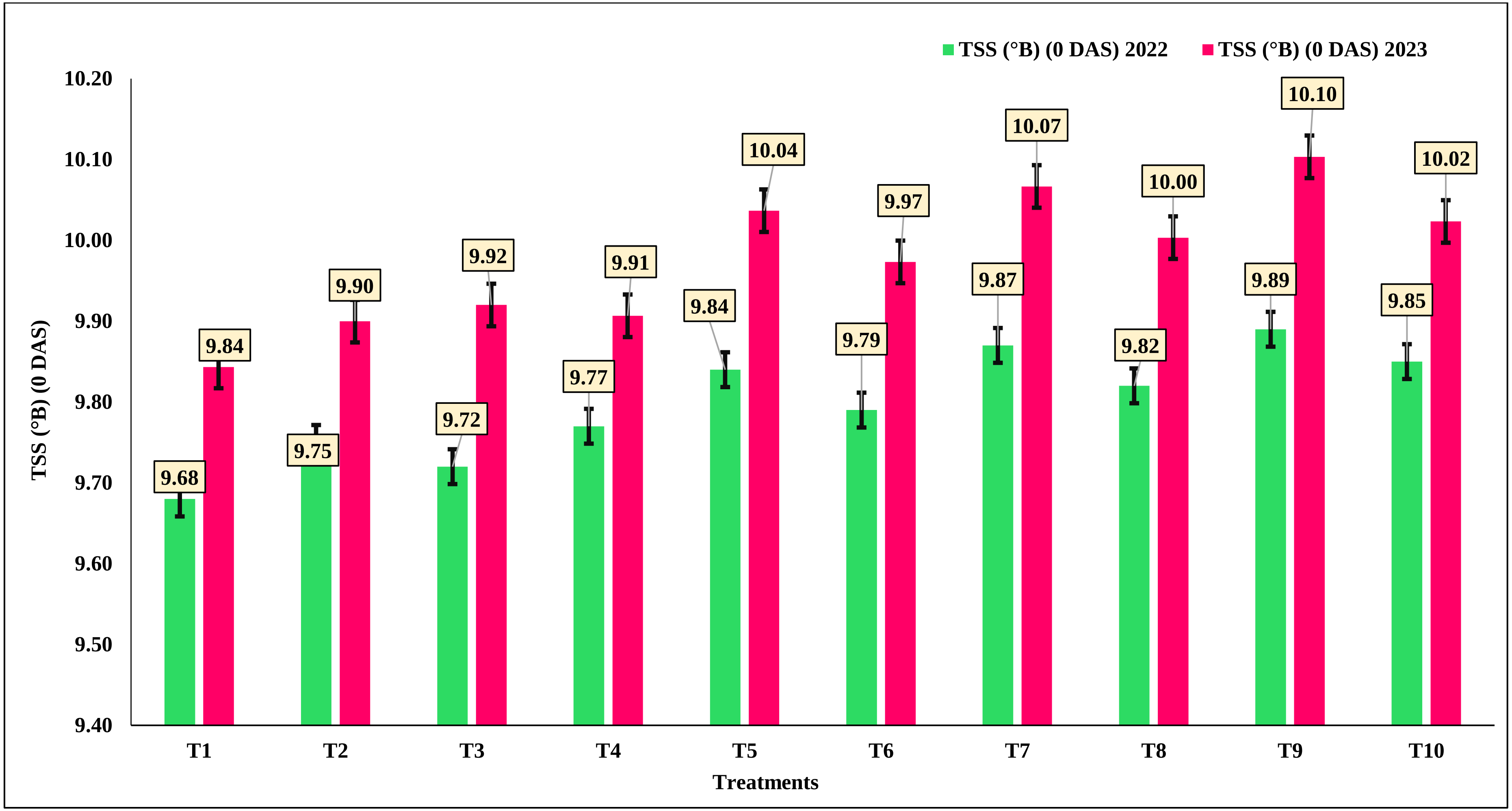

Fig. 4.62: Effect of nano-Zn and nano-Cu on TSS °B (0 DAS) in guava

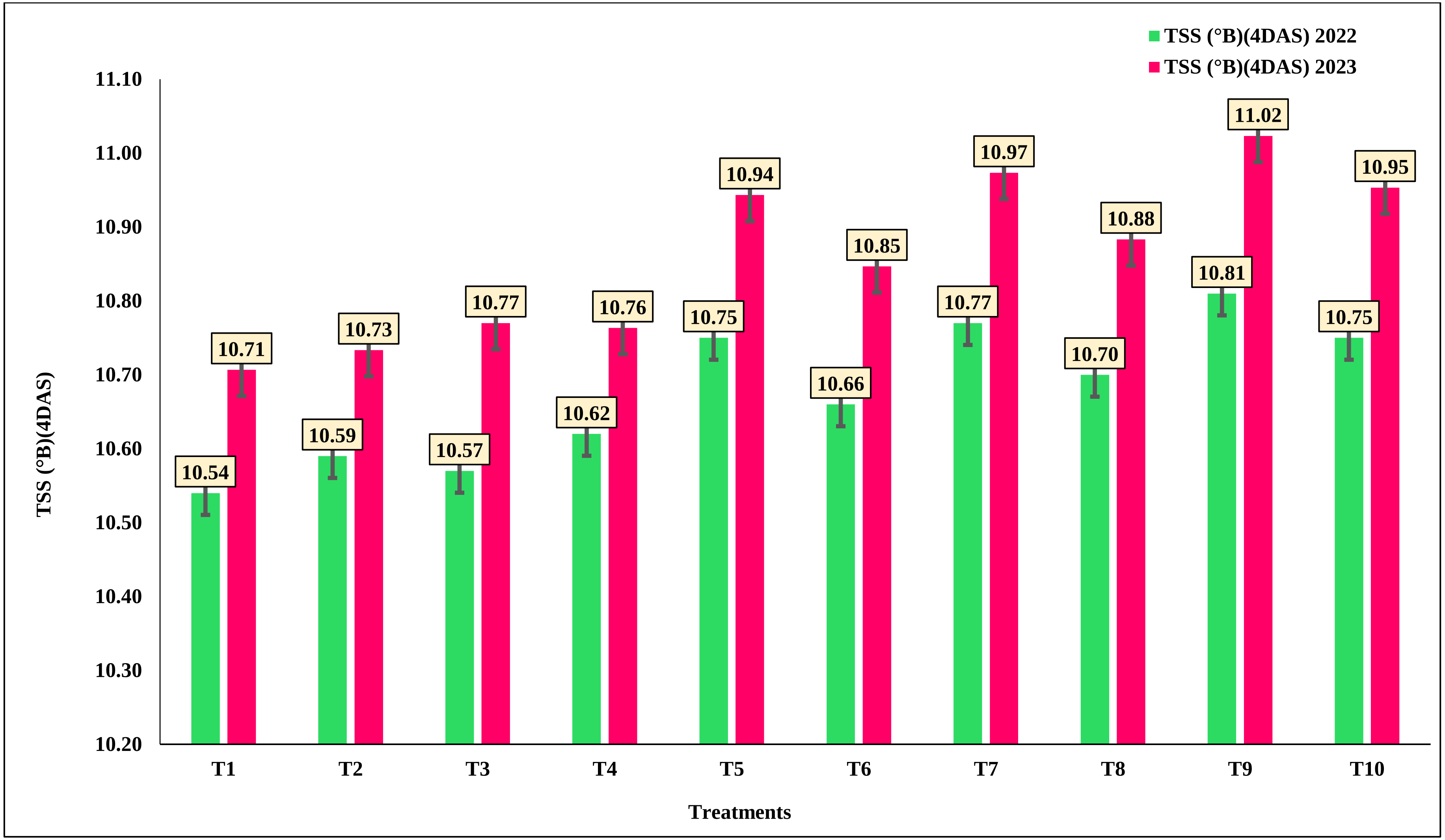

Fig. 4.63: Effect of nano-Zn and nano-Cu on TSS °B (4 DAS) in guava

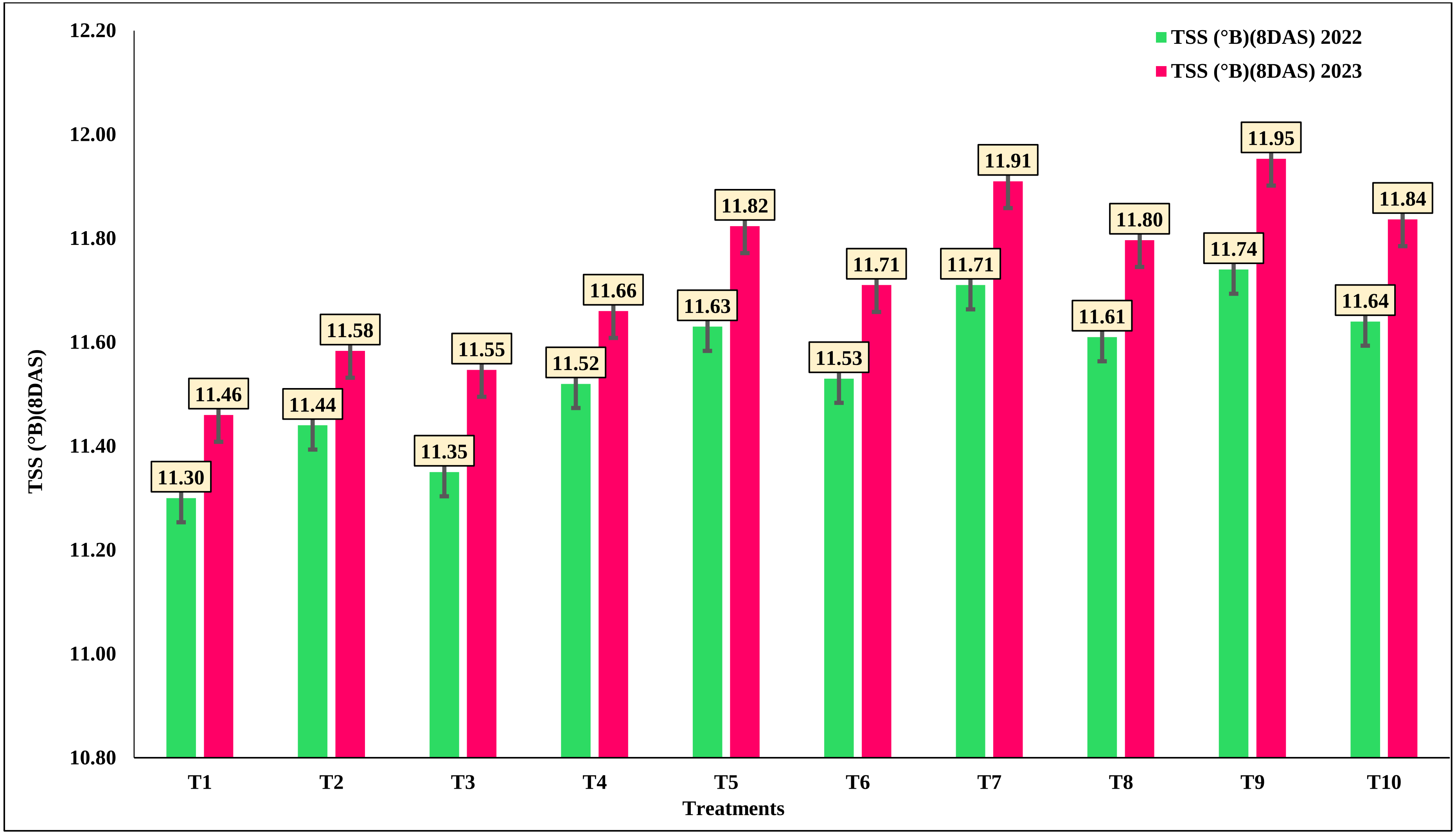

Fig. 4.64: Effect of nano-Zn and nano-Cu on TSS °B (8 DAS) in guava

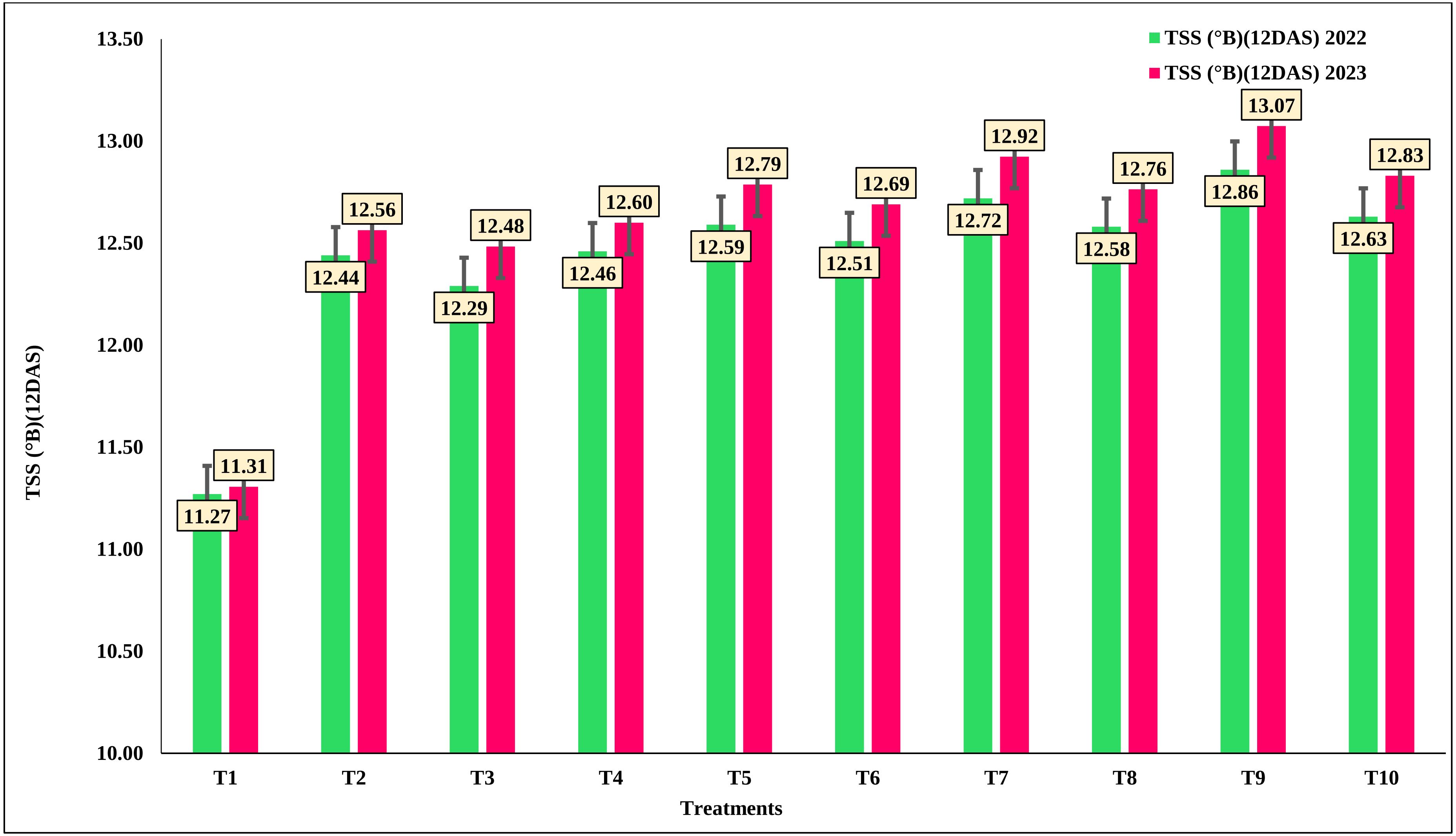

Fig. 4.65 Effect of nano-Zn and nano-Cu on TSS °B (12 DAS) in guava

4.6.17 Titratable acidity (%) (0 DAS)

Table no. 4.21 provides information about the variation in titratable acidity (%) on zero day of storage observed throughout the two years of the experiment (2022 and 2023). A keen perusal of the data indicates there was a substantial effect of pre-harvest application of nano-micronutrients on titratable acidity (%) on zero day of storage in guava fruit during both the years of the experiment, graphically presented in figure no.4.66.

During the first year of the experiment (2022), the maximum titratable acidity (%) on the zero day of storage was recorded in treatment T_1 (control) which was 1.23 % this was at nominal with treatment T_2, and T_3 with the value of 1.23 and 1.23 % respectively. The minimum titratable acidity (%) were observed in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] with a value of 0.98 %.

In the second year of the trial (2023), The maximum titratable acidity (%) on the zero day of storage was recorded in treatment T_3 (nano-Zn_2(60ppm)) was 1.40 % at nominal with T_1 and T_2 with the same value of 1.37 and 1.40 % respectively. Instead, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] recorded the minimum titratable acidity (%) on zero day of storage 1.05 %.

Data combined for two years (2022 and 2023) showed that treatment T_2 (nano-Zn_1(40ppm)) had the maximum titratable acidity (%) on the zero day of storage 1.32 %. This was at nominal with treatments T_1 and T_3 with the values of 1.30 and 1.31 % respectively. Instead, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the lowest titratable acidity (%) percentage on the zero day of storage, measuring 1.05 %. Statistically, all the treatments made a substantial impact on the titratable acidity (%) on the zero day of storage of the guava plants.

4.6.18 Titratable acidity (%) (4 DAS)

Table no. 4.21 provides information about the variation in titratable acidity (%) on the fourth day of storage observed throughout the two years of the experiment (2022 and 2023). A keen perusal of the data indicates there was a substantial effect of pre-harvest application of nano-micronutrients on titratable acidity (%) on the fourth day of storage in guava fruit during both years of the experiment, graphically presented in figure no.4.67.

During the first year of the experiment (2022), the maximum titratable acidity (%) on the fourth day of storage was resulted in T_1 substantially different from other treatments with a value of 0.95 %. The minimum titratable acidity (%) was observed in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] with a value of 0.74 %.

In the second year of the trial (2023), The maximum titratable acidity (%) on the fourth day of storage was recorded in treatment T_1 (control) was 1.09 % at nominal with T_2, T_3, and T_4 with the same value 1.09 %. Instead, treatment T_1 (control) recorded the minimum titratable acidity (%) on the fourth day of storage was 0.86 % at nominal with T_{10} with the value of 0.91%.

Data combined for two years (2022 and 2023) showed that treatment T_1 (control) had the maximum titratable acidity (%) on the fourth day of storage was 1.02% at nominal with T_2, and T_3 with same values of 1.09 %. Instead, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the lowest titratable acidity (%) percentage on the fourth day of storage, measuring 0.80 %. Statistically, all the treatments made a substantial impact on the titratable acidity (%) on the fourth day of storage of the guava plants.

4.6.19 Titratable acidity (%) (8 DAS)

Table no. 4.21 provides information about the variation in titratable acidity (%) on the eight day of storage observed throughout the two years of the experiment (2022 and 2023). A keen perusal of the data indicates there was a substantial effect of pre-harvest application of nano-micronutrients on titratable acidity (%) on the eight day of storage in guava fruit during both the years of the experiment, graphically presented in figure no.4.68.

During the first year of the experiment (2022), the maximum titratable acidity (%) on the eighth day of storage was resulted in T_1 substantially different from other treatments with value of 0.81 %. The minimum titratable acidity (%) was observed in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] with a value of 0.68 %.

In the second year of the trial (2023), The maximum titratable acidity (%) on the eight day of shelf-life studies was resulted in T_2 and T_3 with the same value of 0.96 % at nominal with T_1, and T_4 with the value of 0.94 and 0.92 percent respectively. Insted, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] noted the lowermost titratable acidity (%) on the eighth day of shelf-life studies was 0.80 % at nominal with T_8, and T_{10} with a value of 0.84 and 0.81 percent respectively.

Data combined for two years (2022 and 2023) showed the maximum titratable acidity (%) in treatment T_1, and T_2 with the same value of 0.88 percent at nominal with T_3 with the value of

0.87 %. Instead, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the lowest titratable acidity (%) percentage on the eight day of storage, measuring 0.74 % at nominal with T_{10} with a value of 0.76 %. Statistically, all the treatments made a substantial impact on the titratable acidity (%) on the eight day of storage of the guava plants.

4.6.20 Titratable acidity (%) (12 DAS)

Table no. 4.21 provides information about the variation in titratable acidity (%) on the twelfth day of storage observed throughout the two years of the experiment (2022 and 2023). A keen perusal of the data indicates there was a substantial effect of pre-harvest application of nano-micronutrients on titratable acidity (%) on the twelfth day of storage in guava fruit during both the years of the experiment, graphically presented in figure no.4.69.

During the first year of the experiment (2022), the maximum titratable acidity (%) on the twelfth day of storage was recorded in treatment T_1 (control) which was 0.82 % which was substantially different from all the treatments. The minimum titratable acidity (%) were observed in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] with a value of 0.52 %.

In the second year of the trial (2023), The maximum titratable acidity (%) on the twelfth day of storage was recorded in treatment T_2, using nano-Zn_1(40ppm) that was 0.84 % at nominal with T_3 (nano-Zn_2(60ppm)) with the value of 0.81 percent. Instead, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] recorded the minimum titratable acidity (%) on the twelfth day of shelf-life studies was 0.65 % at nominal with T_8 and T_{10} with the value of 0.68 and 0.66 % respectively.

Data combined for two years (2022 and 2023) showed that treatment T_1 (control) had the maximum titratable acidity (%) on the twelfth day of shelf-life studies was 0.77 % at nominal with T_2 with the value of 0.75%. Instead, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the lowest titratable acidity (%) percentage on the twelfth day of shelf-life studies, measuring 0.59 % at nominal with T_8 and T_{10} with the same value of 0.61 %. Statistically, all the treatments made a substantial impact on the titratable acidity (%) on the twelfth day of shelf-life studies of the guava plants. Foliar application of nano Zn and nano Cu influences titratable acidity differently.

Nano Zn tends to reduce acidity levels by enhancing sugar metabolism, while nano Cu may have varied effects. Both nanoparticles can modulate enzymatic activity, impacting acidity levels, thus affecting overall fruit quality and taste.

Foliar application of 1% zinc sulphate substantially increased TSS in guava fruits. A combination treatment ($CuSO_4$@1%+$FeSO_4$@1%+$ZnSO_4$@1%+Borax@0.50%) minimized physiological weight loss over storage days, ensuring better preservation for up to 7.10 days compared to the control, which exhibited poorer quality maintenance (Munde *et al*, 2018). Defoliation treatments substantially improved fruit quality parameters in common seedy guava trees. Notably, 10% urea and $ZnSO_4$ 2% + NH_4NO_3 4% enhanced titratable acidity, firmness, and vitamin C content, leading to superior fruit quality during storage. Summer harvests showed increased weight loss and decay, mitigated by improved treatments (El-Baz *et al*, 2011). It confirmed by Giram *et al*. (2021), foliar application of micronutrients substantially influenced guava quality attributes. $ZnSO_4$ 1.0% + boron 1.0% + $CuSO_4$ 1.0% + $MgSO_4$ 1.0%) resulted in the maximum TSS, indicating varying effects on titratable acidity among treatments.

Table no. 4.21: Effect of nano-Zn and nano-Cu on titratable acidity (%) at 0 DAS, 4 DAS, 8 DAS, and 12 DAS of guava.

Treatments	Titratable acidity (%)											
	1 (DAS)			4 (DAS)			8 (DAS)			12 (DAS)		
	2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T$_1$	1.23±0.003^{f}	1.37±0.02^{def}	1.30±0.020^{ef}	0.95±0.003^{h}	1.09±0.02^{f}	1.02±0.012^{f}	0.81±0.005^{h}	0.94±0.02^{de}	0.88±0.011^{f}	0.82±0.005^{i}	0.73±0.01^{cde}	0.77±0.008^{e}
T$_2$	1.23±0.005^{ef}	1.40±0.02^{ef}	1.32±0.025^{f}	0.92±0.005^{g}	1.09±0.01^{f}	1.01±0.008^{f}	0.79±0.003^{g}	0.96±0.02^{e}	0.88±0.015^{f}	0.66±0.003^{h}	0.84±0.02^{f}	0.75±0.014^{e}
T$_3$	1.22±0.008^{ef}	1.40±0.008^{f}	1.31±0.005^{f}	0.90±0.003^{fg}	1.09±0.01^{f}	1.00±0.005^{ef}	0.78±0.003^{fg}	0.96±0.01^{e}	0.87±0.008^{f}	0.63±0.003^{g}	0.81±0.01^{f}	0.72±0.006^{d}
T$_4$	1.20±0.003^{e}	1.35±0.02^{de}	1.28±0.020^{e}	0.9±0.010f^{g}	1.05±0.02^{ef}	0.97±0.014^{de}	0.77±0.008^{ef}	0.92±0.01^{cde}	0.85±0.008^{e}	0.61±0.005^{f}	0.76±0.02^{e}	0.68±0.014^{c}
T$_5$	1.17±0.003^{d}	1.28±0.01^{c}	1.23±0.010^{d}	0.87±0.011^{e}	0.98±0.008^{c}	0.92±0.006^{c}	0.74±0.003^{cd}	0.85±0.008^{b}	0.80±0.003^{c}	0.59±0.003^{e}	0.70±0.01^{bcd}	0.65±0.005^{b}
T$_6$	1.20±0.003^{e}	1.350.01^{d}	1.28±0.011^{e}	0.88±0.008^{ef}	1.03±0.02^{de}	0.96±0.015^{d}	0.76±0.005^{de}	0.90±0.008^{cd}	0.83±0.003^{de}	0.59±0.003^{e}	0.74±0.01^{de}	0.67±0.010^{bc}
T$_7$	1.15±0.012^{d}	1.30±0.01^{c}	1.23±0.020^{d}	0.84±0.006^{d}	0.98±0.01^{cd}	0.91±0.012^{c}	0.73±0.003^{c}	0.88±0.01^{bc}	0.81±0.010^{cd}	0.57±0.003^{d}	0.72±0.01^{cde}	0.65±0.010^{b}
T$_8$	1.07±0.011^{b}	1.21±0.01^{b}	1.14±0.020^{b}	0.780.003^{b}	0.92±0.005^{b}	0.85±0.033^{b}	0.70±0.003^{b}	0.84±0.00^{ab}	0.77±0.003^{b}	0.54±0.003^{b}	0.68±0.005^{abc}	0.61±0.003^{a}
T$_9$	0.98±0.014^{a}	1.11±0.003^{a}	1.05±0.015^{a}	0.74±0.005^{a}	0.86±0.01^{a}	0.80±0.012^{a}	0.68±0.005^{a}	0.80±0.01^{a}	0.74±0.012^{a}	0.52±0.003^{a}	0.65±0.01^{a}	0.59±0.005^{a}
T$_{10}$	1.12±0.011^{c}	1.22±0.003^{b}	1.17±0.010^{c}	0.81±0.005^{c}	0.91±0.006^{ab}	0.86±0.00^{b}	0.71±0.005^{b}	0.81±0.006^{a}	0.76±0.00^{ab}	0.56±0.005^{c}	0.66±0.006^{ab}	0.61±0.00^{a}
S. Em (±)	0.014	0.017	0.086	0.011	0.015	0.013	0.007	0.011	0.009	0.014	0.011	0.011

T$_1$[Control], T$_2$[nano-Zn$_1$(40ppm)], T$_3$[nano-Zn$_2$(60ppm)), T$_4$[(Cu$_1$(20ppm)], T$_5$ [Cu$_2$(30ppm)], T$_6$ [nano-Zn$_1$(40ppm) + Cu$_1$(20ppm)], T$_7$ [nano-Zn$_1$(40ppm) + Cu$_2$(30ppm)], T$_8$ [nano-Zn$_2$(60ppm) + Cu$_1$(20ppm)], T$_9$ [nano-Zn$_2$(60ppm) + Cu$_2$(30ppm)], T$_{10}$ [ZnSO$_4$]

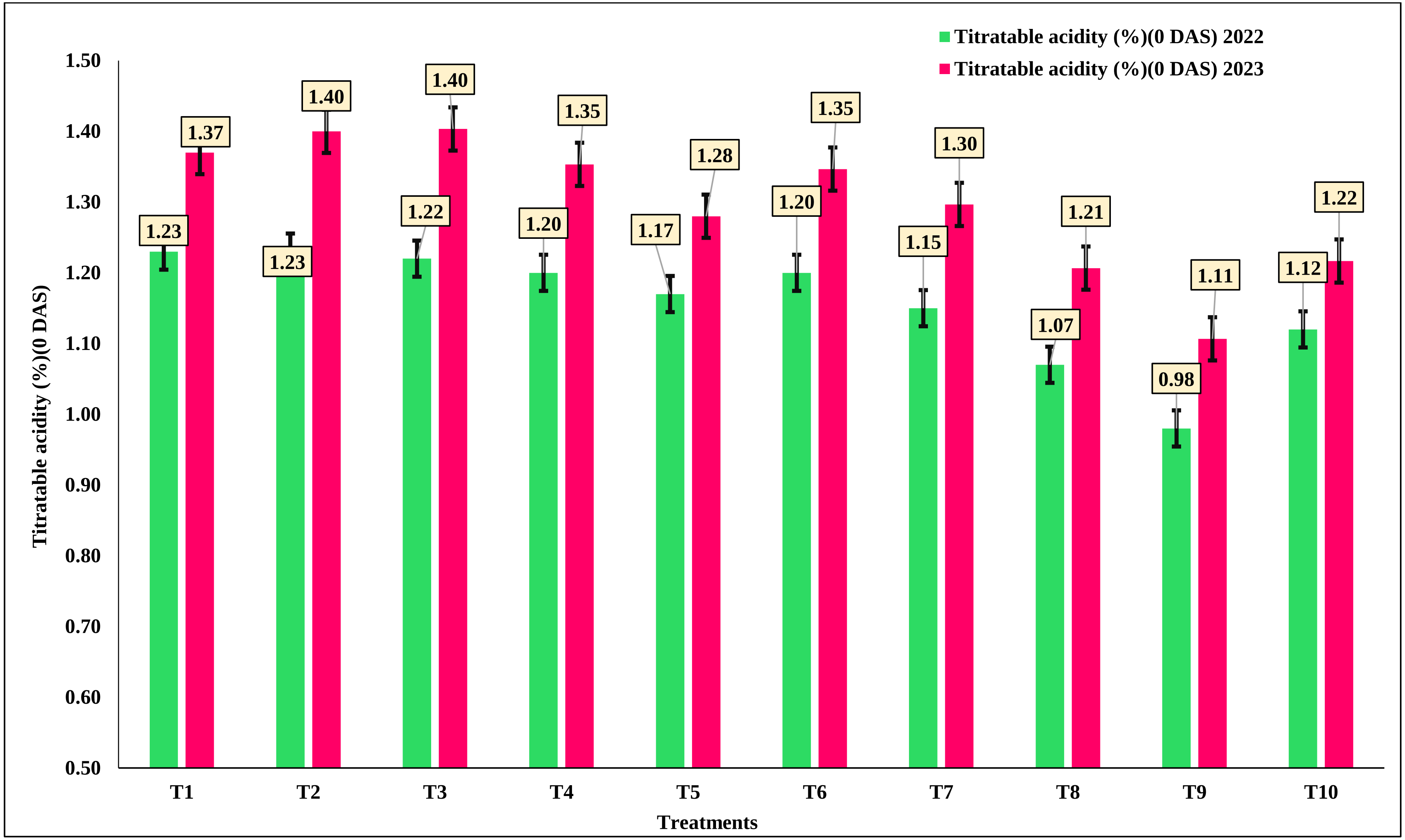

Fig. 4.66: Effect of nano-Zn and nano-Cu on titratable acidity % (0 DAS) in guava

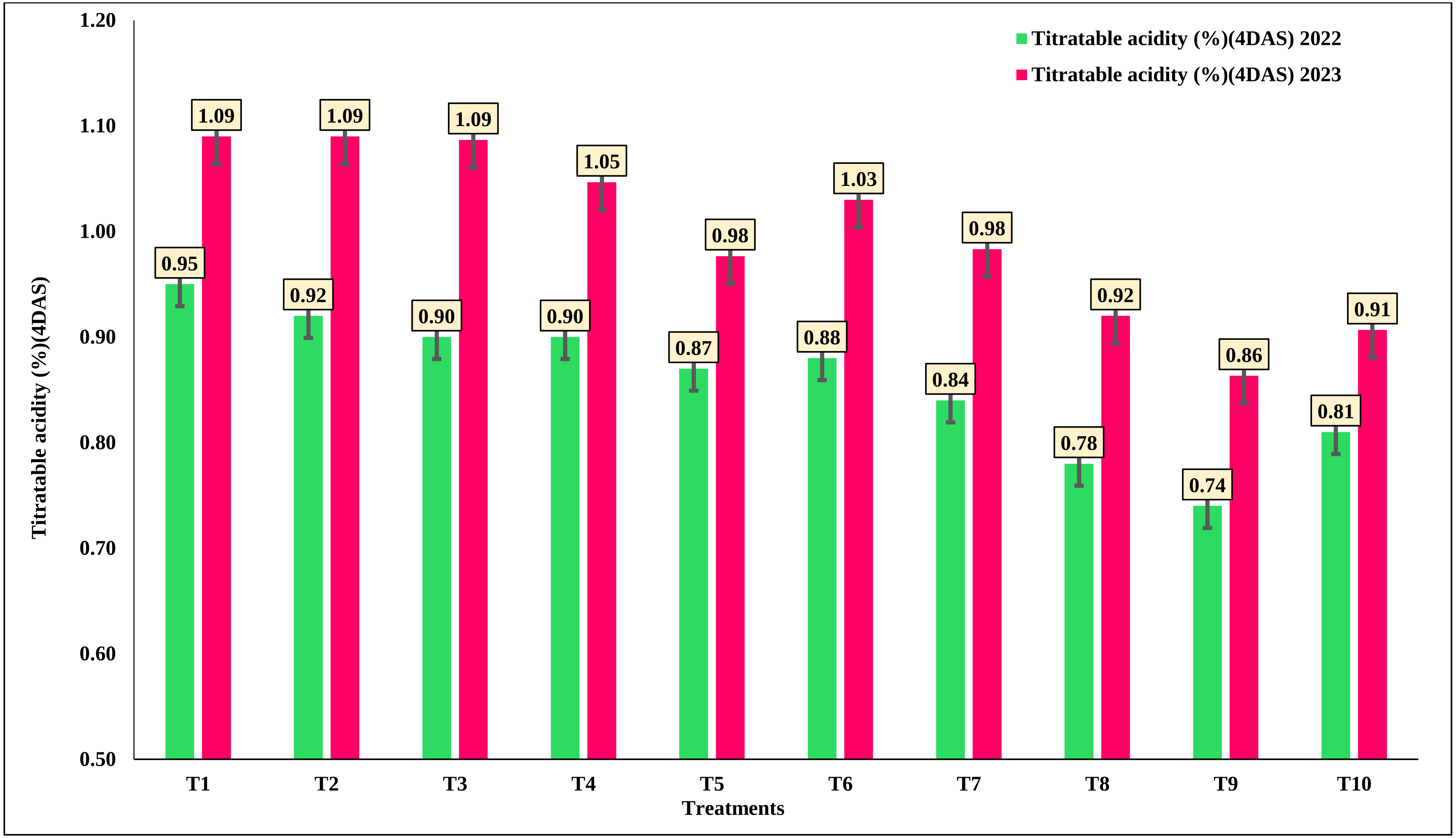

Fig. 4.67: Effect of nano-Zn and nano-Cu on titratable acidity % (4 DAS) in guava

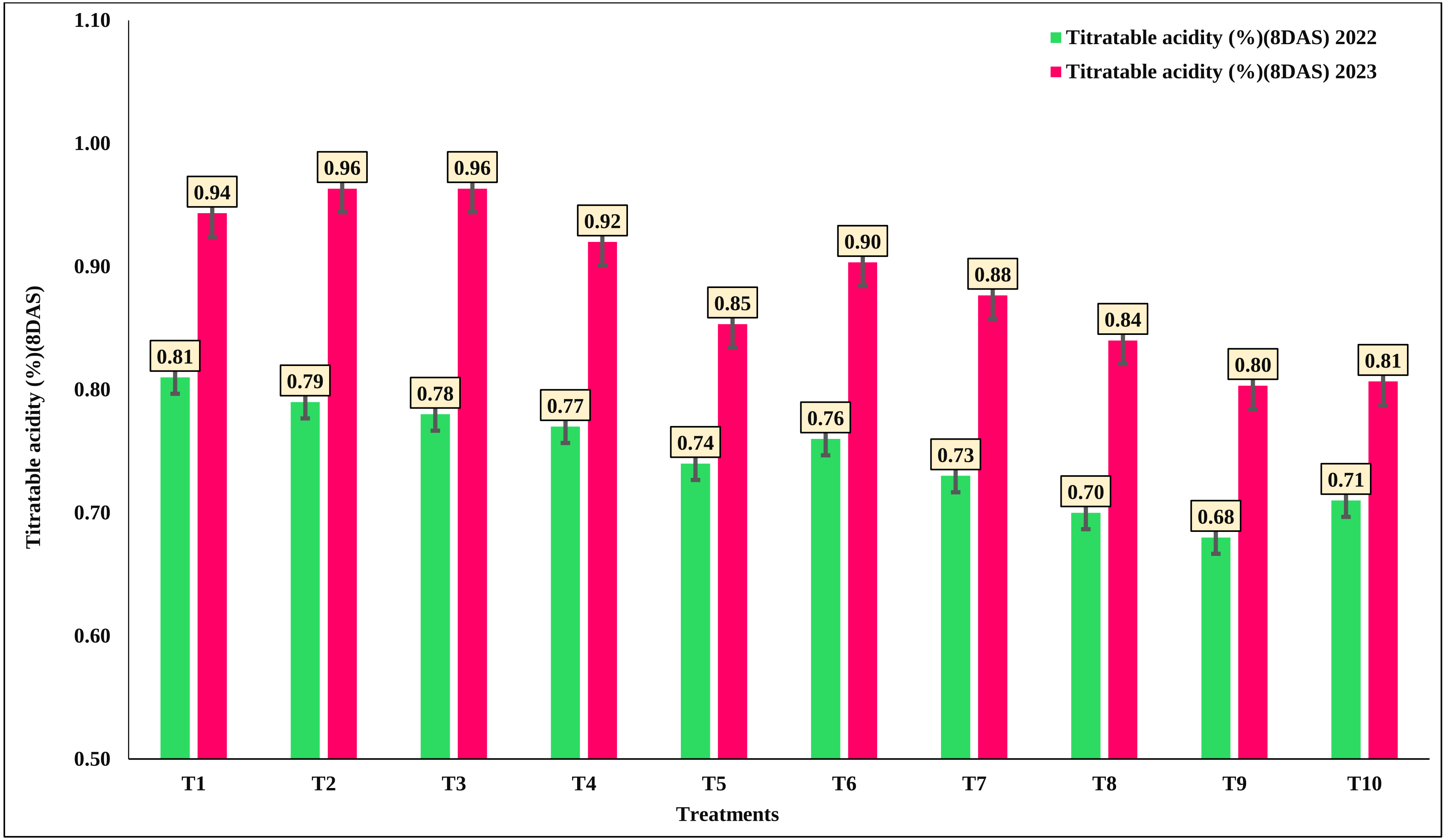

Fig. 4.68: Effect of nano-Zn and nano-Cu on titratable acidity % (8 DAS) in guava

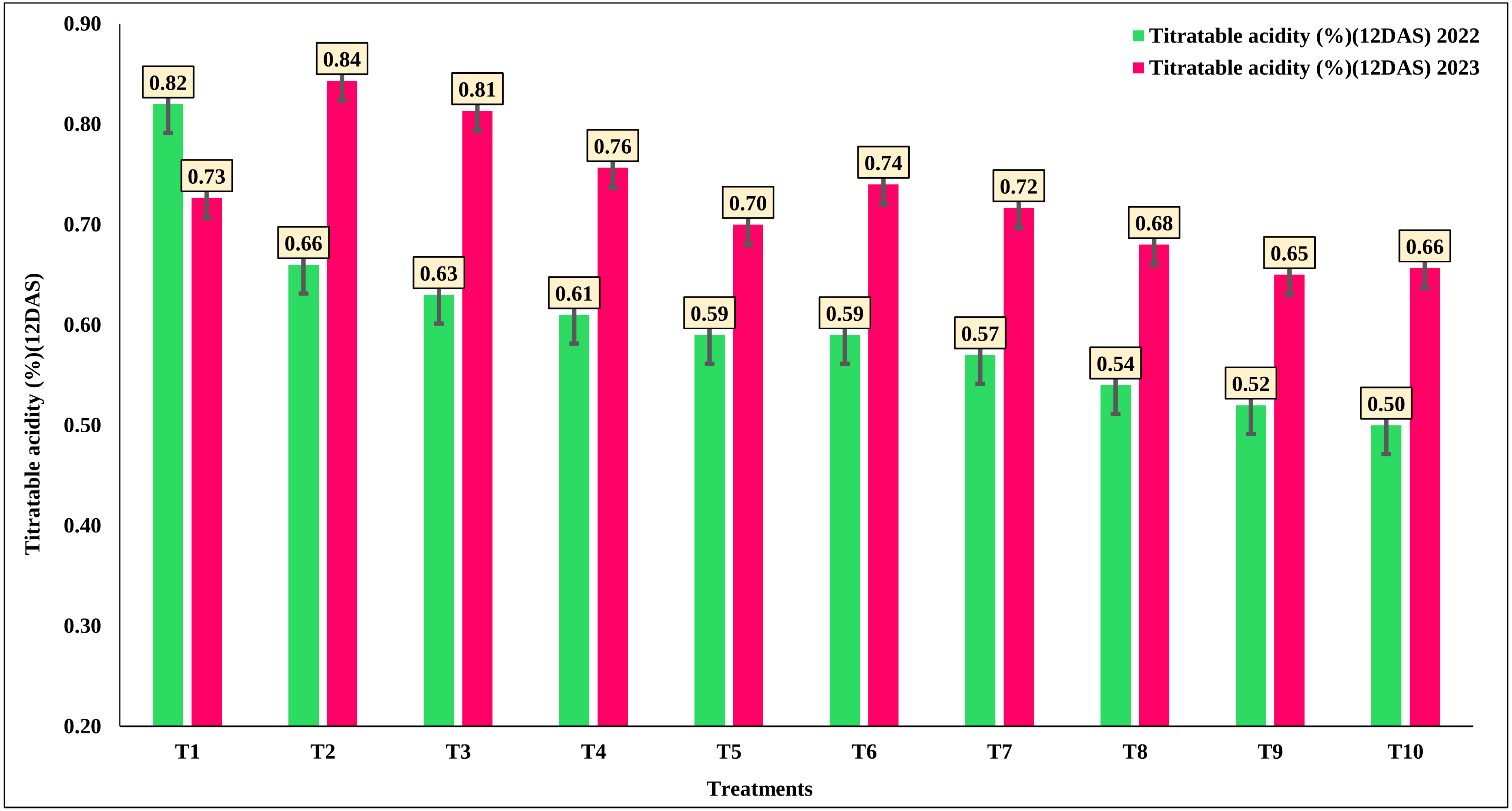

Fig. 4.69: Effect of nano-Zn and nano-Cu on titratable acidity % (12 DAS) in guava

4.6.21 TSS: Acid ratio (0 DAS)

Table no. 4.22 provides information about the variation in the TSS: Acid ratio on the zero day of storage observed throughout the two years of the experiment (2022 and 2023). Nano-micronutrients on the Total Soluble Solids: Acid ratio on the zero day of storage in guava fruit during both the years of the experiment, graphically presented in figure no.4.70.

During the first year of the experiment (2022), the maximum TSS: Acid ratio on the zero day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 10.06 substantially different from other treatments. The lowermost TSS: Acid ratio was resulted in T_1 with a value of 7.82 at nominal with T_2 and T_3 with the value of 7.93 and 7.95 respectively.

In the second year of the trial (2023), The maximum TSS: Acid ratio on the zero day of shelf-life studies was recorded in treatment T_9, using nano-Zn_2(60ppm) + Cu_2(30ppm) that was 9.13 substantially different from other treatments. Insted, treatment T_3 (nano-Zn_2 (60ppm)) recorded the minimum TSS: Acid ratio on the zero day of shelf-life studies with a value of 7.07 at nominal with T_1, T_2, and T_4 ranging from 7.08 to 7.32.

Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum TSS: Acid ratio on zero day of storage 9.13 substantially different from other treatments. Instead, treatment T_2 (nano-Zn_1 (40ppm)) resulted in the lowest TSS: Acid ratio on the zero day of storage, measuring 7.50 at nominal with T_1 and T_3 with the value of 7.51 each. Statistically, all the treatments made a substantial impact on the TSS: Acid ratio on the zero day of storage of the guava plants.

4.6.22 TSS: Acid ratio (4 DAS)

Table no. 4.22 provides information about the variation in TSS: Acid ratio on the fourth day of storage recorded throughout the two years of the experiment (2022 and 2023). Nano-micronutrients impact on the TSS: Acid ratio on the fourth day of storage in guava fruit during the trials of the experiment, graphically presented in figure no.4.71.

During the first year of the experiment (2022), the maximum TSS: Acid ratio on the fourth day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 14.61 substantially different from other treatments. The lowermost TSS: Acid ratio was resulted in treatment T_1 with a value of 11.02.

In the second year of the trial (2023), The maximum TSS: Acid ratio on the fourth day of storage was recorded in treatment T_9, using nano-Zn_2(60ppm) + Cu_2(30ppm) that was 12.78 substantially different from other treatments. Instead, T_2 (nano-Zn_1(40ppm)) recorded the minimum TSS: Acid ratio on the fourth day of storage was 9.85 at nominal with T_1, T_3, and T_4 ranging from 9.83 to 10.29.

Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum TSS: Acid ratio on the fourth day of storage was 13.70 substantially different from other treatments. In contrast, treatment T_1 (Control) resulted in the lowest TSS: Acid ratio on the fourth day of storage, measuring 10.43 at nominal with T_2, and T_4 with the values of 10.68 and 10.79 respectively. Statistically, all the treatments made a substantial impact on the TSS: Acid ratio on the fourth day of storage of the guava plants.

4.6.23 TSS: Acid ratio (8 DAS)

Table no. 4.22 provides information about the variation in TSS: Acid ratio on the eight days of storage resulted throughout the two years of the experiment (2022 and 2023). Nano-micronutrients impact on the TSS: Acid ratio on the eight days of storage in guava fruit during both the years of the experiment, graphically presented in figure no.4.72.

During the first year of the experiment (2022), the maximum TSS: Acid ratio on the eight day of storage was resulted in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 17.26 substantially higher from other treatments. The lowermost TSS: Acid ratio was resulted in T_1 with a value of 13.95.

In 2023, The maximum TSS: Acid ratio on the eight day of shelf-life studies was caused in treatment T_9, using nano-Zn_2(60ppm) + Cu_2(30ppm) that was 14.90 at nominal with T_{10} the value was 14.68. Instead, treatment T_3 (nano-Zn_2(60ppm)) recorded the minimum TSS: Acid ratio on the eight day of storage was 11.99 at nominal withs T_1, and T_2 with the value of 12.16 and 12.04 respectively.

Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum TSS: Acid ratio on the eight day of storage was 16.08 substantially maximum from other treatments. Instead, T_1 (Control) resulted in the lowest TSS: Acid ratio on the eight day of storage, measuring 13.05 at nominal with T_2 and T_3 with a value of 13.23 and 13.24 respectively. Statistically, all the treatments made a substantial impact on the TSS: acid ratio on the eight days of storage of the guava plants.

4.6.24 TSS: Acid ratio (12 DAS)

Table no. 4.22 provides information about the variation in TSS: Acid ratio on the twelfth day of storage observed throughout the two years of the experiment (2022 and 2023). Nano-micronutrients impact on the TSS: Acid ratio on the twelfth day of storage in guava fruit during both the years of the experiment, graphically presented in figure no.4.73.

During the first year of the experiment (2022), the maximum TSS: Acid ratio on the twelfth day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 24.41 substantially maximum from other treatments. The lowermost TSS: Acid ratio was resulted in T_1 (no treatment) with a value of 13.75.

In the second year of the trial (2023), The maximum TSS: Acid ratio on the twelfth day of storage was recorded in treatment T_9, using nano-Zn_2(60ppm) + Cu_2(30ppm) that was 20.13 at nominal with T_{10} with the value of 19.54. Instead, treatment T_2 (nano-Zn_1(40ppm)) recorded the minimum TSS: Acid ratio on the twelfth day of storage was 14.92 at nominal with T_1 and T_3 with the values of 15.57 and 15.36 respectively.

Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum TSS: acid ratio on the twelfth day of storage was 22.27 substantially maximum from treatments. Instead, treatment T_1 (Control) resulted in the lowest TSS: Acid ratio on the twelfth day of storage, measuring 14.66. Statistically, all the treatments made a substantial impact on the TSS: Acid ratio on the twelfth day of storage of the guava plants.

Defoliation treatments substantially improved the TSS/acid ratio in guava trees, with notable enhancement observed in the combination treatment of $ZnSO_4$ 2% + NH_4NO_3 4%. This treatment demonstrated the highest improvement in fruit quality during storage, particularly after 9 days, indicating its effectiveness in maintaining fruit freshness and acidity balance over time.

Table no. 4.22: Effect of nano-Zn and nano-Cu on TSS: Acid ratio at 0 DAS, 4 DAS, 8 DAS, and 12 DAS of guava.

Treatments	TSS: Acid ratio											
	0 (DAS)			4 (DAS)			8 (DAS)			12 (DAS)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	7.82 ± 0.032^{a}	7.19 ± 0.113^{ab}	7.51 ± 0.072^{a}	11.02 ± 0.028^{a}	9.83 ± 0.158^{a}	10.43 ± 0.083^{a}	13.95 ± 0.067^{a}	12.16 ± 0.217^{ab}	13.05 ± 0.118^{a}	13.75 ± 0.070^{a}	15.57 ± 0.256^{a}	14.66 ± 0.163^{a}
T_2	7.93 ± 0.052^{ab}	7.08 ± 0.112^{a}	7.50 ± 0.068^{a}	11.51 ± 0.075^{b}	9.85 ± 0.164^{a}	10.68 ± 0.073^{ab}	14.42 ± 0.058^{b}	12.04 ± 0.294^{ab}	13.23 ± 0.174^{a}	18.75 ± 0.092^{b}	14.92 ± 0.438^{a}	16.84 ± 0.262^{b}
T_3	7.95 ± 0.063^{ab}	7.07 ± 0.063^{a}	7.51 ± 0.034^{a}	11.66 ± 0.053^{b}	9.91 ± 0.123^{a}	10.79 ± 0.038^{ab}	14.49 ± 0.114^{b}	11.99 ± 0.134^{a}	13.24 ± 0.039^{a}	19.40 ± 0.088^{c}	15.36 ± 0.273^{a}	17.38 ± 0.114^{b}
T_4	8.09 ± 0.017^{b}	7.32 ± 0.098^{ab}	7.71 ± 0.051^{b}	11.81 ± 0.135^{bc}	10.29 ± 0.209^{ab}	11.05 ± 0.155^{bc}	14.90 ± 0.149^{c}	12.68 ± 0.153^{bc}	13.79 ± 0.073^{b}	20.43 ± 0.219^{d}	16.68 ± 0.522^{b}	18.56 ± 0.370^{c}
T_5	8.38 ± 0.020^{c}	7.84 ± 0.066^{c}	8.12 ± 0.031^{c}	12.36 ± 0.147^{d}	11.21 ± 0.063^{c}	11.78 ± 0.077^{d}	15.57 ± 0.073^{d}	13.86 ± 0.146^{d}	14.72 ± 0.043^{c}	21.22 ± 0.103^{e}	18.28 ± 0.294^{d}	19.75 ± 0.149^{d}
T_6	8.13 ± 0.033^{b}	7.41 ± 0.088^{b}	7.77 ± 0.040^{b}	12.03 ± 0.124^{c}	10.54 ± 0.243^{b}	11.29 ± 0.177^{c}	15.17 ± 0.114^{c}	12.97 ± 0.168^{c}	14.07 ± 0.058^{b}	20.96 ± 0.102^{e}	17.16 ± 0.388^{bc}	19.07 ± 0.220^{c}
T_7	8.53 ± 0.083^{c}	7.77 ± 0.073^{c}	8.15 ± 0.070^{c}	12.78 ± 0.110^{e}	11.17 ± 0.157^{c}	11.97 ± 0.114^{d}	15.90 ± 0.072^{e}	13.59 ± 0.187^{d}	14.75 ± 0.098^{c}	22.07 ± 0.109^{f}	18.05 ± 0.380^{cd}	20.06 ± 0.213^{d}
T_8	9.17 ± 0.086^{e}	8.29 ± 0.075^{d}	8.74 ± 0.080^{e}	13.66 ± 0.517^{g}	$11.830.051^{d}$	12.75 ± 0.046^{e}	16.51 ± 0.072^{f}	14.04 ± 0.060^{d}	15.28 ± 0.056^{d}	23.15 ± 0.145^{h}	18.77 ± 0.183^{de}	20.96 ± 0.165^{e}
T_9	10.06 ± 0.173^{f}	$9.130.020^{e}$	9.60 ± 0.089^{f}	14.61 ± 0.133^{h}	12.78 ± 0.325^{e}	13.70 ± 0.226^{f}	17.26 ± 0.163^{g}	14.90 ± 0.406^{e}	16.08 ± 0.283^{e}	24.41 ± 0.167^{i}	20.13 ± 0.400^{f}	22.27 ± 0.195^{f}
T_{10}	8.80 ± 0.101^{d}	8.24 ± 0.015^{d}	8.52 ± 0.055^{d}	$13.280.108^{f}$	12.08 ± 0.101^{d}	12.68 ± 0.021^{e}	16.39 ± 0.126^{f}	14.68 ± 0.147^{e}	15.54 ± 0.026^{d}	22.56 ± 0.237^{g}	$19.540.208^{ef}$	21.05 ± 0.016^{e}
S. Em (±)	0.124	0.118	0.120	0.197	0.188	0.190	0.188	0.198	0.189	0.524	0.331	0.405

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ Cu_2(30ppm)], T_{10} [$ZnSO_4$]

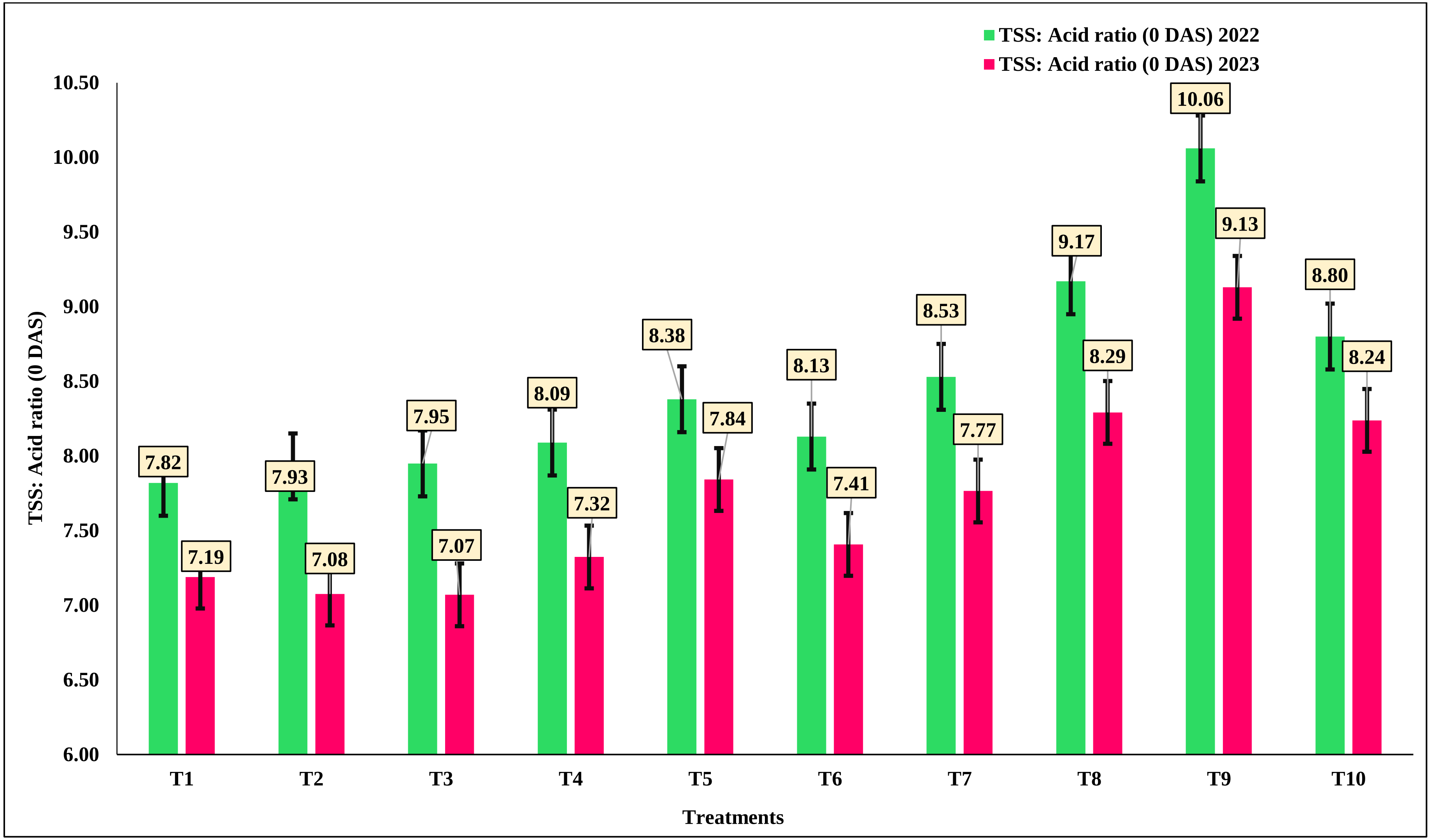

Fig. 4.70: Effect of nano-Zn and nano-Cu on TSS: Acid ratio (0 DAS) in guava

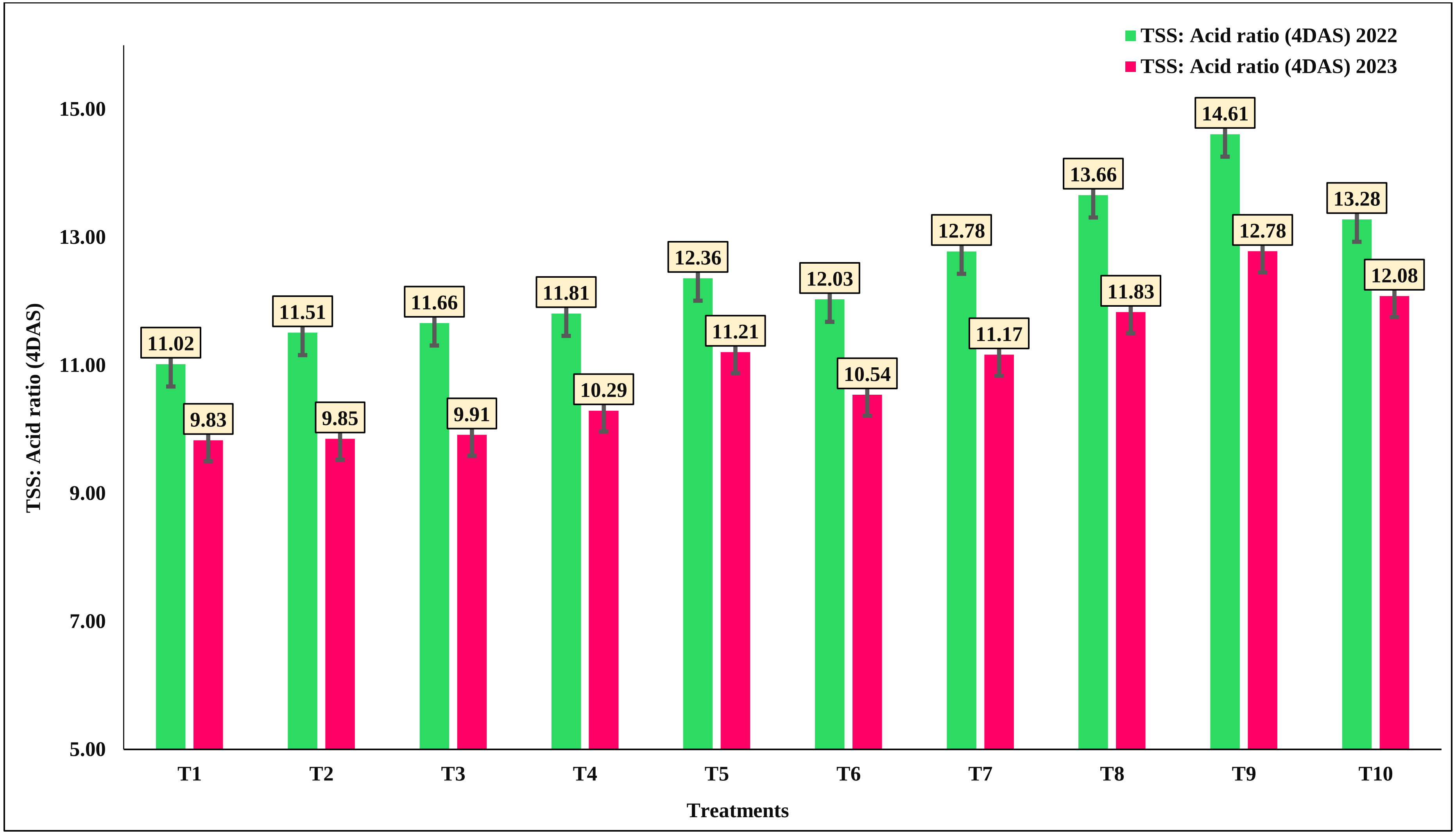

Fig. 4.71: Effect of nano-Zn and nano-Cu on TSS: Acid ratio (4 DAS) in guava

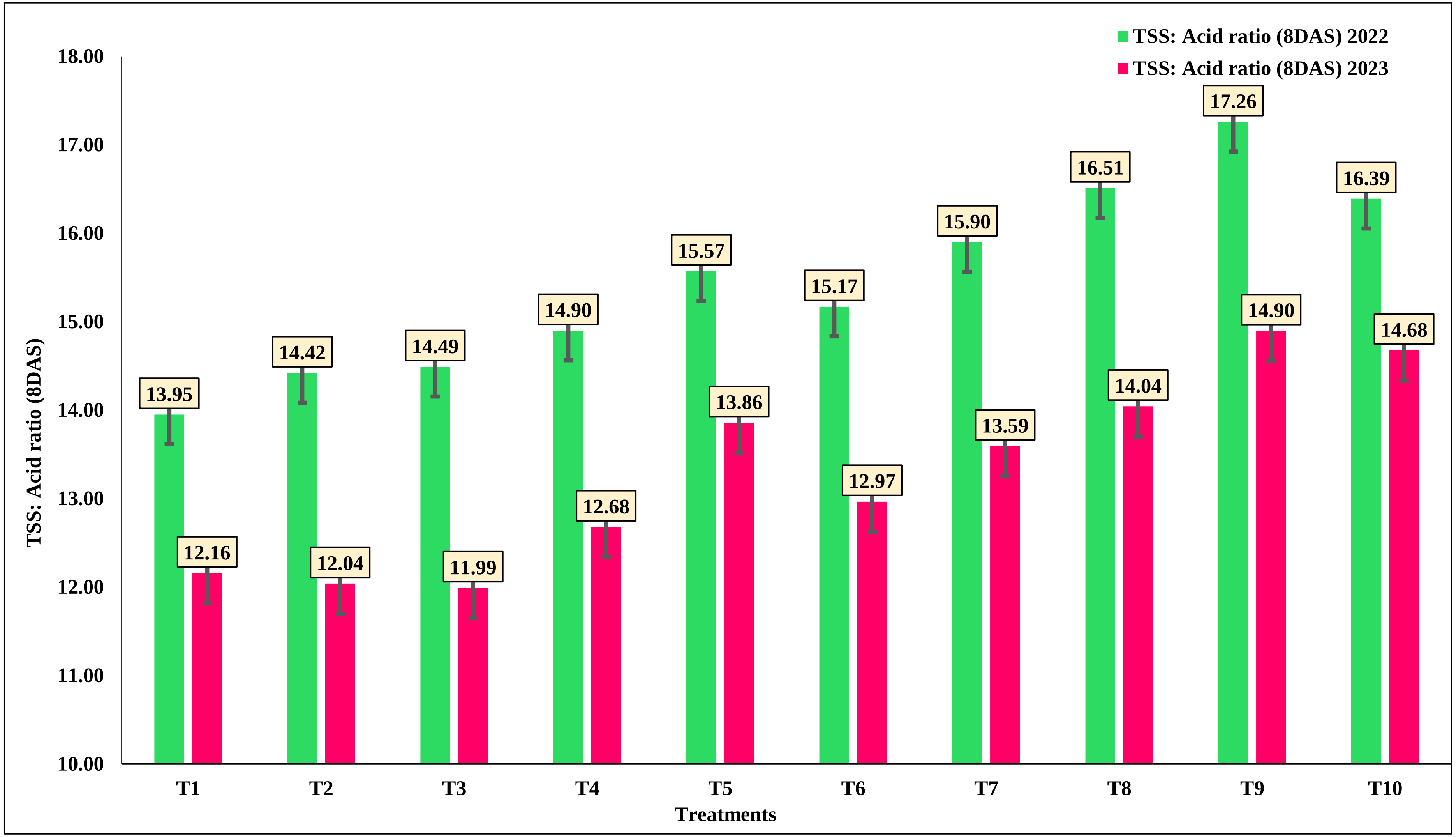

Fig. 4.72: Effect of nano-Zn and nano-Cu on TSS: Acid ratio (8 DAS) in guava

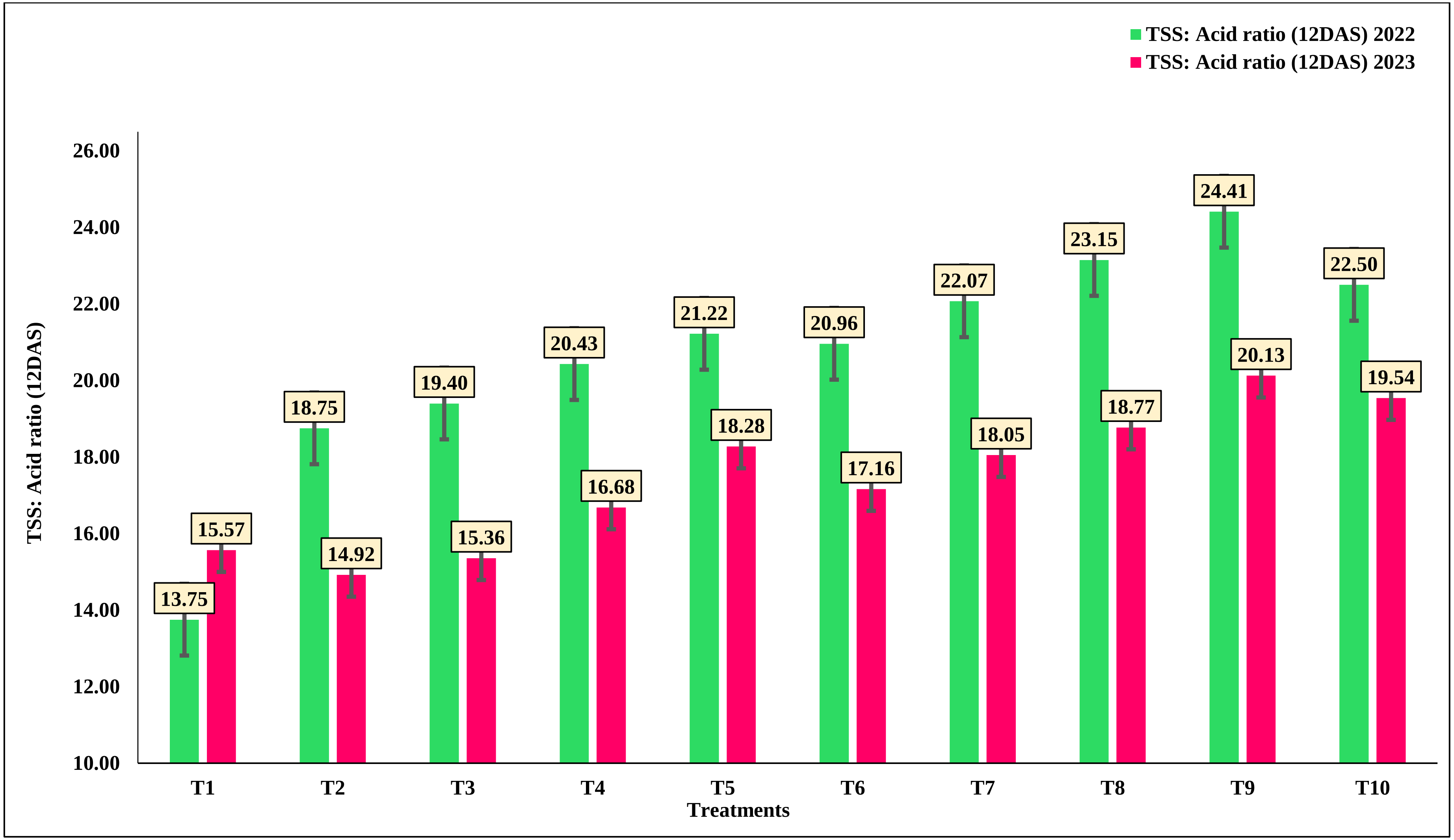

Fig. 4.73: Effect of nano-Zn and nano-Cu on TSS: Acid ratio (12 DAS) in guava

4.6.25 Ascorbic acid (mg/100g) (0 DAS)

Table no. 4.23 presents the data on the variation in ascorbic acid (mg/100g) during the two-year experiment (2022 and 2023). Nano-micronutrient treatments impact on the ascorbic acid (Vit-C) of the guava fruit during both years of the experiment, graphically presented in figure no.4.74.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was recorded with the highest ascorbic acid (Vit-C) on the zero day of storage was 268.90mg/100g substantially maximum from other treatments. The lowest ascorbic acid (Vit-C) on the zero day of storage was 246.14 recorded in treatment T_1 (Control).

In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum ascorbic acid (Vit-C) on the zero day of storage, which was 271.12 mg/100g substantially maximum from other treatments. Rest of the treatments showed substantial differences in ascorbic acid on the zero day of storage. Treatment T_1 (Control) recorded the lowest ascorbic acid (Vit-C) on the zero day of storage was 247.64 mg/100g.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the superior ascorbic acid (Vit-C) on the zero day of shelf-life studies, a value of 270.01 mg/100g substantially maximum from other treatments. Instead, the treatment T_1 was noted with the lowest ascorbic acid (Vit-C) on the zero day of shelf-life studies, a value of 246.89 mg/100g.

4.6.26 Ascorbic acid (mg/100g) (4 DAS)

Table no. 4.23 presents the data on the variation in ascorbic acid (mg/100g) on the fourth day of storage during the two-year experiment (2022 and 2023). Nano-micronutrient treatments impact on the ascorbic acid (mg/100g) on the fourth day of storage of the guava during both years of the experiment, graphically presented in figure no.4.75.

In 2022, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was noted with the superior ascorbic acid on the fourth day of shelf-life studies was 262.84 mg/100g it was substantially superior from other treatments. The lowest ascorbic acid (Vit-C) on the fourth day of shelf-life studies was 232.28 mg/100g noted in treatment T_1 (Control).

In 2023, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] concluded in the superior ascorbic acid (Vit-C) (mg/100g) on the fourth day of shelf-life studies, which was 265.05 mg/100g it is substantially superior from other treatments. Rest of the treatments ensued substantial differences in ascorbic acid (Vit-C) on the fourth day of shelf-life studies. Treatment T_1 (Control) noted the lowest ascorbic acid (Vit-C) on the fourth day of shelf-life studies was 233.77 mg/100g.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] ensued in the superior ascorbic acid on the fourth day of shelf-life studies, with a value of 263.95 mg/100g it was substantially superior from other treatments. Instead, treatment T_1 was noted with the lowest ascorbic acid (Vit-C) on the fourth day of shelf-life studies, a value of 233.03 mg/100g.

4.6.27 Ascorbic acid (mg/100g) (8 DAS)

Table no. 4.23 presents the data on the variation in ascorbic acid (mg/100g) on the eighth day of shelf-life studies during the two-year experiment (2022 and 2023). Nano-micronutrient treatments impact on the ascorbic acid on the eight day of shelf-life studies of the guava fruit during both years of the experiment, graphically presented in figure no.4.76.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was noted with the superior ascorbic acid on the eight day of shelf-life studies was 255.73 mg/100g it is substantially superior from other treatments. The minimum ascorbic acid on the eight day of shelf-life studies was 227.38 mg/100g noted in treatment T_1 (Control).

In 2023, the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] noted in the superior ascorbic acid on the eight days of shelf-life studies, which was 257.95 mg/100g it was substantially superior from other treatments. Rest of the other treatments resulted substantial differences in ascorbic acid (Vit-C) on the eight days of shelf-life studies. Treatment T_1 (control) noted the lowest ascorbic acid on the eight day of self-life studies was 228.88 mg/100g.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] ensued in the superior ascorbic acid on the eight day of self-life studies, with a value of 256.84 mg/100g it is substantially superior from other treatments. Instead, treatment T_1 was noted with the lowest ascorbic acid on the eight day of self-life studies, a value of 228.13 mg/100g.

4.6.28 Ascorbic acid (mg/100g) (12 DAS)

Table no. 4.23 presents the data on the variation in ascorbic acid (mg/100g) on the twelfth day of shelf-life studies during the two-year experiment (2022 and 2023). Nano-micronutrient treatments impact on the ascorbic acid on the twelfth day of shelf-life studies of the guava during both years of the experiment, graphically presented in figure no.4.77.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was recorded with the highest ascorbic acid on the twelfth day of shelf-life studies was 237.73 mg/100g it is substantially superior from other treatments. The minimum ascorbic acid on the twelfth day of shelf-life studies was 216.15 mg/100g noted in treatment T_3 (nano-Zn_2(60ppm)) at nominal with T_2 and T_4 with the values of 217.80 and 218.34 mg/100g respectively.

In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the superior ascorbic acid (mg/100g) on the twelfth day of shelf-life studies, which was 237.73 mg/100g it is substantially superior from other treatments. Rest of the treatments resulted substantial superior in Vit-C on the twelfth day of shelf-life studies. Treatment T_3 (nano-Zn_2(60ppm)) noted the lowest ascorbic acid (mg/100g) on the twelfth day of shelf-life studies which was 216.15 mg/100g This was at nominal with treatment T_1, T_2, and T_4 ranging from 216.77 to 218.34 mg/100g.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] ensued in the superior ascorbic acid (mg/100g) on the twelfth day of shelf-life studies, with a value of 237.73 mg/100g it was substantially superior from other treatments. Instead, treatment T_3 (nano-Zn_2(60ppm)) was noted with the lowest ascorbic acid (mg/100g) on the twelfth day of shelf-life studies, a value of 216.15 mg/100g at nominal with T_2, and T_4 with the values of 217.80 and 218.34 mg/100g respectively.

In treatment T_9, the ascorbic acid content was observed to be highest during subsequent days of storage, possibly attributed to an increase in total soluble sugars within the fruits. This trend closely aligns with the findings of Jagtar Singh *et al.* (1978). However, over the storage period, there was a decline in ascorbic acid content, as indicated in Table 4.23.

Application of nano-Zn and Cu was effective in reducing the post-harvest degradation of indigenous ascorbic acid in guava fruits during storage, consistent with the findings of Deepthi *et al.* (2016). These results also resonate with the study conducted by Rajkumar *et al.* (2005) in papaya.

Table no. 4.23: Effect of nano-Zn and nano-Cu on ascorbic acid (mg/100g) at 0 DAS, 4 DAS, 8 DAS, and 12 DAS of guava.

Treatments	Ascorbic acid (mg/100g)											
	0 (DAS)			4 (DAS)			8 (DAS)			12 (DAS)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	246.14±0.864[a]	247.64±1.214[a]	246.89±1.039[a]	232.28±1.691[a]	233.77±2.0221[a]	233.03±1.856[a]	227.38±0.376[a]	228.88±0.696[a]	228.13±0.531[a]	227.58±1.849[d]	216.77±1.036[a]	222.18±1.438[c]
T_2	252.32±0.518[b]	253.80±0.443[b]	253.07±0.454[b]	245.58±0.595[bc]	247.06±0.925[bc]	246.32±0.759[bc]	237.45±0.540[bc]	238.93±0.843[b]	238.20±0.686[b]	217.8±0.317[ab]	217.79±0.312[ab]	217.80±0.314[ab]
T_3	251.89±1.108[b]	253.76±1.401[b]	252.83±1.252[b]	242.89±0.427[b]	244.75±0.703[b]	243.82±0.554[b]	236.09±0.722[b]	237.96±0.382[b]	237.03±0.552[b]	216.15±0.588[a]	216.15±0.588[a]	216.15±0.588[a]
T_4	253.17±0.468[b]	254.31±0.468[b]	253.74±0.468[b]	246.39±1.554[cd]	247.53±1.551[bc]	246.97±1.554[bc]	238.03±0.492[c]	239.17±0.489[b]	238.60±0.492[b]	218.34±0.433[ab]	218.34±0.433[ab]	218.34±0.433[ab]
T_5	259.12±0.505[c]	260.98±0.565[c]	260.05±0.505[c]	252.08±1.071[e]	253.94±1.069[e]	253.01±1.005[e]	246.14±0.511[e]	248.01±0.219[d]	247.08±0.349[d]	228.71±0.501[d]	228.71±0.501[d]	228.71±0.501[d]
T_6	257.22±1.419[c]	258.73±1.145[c]	257.98±1.282[c]	247.13±0.277[cd]	248.64±0.578[cd]	247.89±0.425[cd]	239.97±0.501[d]	241.49±0.543[c]	240.73±0.403[c]	219.44±0.683[b]	219.44±0.683[b]	219.44±0.683[b]
T_7	264.13±1.945[d]	265.67±2.064[d]	264.90±1.999[d]	258.51±1.291[f]	260.04±0.970[f]	259.28±1.130[f]	250.78±0.338[f]	252.32±0.441[f]	251.55±0.358[f]	235.50±0.827[e]	235.51±0.827[e]	235.51±0.827[e]
T_8	258.46±0.562[c]	260.32±0.904[c]	259.39±0.733[c]	249.75±0.998[de]	251.61d±1.990[e]	250.68±1.088[de]	240.10±0.210[d]	241.95±0.543[c]	241.03±0.374[c]	223.96±1.007[c]	223.97±1.007[c]	223.97±1.010[c]
T_9	268.90±0.406[e]	271.12±0.367[e]	270.01±0.385[e]	262.84±0.978[g]	265.05±0.970[g]	263.95±0.975[g]	255.73±0.593[g]	257.95±0.635[g]	256.84±0.615[g]	237.73±1.011[e]	237.73±1.010[e]	237.73±1.011[e]
T_{10}	263.510.518[d]	264.71±0.552[d]	264.12±0.536[d]	257.67±1.270[f]	258.87±1.298[f]	258.27±1.285[f]	249.39±0.677[f]	250.59±0.696[e]	249.99±0.688[e]	230.15±0.758[d]	230.16±0.758[d]	230.16±0.758[d]
S. Em (±)	1.229	1.25	1.241	1.584	1.605	1.594	1.480	1.501	1.490	1.363	1.433	1.365

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ Cu_2(30ppm)], T_{10} [$ZnSO_4$]

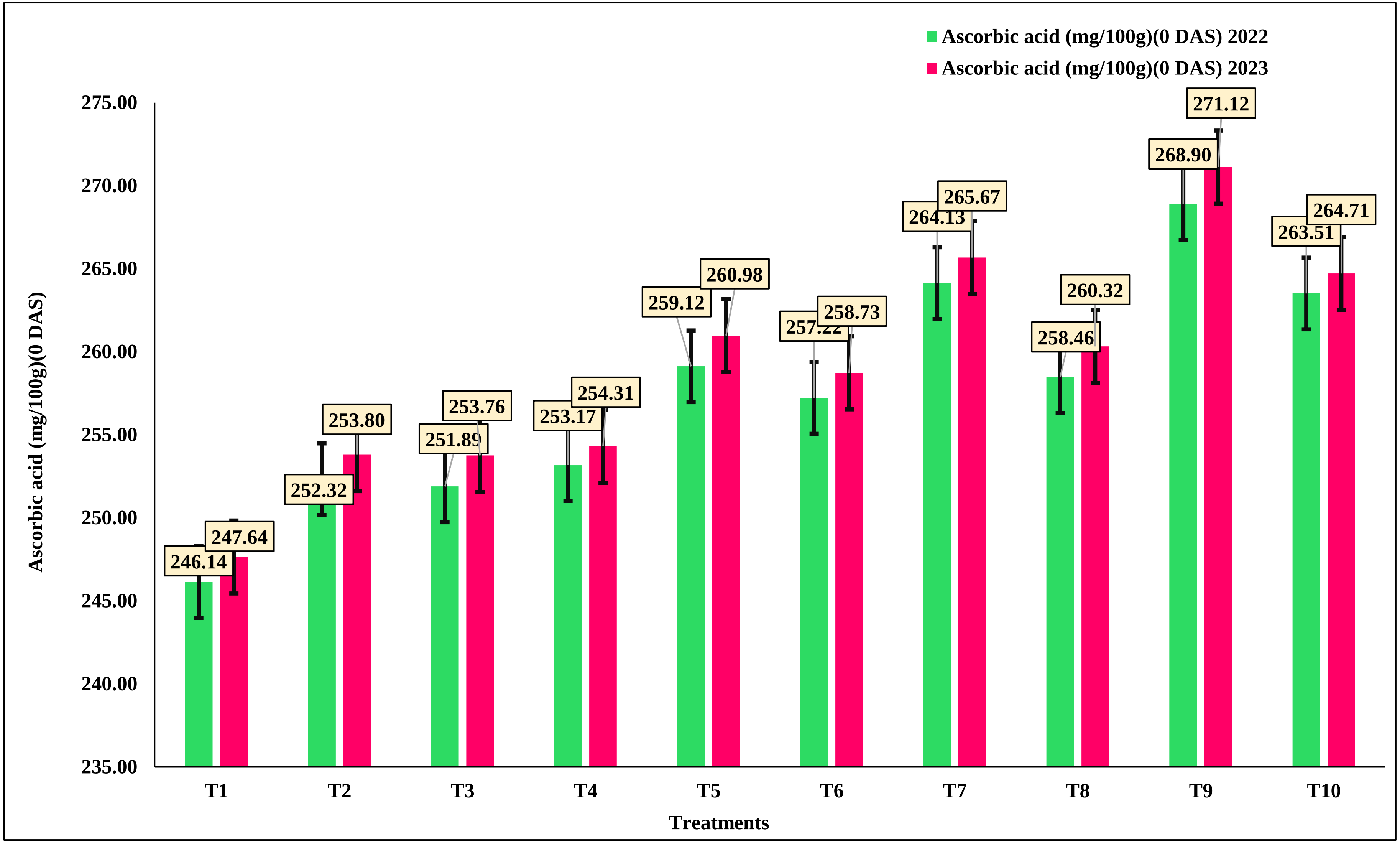

Fig. 4.74: Effect of nano-Zn and nano-Cu on ascorbic acid (mg/100g) (0 DAS) in guava

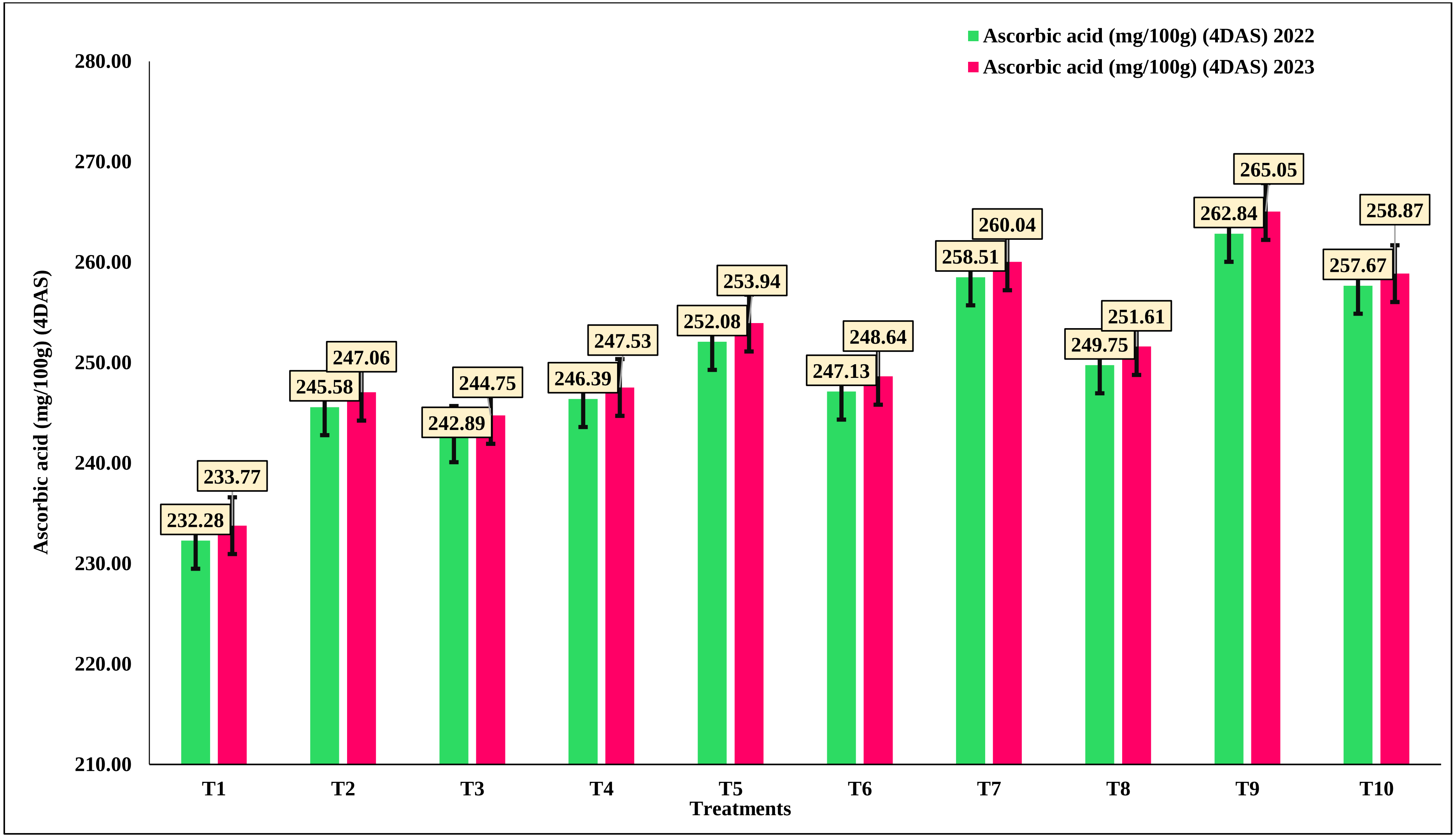

Fig. 4.75: Effect of nano-Zn and nano-Cu on ascorbic acid (mg/100g) (4 DAS) in guava

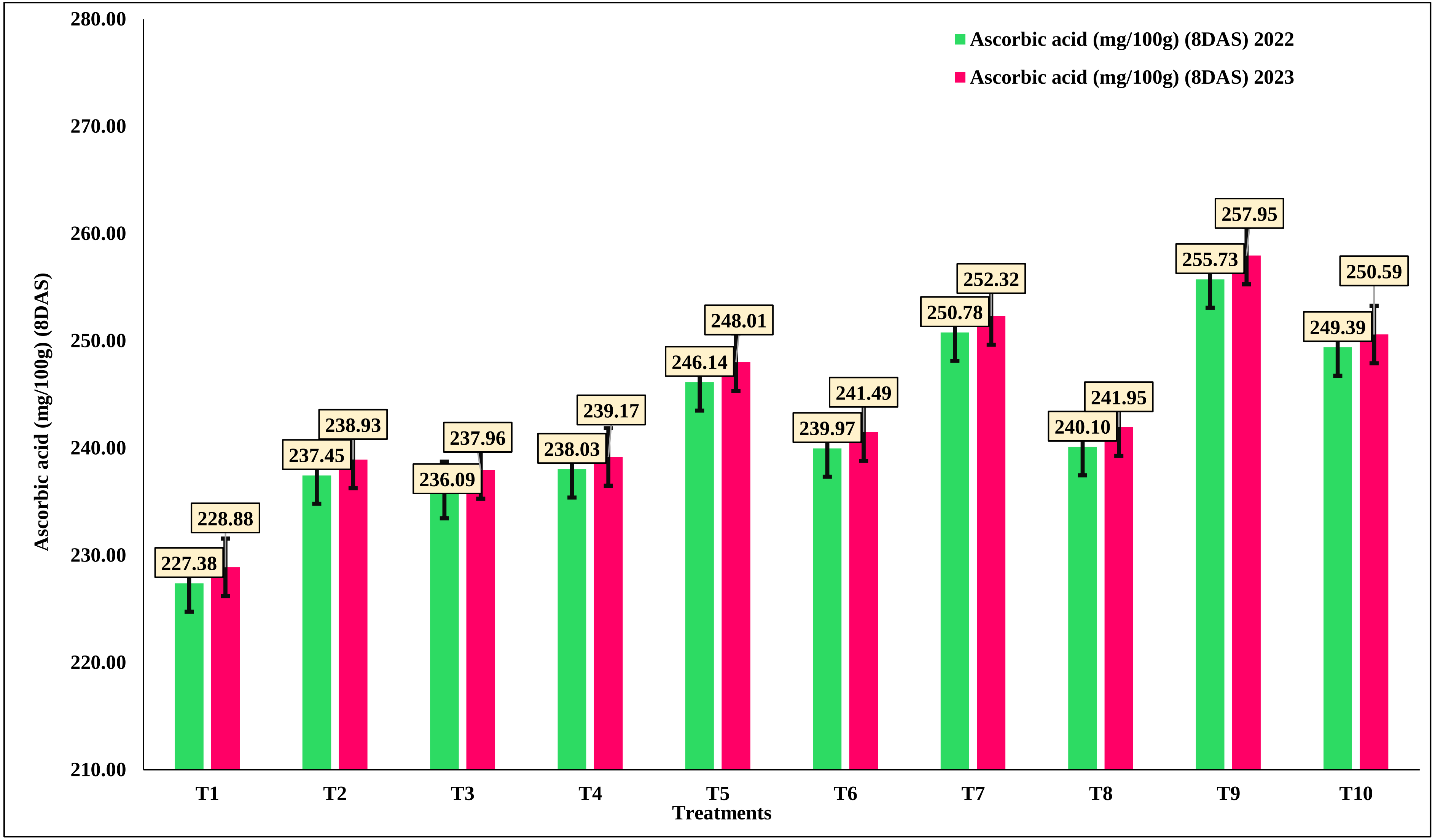

Fig. 4.76: Effect of nano-Zn and nano-Cu on ascorbic acid (mg/100g) (8 DAS) in guava

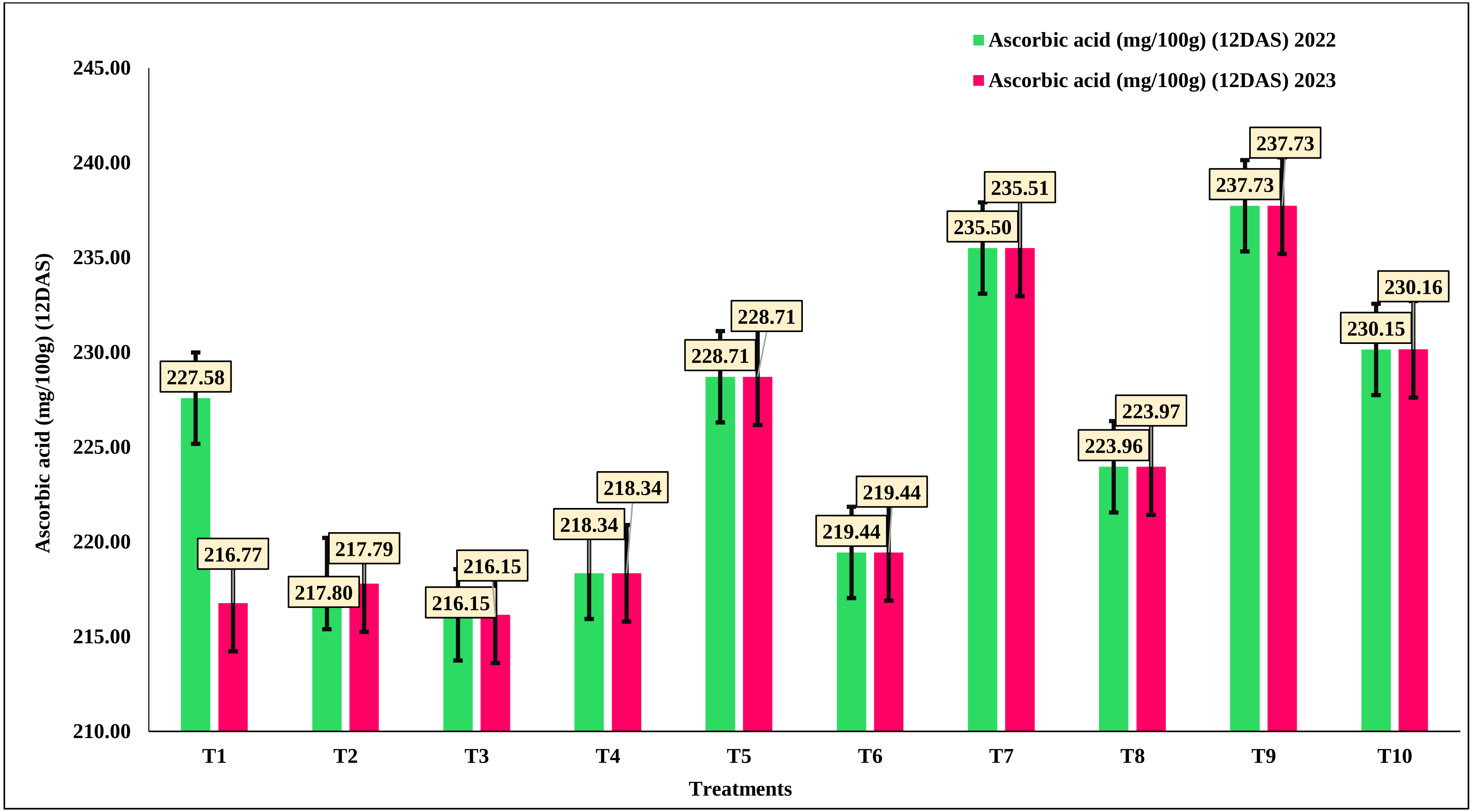

Fig. 4.77: Effect of nano-Zn and nano-Cu ascorbic acid (mg/100g) (12 DAS) in guava

4.6.29 Antioxidants DPPH (%) (0 DAS)

Table no. 4.24 shows the data on the variation in the antioxidants (%) on the zero day of storage during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments impact at antioxidants (%) on the zero day in guava during both the years of the experiment, graphically presented in figure no.4.78.

During the first year of the experiment (2022), the superior antioxidants (%) on the zero day was under treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 48.35% were noted at nominal with T_7 with value of 48.17%. The minimum antioxidants on the zero day 39.58 % was recorded in treatment T_1 (Control).

In the second trial year (2023), statistically, treatments made a substantial impact on the antioxidants (%) on the zero day of guava fruit storage. The Maximum antioxidant (%) on the zero day was 49.31 % was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] it is substantially superior from other treatments. The lowest antioxidants (%) on the zero day of shelf-life studies was 40.00 % in treatment T_1 (Control).

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the superior antioxidants (%) on the zero day of shelf-life studies, with a value of 48.84 % which was substantially superior from other treatments. Instead, treatment T_1 had the lowest value of antioxidants, 39.79 %.

4.6.30 Antioxidants DPPH (%) (4 DAS)

Table no. 4.24 shows the data on the variation in the antioxidants (%) on the fourth day of storage during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments impact on antioxidants (%) on the fourth day in guava during both years of the experiment, graphically presented in figure no.4.79.

During the first year of the experiment (2022), the maximum antioxidants (%) on the fourth day of storage was under treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 47.28 % were noted it is substantially superior from other treatments. The minimum antioxidants (%) on the fourth day of shelf-life studies was 39.44 % were ensued in treatment T_1 (no treatment).

In 2023, statistically, treatments made a substantial impact on the antioxidants (%) on the fourth day of guava fruit storage. The superior antioxidants on the fourth day of shelf-life studies were in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 48.24 % it was substantially superior from other treatments. The lowest antioxidants (%) on the fourth day of shelf-life studies 39.85 % was in treatment T_1 (Control) was observed.

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the superior antioxidants (%) on the fourth day of shelf-life studies, with a value of 47.77 % which was substantially superior with all the treatments. Instead, treatment T_1 had the lowest antioxidants on the fourth day of shelf-life studies, with a value of 39.65 %.

4.6.31 Antioxidants DPPH (%) (8 DAS)

Table no. 4.24 shows the data on the variation in the antioxidants (%) on the eighth day of storage during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments impact on antioxidants (%) on the eight day of storage in guava during both years of the experiment, graphically presented in figure no.4.80.

In 2022, the maximum antioxidants (%) on the eight day of shelf-life studies was under T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 42.39 % were recorded which was substantially superior with all the treatments. The minimum antioxidants on the eighth day of storage were 35.63 % which was noted in treatment T_1 (Control).

In 2023, statistically, treatments made a substantial impact on the antioxidants (%) on the eight days of shelf-life studies of guava fruit. The superior antioxidants on the eighth day of shelf-life studies were noted on treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 43.34% which was substantially superior with the other treatments. The lowest antioxidants on the eight days of shelf-life studies were 36.04 % in treatment T_1.

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the superior antioxidants (%) on the eight days of shelf-life studies, with a value of 42.87 % which was substantially superior with the other treatments. In contrast, treatment T_1 had the lowest antioxidants (%) on the eight days of shelf-life studies, with a value of 35.84 %.

4.6.32 Antioxidants DPPH (%) (12 DAS)

Table no. 4.24 shows the data on the variation in the antioxidants (%) on the of storage during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments impact on antioxidants (%) on the twelfth day of storage in guava during both years of the experiment, graphically presented in figure no.4.81.

During the first year of the experiment (2022), the maximum antioxidants (%) on the twelfth day of shelf-life studies was under T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] where 37.51% were noted it was substantially superior from other treatments. The minimum antioxidants (%) on the twelfth day of shelf-life studies were 30.66 % which was noted in treatment T_1.

In the second trial year (2023), statistically, treatments made a substantial impact on the antioxidants (%) on the twelfth day of guava fruit storage. The maximum antioxidants (%) on the twelfth day of storage were recorded on treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 38.47% it is substantially superior from other treatments. The lowest antioxidants (%) on the twelfth day were noted 31.07 % in treatment T_1.

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] gave the superior antioxidants (%) on the twelfth day, with a value of 38.00 % it is substantially superior from other treatments. Instead, treatment T_1 had the lowest antioxidants (%) on the twelfth day of shelf-life studies, with a value of 30.87 %.

Table no. 4.24 Effect of nano-Zn and nano-Cu on antioxidants at 0 DAS, 4 DAS, 8 DAS, and 12 DAS of guava.

Treatments	Antioxidants (%)											
	0 (DAS)			4 (DAS)			8 (DAS)			12 (DAS)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	39.58±0.017^{a}	40.00±0.036^{a}	39.79±0.176^{a}	39.44±0.023^{a}	39.85±0.038^{a}	39.65±0.023^{a}	35.63±0.095^{a}	36.04±0.060^{a}	35.84±0.077^{a}	30.66±0.043^{a}	31.070.073^{a}	30.87±0.056^{a}
T_2	45.60±0.191^{bc}	45.98±0.202^{c}	45.79±0.198^{bc}	44.62±0.020^{b}	45.00±0.033^{c}	44.81±0.027^{c}	39.42±0.014^{b}	39.80±0.012^{c}	39.61±0.012^{bc}	35.43±0.081^{bc}	35.81±0.092^{b}	35.62±0.866^{b}
T_3	45.43±0.115^{b}	45.72±0.094^{b}	45.58±0.105^{b}	45.73±0.020^{d}	46.03±0.010^{f}	45.88±0.013^{f}	39.29±0.117^{b}	39.59±0.098^{b}	39.44±0.108^{b}	35.58±0.082^{c}	35.87±0.098^{b}	35.73±0.90^{b}
T_4	45.76±0.015^{cd}	46.21±0.030^{c}	45.99±0.020^{cd}	44.95±0.017^{c}	45.40±0.024^{e}	45.18±0.017^{e}	39.50±0.141^{b}	39.95±0.132^{c}	39.73±0.136^{c}	35.39±0.031^{b}	35.84±0.048^{b}	35.62±0.393^{b}
T_5	45.76±0.011^{cd}	46.06±0.016^{c}	45.91±0.003^{c}	44.56±0.026^{b}	44.87±0.010^{b}	44.72±0.015^{b}	40.25±0.037^{c}	40.55±0.042^{d}	40.40±0.037^{d}	35.79±0.026^{d}	36.09±0.034^{c}	35.94±0.266^{c}
T_6	45.85±0.014^{d}	46.50±0.017^{d}	46.18±0.015^{d}	44.58±0.008^{b}	45.23±0.166^{d}	44.91±0.008^{d}	40.23±0.070^{c}	40.88±0.087^{e}	40.55±0.078^{d}	36.46±0.060^{e}	37.11±0.071^{d}	35.79±0.066^{d}
T_7	48.17±0.014^{fg}	48.62±0.018^{f}	48.40±0.012^{f}	47.16±0.028^{g}	47.61±0.049^{g}	47.39±0.038^{h}	42.10±0.011^{e}	42.55±0.011^{f}	42.33±0.000^{e}	37.35±0.057^{f}	37.80±0.034^{e}	37.58±0.046^{e}
T_8	46.20±0.008^{e}	47.14±0.020^{e}	46.67±0.014^{e}	46.76±0.005^{e}	47.70±0.005^{g}	47.23±0.000^{g}	41.76±0.029^{d}	42.70±0.028^{fg}	42.23±0.028^{e}	36.36±0.049^{e}	37.30±0.044^{d}	36.83±0.046^{d}
T_9	48.35±0.066^{g}	49.31±0.078^{h}	48.84±0.072^{g}	47.28±0.018^{h}	48.24±0.032^{h}	47.77±0.025^{i}	42.39±0.041^{f}	43.34±0.053^{h}	42.87±0.047^{f}	37.51±0.040^{g}	38.47±0.024^{f}	38.00±0.032^{f}
T_{10}	48.06±0.017^{f}	48.91±0.020^{g}	48.49±0.018^{f}	46.82±0.017^{f}	47.66±0.014^{g}	47.24±0.013^{g}	41.96±0.037^{e}	42.83±0.048^{g}	42.41±0.044^{e}	36.36±0.058^{e}	37.210.049^{d}	36.79±0.051^{d}
S. Em (±)	0.440	0.463	0.451	0.406	0.430	0.418	0.356	0.386	0.371	0.338	0.359	0.348

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm) + Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm) + Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)], T_{10} [$ZnSO_4$]

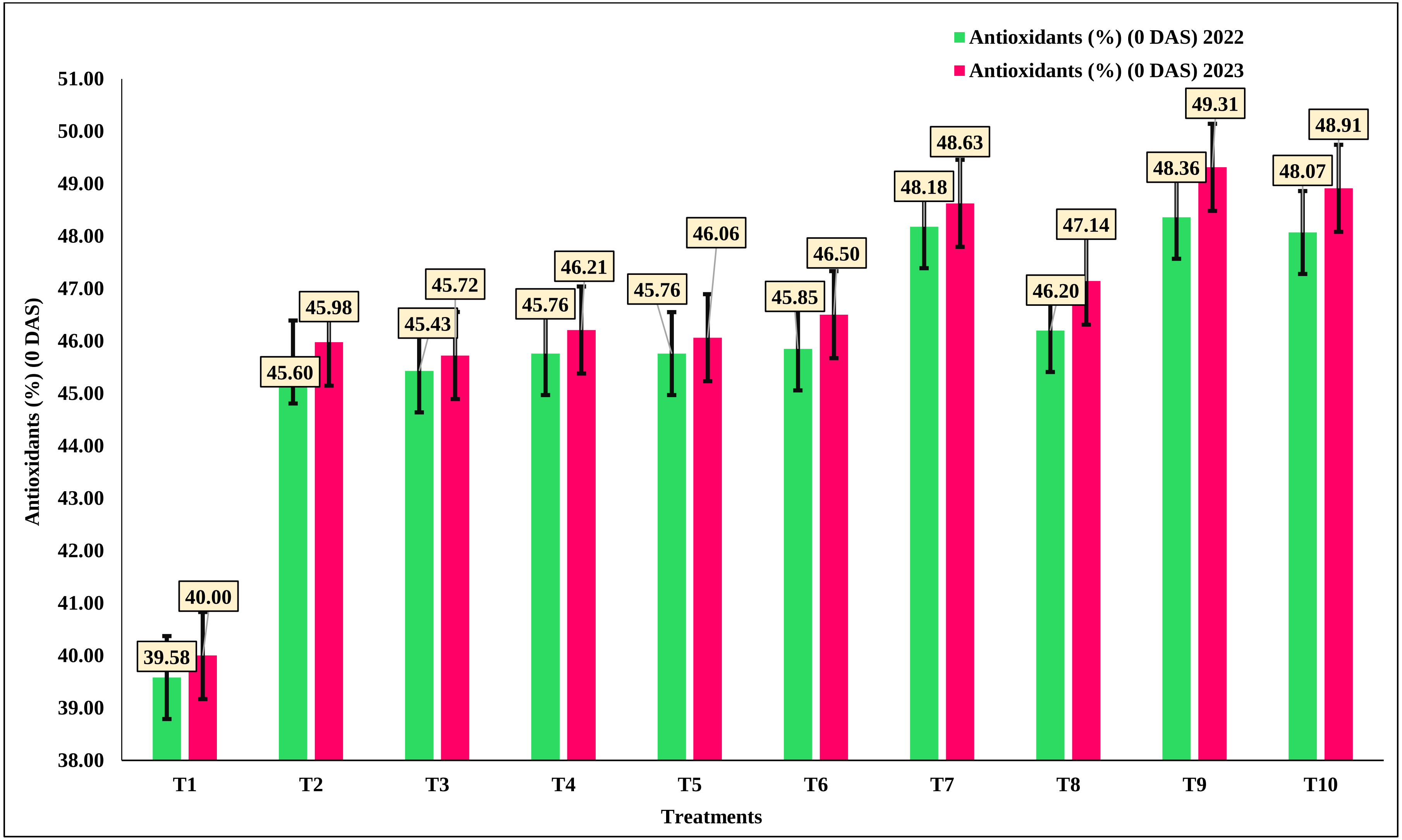

Fig. 4.78: Effect of nano-Zn and nano-Cu on antioxidants (%) (0 DAS) in guava

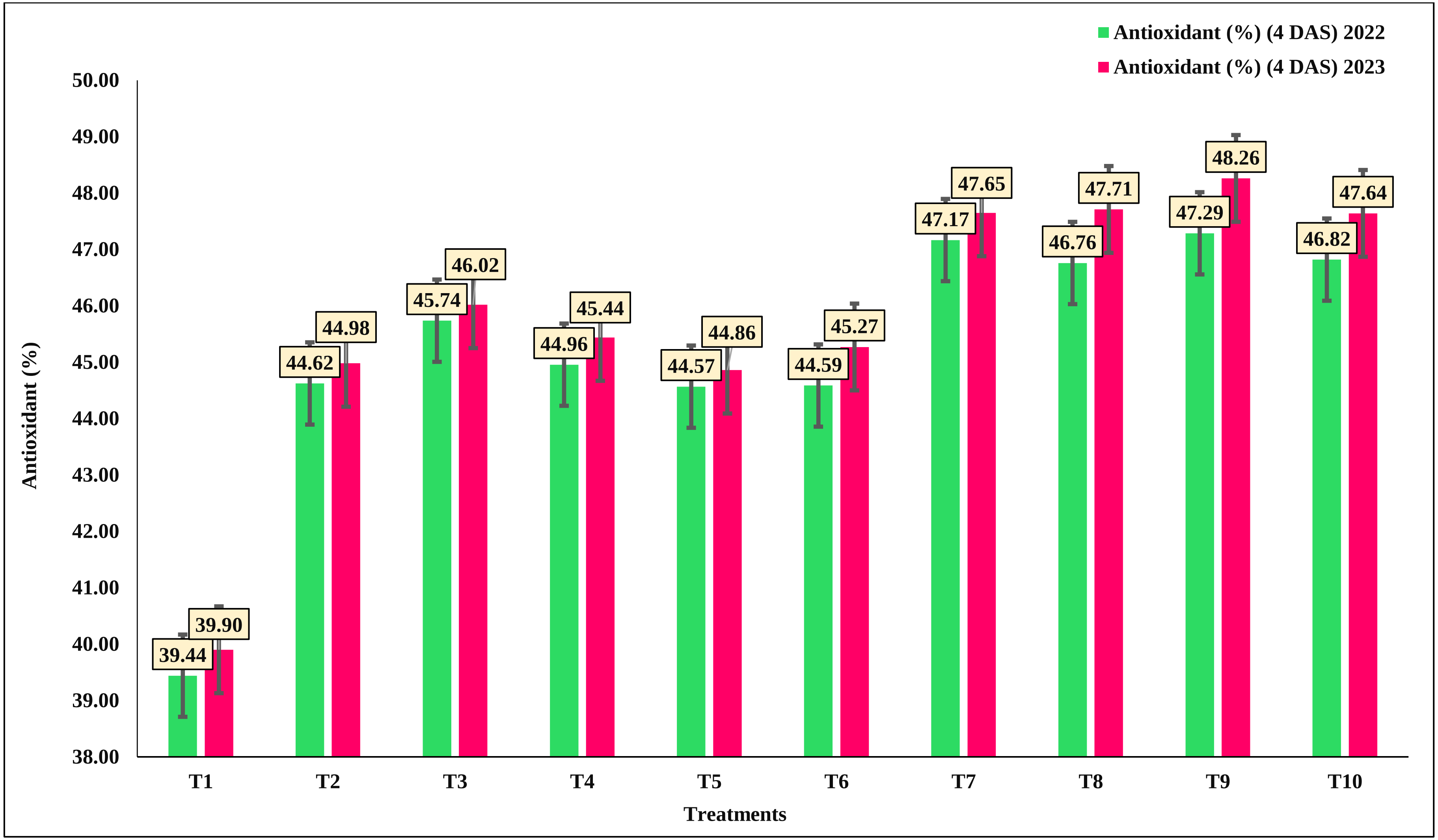

Fig. 4.79: Effect of nano-Zn and nano-Cu on antioxidants (%) (4 DAS) in guava

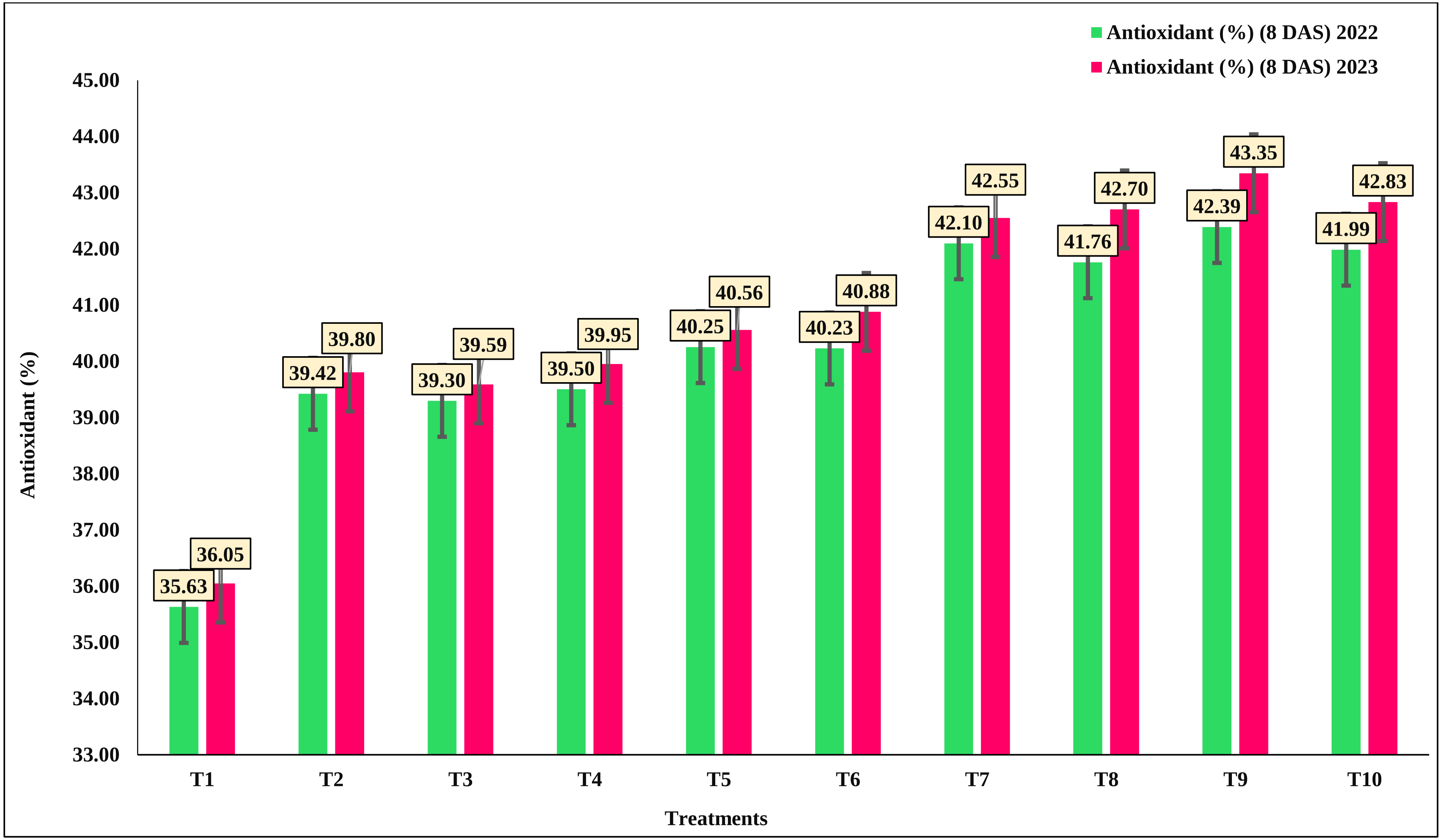

Fig. 4.80: Effect of nano-Zn and nano-Cu on antioxidants (%) (8 DAS) in guava

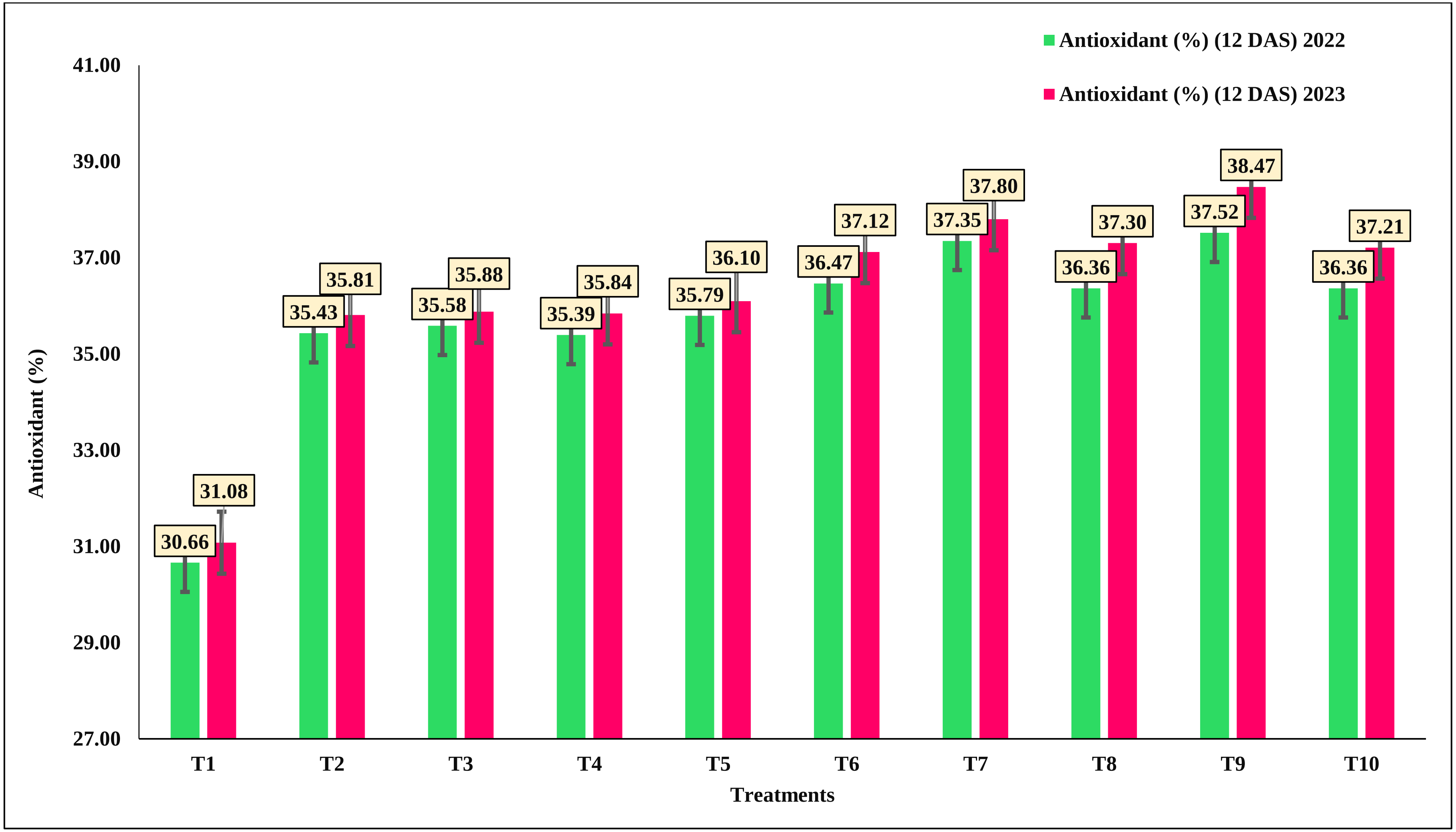

Fig. 4.81: Effect of nano-Zn and nano-Cu on antioxidants (%) (12 DAS) in guava

4.6.33 Firmness (kg/in^2) (0 DAS)

Table no. 4.25 provides information about the variation in firmness (kg/in^2) on the zero day of storage observed throughout the two years of the experiment (2022 and 2023). Nano-micronutrients treatment impact on firmness (kg/in^2) on the zero day of storage in guava fruit during both the years of the experiment, graphically presented in figure no.4.82.

During the first year of the experiment (2022), the superior firmness (kg/in^2) on the zero day of shelf-life studies was noted in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] and T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] which was 5.71kg/in^2. This was no substantial difference. The lowest firmness (kg/in^2) was ensued in treatment T_1 with a value of 5.00 kg/in^2.

In the second year of the trial (2023), The superior firmness (kg/in^2) on the zero day of shelf-life studies was noted in treatments T_5 and T_7, with the same value of 5.95 kg/in^2 at nominal with T_6, T_8, T_9 and T_{10} ranging from 5.54 to 5.90. Instead, treatment T_1 (Control) noted the minimum firmness on the zero day of shelf-life studies was 5.00 kg/in^2 at nominal with T_2 with a value of 5.33 kg/in^2.

Data combined for two years (2022 and 2023) showed that treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] had the maximum firmness (kg/in^2) on the zero day of shelf-life studies was 5.80 kg/in^2. This was at nominal with treatments T_2, T_3, T_4, T_5, T_6, T_7, T_9, and T_{10} ranging from 5.25 to 5.76 kg/in. Instead, treatment T_1 ensued in the lowest firmness (kg/in) on the zero day of shelf-life studies, measuring 5.00 kg/in^2 at nominal with T_2, T_3, T_4, T_6, and T_7 ranging from 5.25 to 5.74 kg/in^2.

4.6.34 Firmness (kg/in^2) (4 DAS)

Table no. 4.25 provides information about the variation in firmness (kg/in^2) on the fourth day of shelf-life studies noted throughout the two years of the experiment (2022 and 2023). Nano-micronutrients impact on firmness (kg/in^2) on the fourth day of shelf-life studies in guava fruit during the trial of the experiment, graphically presented in figure no.4.83.

In 2022, the superior firmness (kg/in^2) on the fourth day of shelf-life studies was noted in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 5.50 kg/in^2 this was found no substantial difference. The lowest firmness was observed in treatment T_1 (control) with a value of 4.78 kg/in^2.

In the second year of the trial (2023), The superior firmness (kg/in^2) on the fourth day of shelf-life studies was noted in treatment T_7, using nano-Zn_1(40ppm) + Cu_2(30ppm) was 5.82

kg/in^2 at nominal with T_5, T_6, T_8, T_9, and T_{10} ranging from 5.39 to 5.81 kg/in^2. Instead, treatment T_1 noted the minimum firmness (kg/in^2) on the fourth day of shelf-life studies was 4.87 kg/in^2 at nominal with T_2 with a value of 5.18 kg/in^2.

Data combined for two years (2022 and 2023) showed that treatment T_8 [nano-Zn_2(60ppm) + Cu_1(20ppm)] had the superior firmness (kg/in^2) on the fourth day of shelf-life studies was 5.60 kg/in^2 at nominal with T_3, T_4, T_5, T_6, T_7, T_9, and T_{10} ranging from 5.21 to 5.56 kg/in^2. Instead, treatment T_1 (Control) ensued in the lowest firmness (kg/in^2) on the fourth day of shelf-life studies, measuring 4.83 kg/in^2 at nominal with T_2, T_3, and T_4 ranging from 5.07 to 5.22 kg/in^2.

4.6.35 Firmness (kg/in^2) (8 DAS)

Table no. 4.25 provides information about the variation in firmness (kg/in^2) on the eight day of storage observed throughout the two years of the experiment (2022 and 2023). Nano-micronutrients impact on firmness (kg/in^2) on the eighth day of storage in guava fruit during both the years of the experiment, graphically presented in figure no.4.84.

During the first year of the experiment (2022), the maximum firmness (kg/in^2) on the eight day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 5.00 kg/in^2 this was found no substantial difference. The lowest firmness (kg/in^2) was resulted in treatment T_1 with a value of 4.29 kg/in^2.

In the second year of the trial (2023), The maximum firmness (kg/in^2) on the eight day of storage were recorded in treatment T_7, using nano-Zn_1(40ppm) + Cu_2(30ppm) was 5.68 kg/in^2 at nominal with T_4, T_5, T_6, T_8, and T_9 ranging from 5.38 to 5.67 kg/in^2. Instead, treatment T_1 noted the minimum firmness (kg/in^2) on the eight day of shelf-life studies was 4.74 kg/in^2 at nominal with T_2, and T_3 with a value of 5.02 and 4.47 kg/in^2 respectively.

Data combined for two years (2022 and 2023) showed that treatment T_7 [nano-Zn_1(40ppm) + Cu_2(30ppm)] had the superior firmness (kg/in^2) on the eight day of shelf-life studies was 5.26 kg/in^2 at nominal with T_2, T_3, T_4, T_5, T_6, T_8, T_9, and T_{10} ranging from 4.71 to 5.24 kg/in^2. Instead, treatment T_1 (Control) resulted in the lowest kg/in on the eight day of shelf-life studies, measuring 4.52 kg/in^2 at nominal withs T_2, T_3, and T_4 ranging from 4.71 to 5.02 kg/in^2.

4.6.36 Firmness (kg/in^2) (12 DAS)

Table no. 4.25 provides information about the variation in firmness (kg/in^2) on the twelfth day of storage observed throughout the two years of the experiment (2022 and 2023). Nano-micronutrients impact on firmness (kg/in^2) on the twelfth day of storage in guava fruit during both the years of the experiment, graphically presented in figure no.4.85.

In 2022, the maximum firmness (kg/in^2) on the eight day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] which was 4.48 kg/in^2 this was found no substantial results. The lowest firmness (kg/in^2) was resulted in treatment T_1 with a value of 3.83 kg/in^2.

In 2023, The superior firmness (kg/in^2) on the twelfth day of shelf-life studies was noted in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was 4.30 kg/in^2 at nominal with T_2, T_3, T_4, T_5, T_6, T_7, T_8, and T_{10} ranging from 3.53 to 4.30 kg/in^2. Instead, treatment T_1 (control) noted the minimum firmness (kg/in^2) on the twelfth day of shelf-life studies was 3.23 kg/in^2 at nominal withs T_2 and T_3 with a value of 3.53 and 3.86 kg/in^2 respectively.

Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the superior firmness (kg/in^2) on the twelfth day of shelf-life studies was 4.39 kg/in^2 at nominal with T_2, T_3, T_4, T_5, T_6, T_7, T_8, and T_{10} ranging from 3.73 to 4.36 kg/in^2. Instead, treatment T_1 (Control) resulted in the lowest firmness (kg/in^2) on the twelfth day of shelf-life studies, measuring 3.53 kg/in^2 which was at nominal T_2, T_3, T_4, T_5, T_6, T_7, and T_{10} ranging from 3.73 to 4.29 kg/in^2.

During the ripening of guava fruit, a significant reduction in firmness was noted. The softening process is attributed to either the conversion of insoluble proto-pectins into soluble pectin or the hydrolysis of starch. In this study, the pre-harvest application of nano-zinc and copper delayed fruit softening, showing notable differences during storage. Fruits treated with nano-Zn2 (60ppm) + Cu2 (20ppm) retained the highest firmness, followed by those treated with nano-Zn2 (60ppm) + Cu2 (30ppm), while the control group showed the least retention of firmness (Table 4.25). The retardation of fruit softening due to nano-Zn and Cu treatments has been reported in several fruits, such as Indian jujube (Zhong *et al.,* 2007) and papaya (Aleryani-Raqeeb A *et al.*, 2008).

Table no. 4.25: Effect of nano-Zn and nano-Cu on firmness (kg/in^2) at 0 DAS, 4 DAS, 8 DAS, and 12 DAS of guava.

Treatments	Firmness (kg/in^2)											
	0 (DAS)			4 (DAS)			8 (DAS)			12 (DAS)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	5.00±0.013^a	5.00±0.046^a	5.00±0.078^a	4.78±0.13^a	4.87±0.052^a	4.83±0.076^a	4.29±0.16^a	4.74±0.044^a	4.52±0.08^a	3.83±0.04^a	3.23±0.011^a	3.53±0.02^a
T_2	5.17±0.02^a	5.33±0.035^{ab}	5.25±0.033^{ab}	4.97±0.05^a	5.18±0.029^{ab}	5.07±0.040^{ab}	4.40±0.08^a	5.02±0.02^{ab}	4.71±0.05^{ab}	3.93±0.08^a	3.53±0.16^{ab}	3.73±0.041^{ab}
T_3	5.31±0.33^a	5.46±0.33^{bc}	5.39±0.33^{ab}	5.09±0.33^a	5.32±0.33^{bc}	5.21±0.31^{abc}	4.58±0.34^a	4.97±0.24^{ab}	4.78±0.29^{ab}	3.99±0.29^a	3.86±0.29^{ab}	3.93±0.29^{ab}
T_4	5.38±0.29^a	5.47±0.014^{bc}	5.42±0.14^{ab}	5.1±0.35^a	5.33±0.017^{bc}	5.22±0.16^{abc}	4.62±0.33^a	5.41±0.098^{cd}	5.02±0.21^{ab}	4.13±0.35^a	4.00±0.35^b	4.07±0.35^{ab}
T_5	5.49±0.14^a	5.95±0.021^d	5.72±0.065^b	5.25±0.33^a	5.81±0.020^d	5.53±0.16^{bc}	4.73±0.35^a	5.67±0.016^d	5.20±0.18^b	4.23±0.32^a	4.09±0.32^b	4.16±0.32^{ab}
T_6	5.39±0.24^a	5.66±0.020^{bcd}	5.53±0.11^{ab}	5.17±0.21^a	5.52±0.037^{bcd}	5.35±0.10^{bc}	4.65±0.22^a	5.38±0.012^{cd}	5.02±0.10^{ab}	4.15±0.19^a	4.02±0.20^b	4.09±0.19^{ab}
T_7	5.52±0.31^a	5.95±0.032^d	5.74±0.176^{ab}	5.30±0.10^a	5.82±0.25^d	5.56±0.05^{bc}	4.83±0.10^a	5.68±0.018^d	5.26±0.05^b	4.33±0.12^a	4.20±0.10^b	4.27±0.11^{ab}
T_8	5.71±0.10^a	5.90±0.24^{cd}	5.80±0.24^b	5.49±0.12^a	5.71±0.011^{cd}	5.60±0.15^c	4.96±0.24^a	5.52±0.23^{cd}	5.24±0.23^b	4.45±0.26^a	4.27±0.27^b	4.36±0.268^b
T_9	5.71±0.10^a	5.80±0.014^{cd}	5.76±0.06^b	5.50±0.26^a	5.61±0.030^{bcd}	5.56±0.15^{bc}	5±0.10^a	5.42±0.003^{cd}	5.21±0.05^b	4.48±0.14^a	4.30±0.13^b	4.39±0.13^b
T_{10}	5.59±0.22^a	5.54±0.035^{bcd}	5.57^b±0.12	5.38±0.23^a	5.39±0.030^{bcd}	5.39±0.13^{bc}	4.89±0.29^a	5.24±0.046^{bc}	5.07±0.16^b	4.36±0.26^a	4.22±0.27^b	4.29±0.26^{ab}
S. Em (±)	0.07	0.064	0.062	0.074	0.060	0.05	0.70	0.062	0.062	0.072	0.08	0.078

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ Cu_2(30ppm)], T_{10} [$ZnSO_4$]

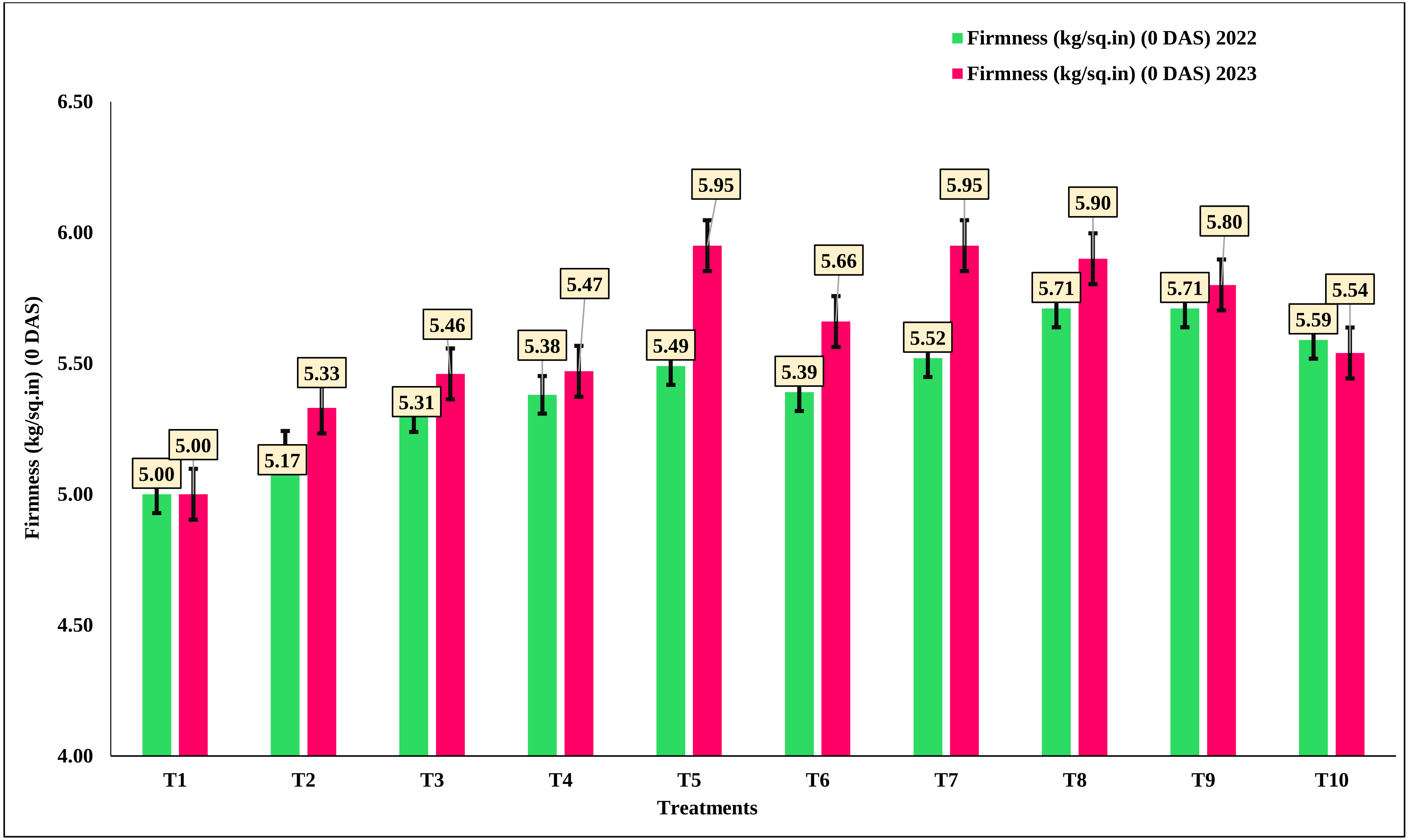

Fig. 4.82 Effect of nano-Zn and nano-Cu on firmness (kg/in^2) (0 DAS) in guava

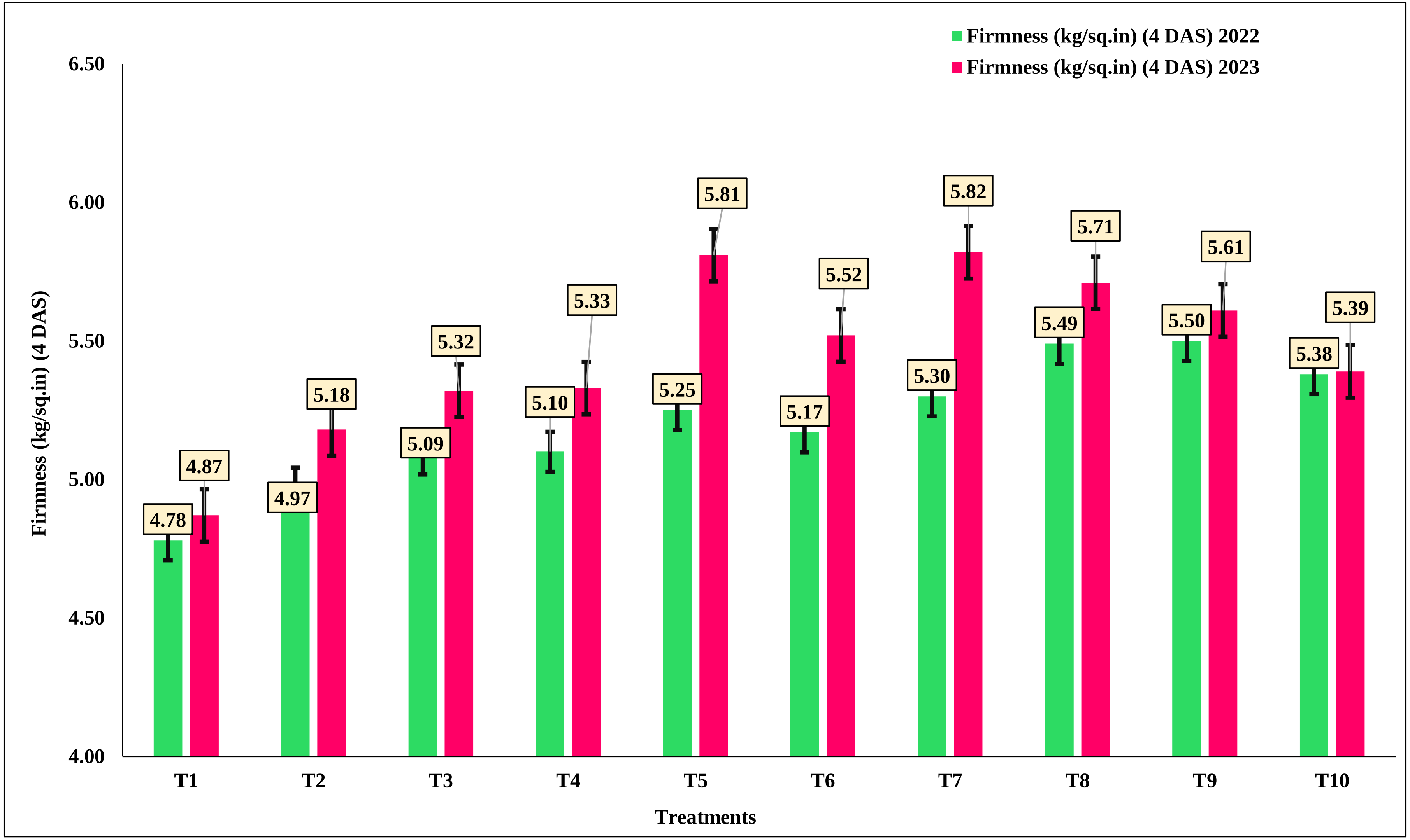

Fig. :4.83 Effect of nano-Zn and nano-Cu on firmness (kg/in^2) (4 DAS) in guava

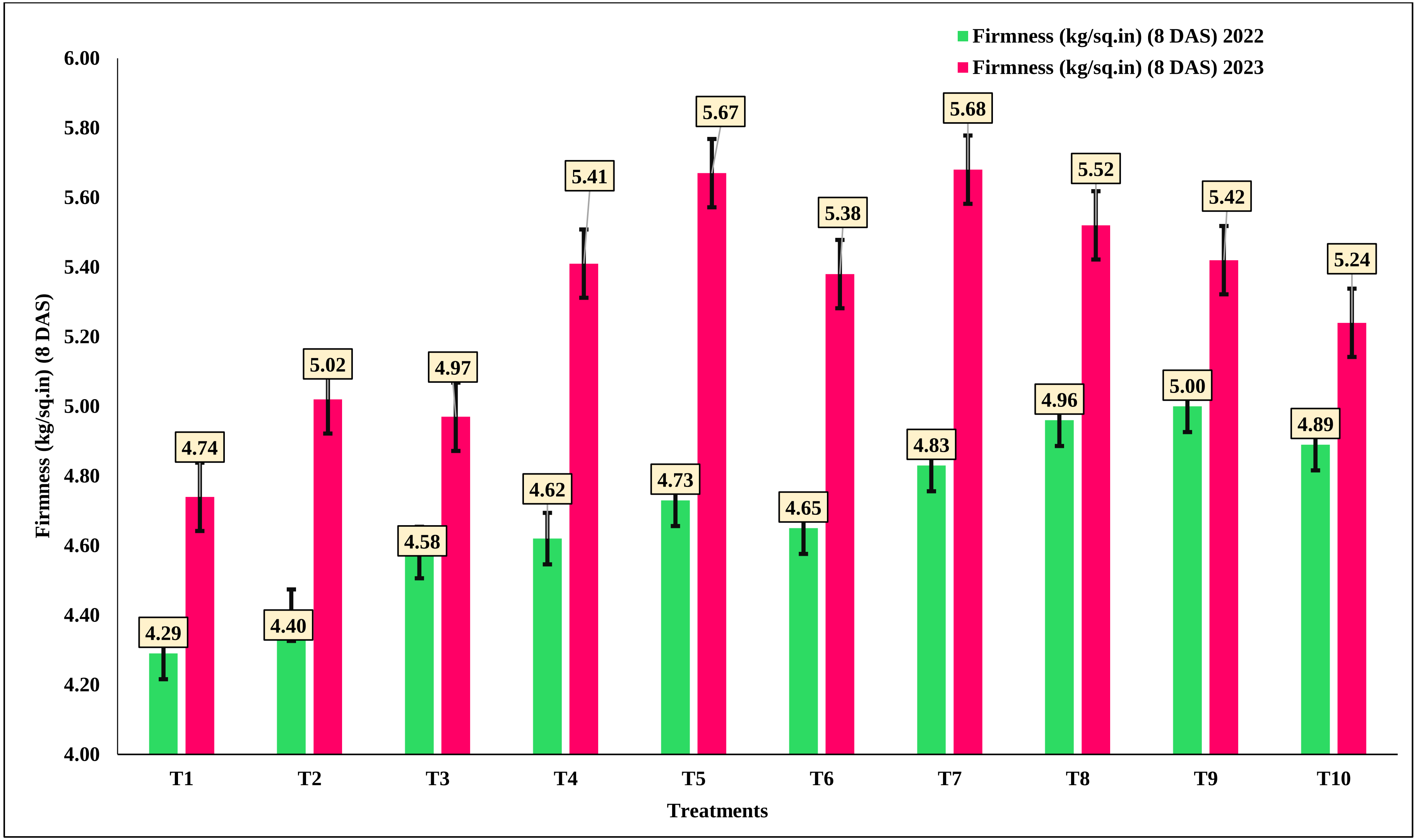

Fig. 4.84: Effect of nano-Zn and nano-Cu on firmness (kg/in^2) (8 DAS) in guava

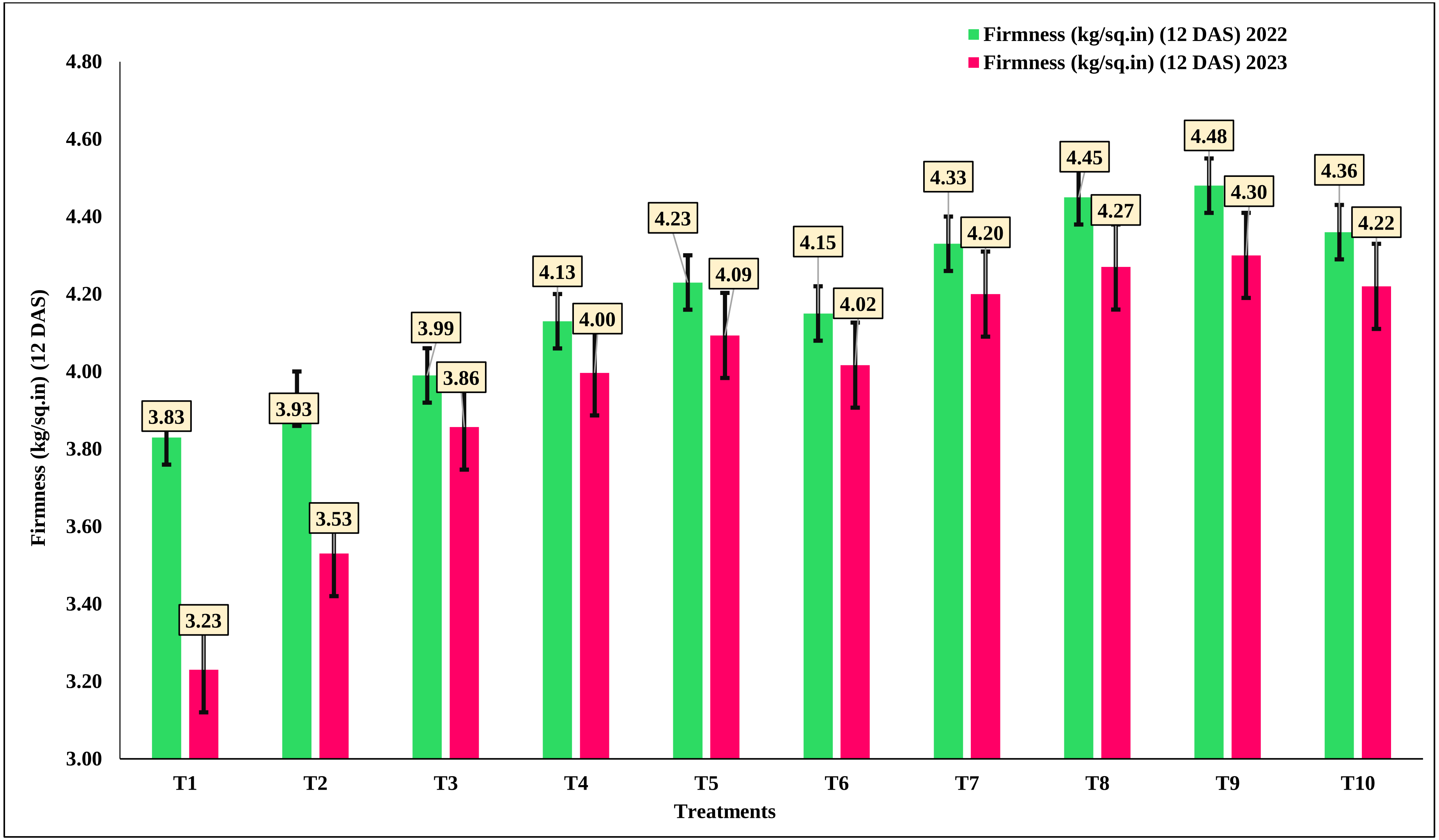

Fig. 4.85: Effect of nano-Zn and nano-Cu on firmness (kg/in^2) (12 DAS) in guava

4.6.37 Pectin content (%) (0 DAS)

Table no. 4.26 presents the data on the variation in pectin content (%) during the two-year experiment (2022 and 2023). Nano-micronutrient treatments impact on the pectin content (%) of the guava during both years of the experiment, graphically presented in figure no.4.86.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was noted with the superior pectin content (%) on the zero day of shelf-life studies was 2.13 % this was superior among the treatments. The lowest pectin content (%) on the zero day of shelf-life studies was 1.47 % noted in treatment T_1 (Control) which was at nominal with the treatment T_2 with a value of 1.57%.

In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the superior pectin content (%) on the zero day of shelf-life studies, which was 2.31 % it is substantially superior from other treatments. Rest of the treatments showed substantial differences in pectin content (%) on the zero day of shelf-life studies. Treatment T_1 (Control) noted the lowest pectin content (%) on the zero day of shelf-life studies was 1.55 %.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] ensued in the superior pectin content (%) on the zero day of shelf-life studies, with a value of 2.22 % it is substantially superior from other treatments. Instead, the treatment T_1 was noted with the lowest pectin content (%) on the zero day of shelf-life studies, a value of 1.51%.

4.6.38 Pectin content (%) (4 DAS)

Table no. 4.26 presents the data on the variation in pectin content (%) on the fourth day of storage during the two-year experiment (2022 and 2023). Nano-micronutrient treatments impact on the pectin content (%) on the fourth day of storage of the guava during both years of the experiment, graphically presented in figure no.4.87.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was recorded with the highest pectin content (%) on the fourth day of storage was 1.94 % the recorded results are highest among the treatments. The lowest pectin content (%) on the fourth day of storage was 1.42 % resulted in treatment T_1 (Control).

In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] ensued in the superior pectin content (%) on the fourth day of shelf-life studies, which was 2.13 % it is substantially superior from other treatments. Rest of the treatments showed substantial differences in pectin content (%) on the fourth day of shelf-life studies. Treatment T_1 (Control) noted the lowest Pectin content (%) on the fourth day of shelf-life studies was 1.50 %.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] ensued in the superior pectin content (%) on the fourth day of shelf-life studies, with a value of 2.04 % it is substantially superior from other treatments. Instead, treatment T_1 was experiential with the lowest pectin content (%) on the fourth day of shelf-life studies, a value of 1.46 %.

4.6.39 Pectin content (%) (8 DAS)

Table no. 4.26 presents the data on the variation in pectin content (%) on the eight day of storage during the two-year experiment (2022 and 2023). Nano-micronutrient treatments impact on the pectin content (%) on the eight day of storage of the guava during both years of the experiment, graphically presented in figure no.4.88.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was noted with the pectin content (%) on the eight day of shelf-life studies was 1.84 % which was at nominal with the treatment T_8 with a value of 1.79 %. The minimum pectin content (%) on the eight day of shelf-life studies was 1.26 % resulted in treatment T_1 (Control).

In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] ensued in the superior pectin content (%) on the eight day of shelf-life studies, which was 2.02 % which was at nominal with the treatment T_8 with a value of 1.96 %. Rest of the treatments showed substantial differences in pectin content (%) on the eight day of shelf-life studies. Treatment T_1 noted the lowest pectin content (%) on the eighth day of shelf-life studies 1.34 %.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] ensued in the superior pectin content (%) on the eight day of shelf-life studies, with a value of 1.93 % which was at nominal with the treatment T_8 with a value of 1.88 %. Instead, treatment T_1 (Control) was observed with the lowest pectin content (%) on the eight day of shelf-life studies, a value of 1.30 %.

4.6.40 Pectin content (%) (12 DAS)

Table no. 4.26 presents the data on the variation in pectin content (%) on the twelfth day of storage during the two-year experiment (2022 and 2023). Nano-micronutrient treatments impact on the pectin content (%) on the twelfth day of storage of the guava during both years of the experiment, graphically presented in figure no.4.89.

During the first year of the experiment (2022), treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] was noted with the superior pectin content (%) on the twelfth day of shelf-life studies was 1.63 % at nominal with T_8 and T_{10} with a value of 1.58 % for each treatment. The minimum pectin content (%) on the twelfth day of shelf-life studies was 1.05 % ensued in treatment T_1 (Control).

In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the superior pectin content (%) on the twelfth day of shelf-life studies, which was 1.81 % it is substantially superior from other treatments. Rest of the other treatments showed substantial differences in pectin content (%) on the twelfth day of shelf-life studies. Treatment T_1 (Control) noted the lowest pectin content (%) on the twelfth day of shelf-life studies was 1.00 %.

Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] resulted in the maximum pectin content (%) on the twelfth day of shelf-life studies, with a value of 1.72 % it is substantially superior from other treatments. Instead, treatment T_1 was observed with the lowest pectin content (%) on the twelfth day of shelf-life studies, a value of 1.03 %.

The pectin content exhibited a continuous decrease throughout the storage period regardless of the treatment. This decline in pectin content can be linked to a reduction in molecular size and esterification of pectin during storage. However, trees treated with nano-Zn and Cu showed a lesser decline compared to untreated ones, as indicated in Table 4.26.

Moreover, treatments in tomato fruit have led to a reduction in the transcripts encoding pectin-degrading enzymes like polygalacturonase and pectin methyl esterase (PME) (Tiwari and Paliyath, 2011). Additionally, the enhanced formation of calcium-pectin ionic bridges due to calcium supplementation (Gupta *et al.,* 1984) may result in higher pectin levels in treated fruits compared to those that are untreated.

Table no. 4.26: Effect of nano-Zn and nano-Cu on pectin content (%) at 0 DAS, 4 DAS, 8 DAS, and 12 DAS of guava.

Treatments	**Pectin content (%)**											
	0 (DAS)			**4 (DAS)**			**8 (DAS)**			**12 (DAS)**		
	2022	**2023**	**Pool**	**2022**	**2023**	**Pool**	**2022**	**2023**	**Pool**	**2022**	**2023**	**Pool**
T_1	1.47±0.012^{a}	1.55±0.014^{a}	1.51±0.01^{a}	1.42±0.008^{a}	1.50±0.006^{a}	1.46±0.008^{a}	1.26±0.005^{a}	1.34±0.01^{a}	1.30±0.006^{a}	1.05±0.06^{a}	1.00±0.00^{a}	1.03±0.020^{a}
T_2	1.57±0.026^{ab}	1.72±0.037^{b}	1.65±0.032^{b}	1.54±0.012^{b}	1.69±0.015^{b}	1.62±0.011^{b}	1.31±0.012^{b}	1.46±0.026^{b}	1.39±0.02^{b}	1.14±0.020^{b}	1.25±0.029^{b}	1.20±0.008^{b}
T_3	1.60±0.058^{b}	1.74±0.075^{b}	1.67±0.06^{b}	1.58±0.02^{bc}	1.72±0.03^{bc}	1.65±0.031^{bc}	1.38±0.014^{c}	1.52±0.026^{b}	1.45±0.018^{c}	1.17±0.025^{b}	1.32±0.014^{c}	1.25±0.010^{c}
T_4	1.65±0.02^{b}	1.79±0.017^{b}	1.72±0.02^{b}	1.63±0.003^{cd}	1.77±0.003^{c}	1.71±0.003^{c}	1.47±0.010^{d}	1.61±0.008^{c}	1.54±0.01^{d}	1.3±0.026^{c}	1.44±0.016^{d}	1.37±0.015d
T_5	1.78±0.05^{cd}	1.91±0.040^{c}	1.85±0.04^{c}	1.73±0.021^{e}	1.86±0.014^{d}	1.80±0.01^{d}	1.55±0.017^{e}	1.68±0.026^{c}	1.62±0.02^{e}	1.41±0.011^{e}	1.54±0.017^{e}	1.48±0.011^{e}
T_6	1.68±0.032^{bc}	1.78±0.023^{b}	1.74±0.027^{b}	1.66±0.02^{d}	1.76±0.025^{bc}	1.71±0.023^{c}	1.53±0.033^{e}	1.63±0.045^{c}	1.58±0.03^{de}	1.35±0.030^{d}	1.45±0.026^{d}	1.40±0.02^{d}
T_7	1.81±0.043^{d}	1.95±0.025^{cd}	1.88±0.033^{c}	1.8±0.032^{f}	1.93±0.024^{e}	1.87±0.025^{e}	1.7±0.010^{f}	1.83±0.026^{d}	1.77±0.017^{f}	1.5±0.036^{f}	1.63±0.017^{f}	1.57±0.015^{f}
T_8	1.96±0.34^{e}	2.13±0.025^{e}	2.05±0.027^{d}	1.85±0.015^{f}	2.02±0.025^{f}	1.94±0.018^{f}	1.79±0.012^{gh}	1.96±0.031^{ef}	1.88±0.023^{gh}	1.58±0.020^{g}	1.76±0.012^{g}	1.67±0.006^{g}
T_9	2.13±0.03^{f}	2.31±0.031^{f}	2.22±0.032^{e}	1.94±0.02^{g}	2.13±0.040^{g}	2.04±0.036^{g}	1.84±0.013^{h}	2.02±0.012^{f}	1.93±0.008^{h}	1.63±0.15^{g}	1.81±0.024^{h}	1.72±0.017^{h}
T_{10}	1.89±0.045^{de}	2.04±0.037^{de}	1.96±0.040^{cd}	1.84±0.02^{f}	1.99±0.012^{ef}	1.91±0.014^{ef}	1.74±0.029^{fg}	1.89±0.030^{de}	1.82±0.028^{fg}	1.58±0.10^{g}	1.730.014^{g}	1.65±0.006^{g}
S. Em (±)	0.036	0.040	0.038	0.02	0.033	0.30	0.036	0.040	0.038	0.19	0.045	0.040

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ Cu_2(30ppm)], T_{10} [$ZnSO_4$]

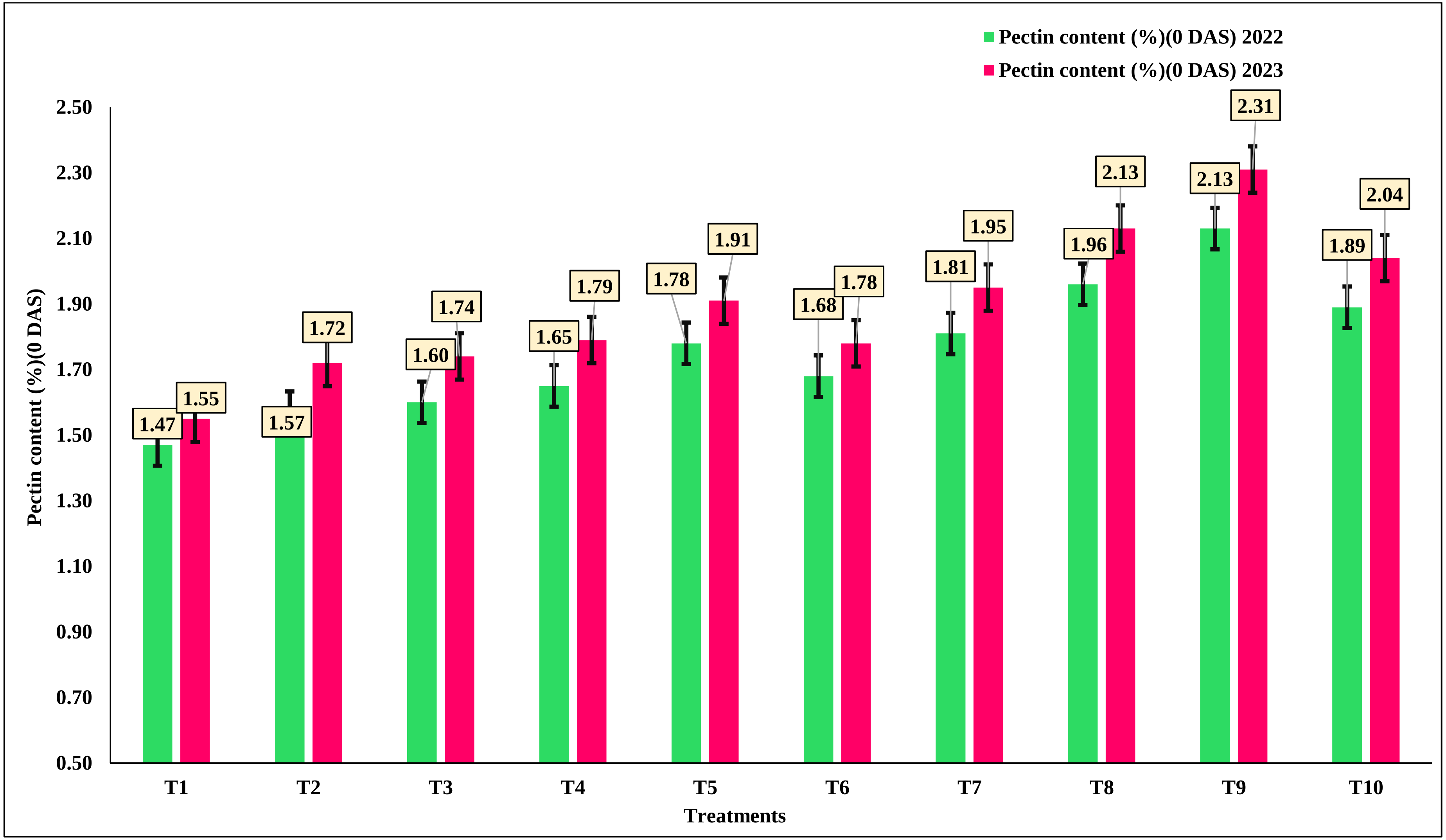

Fig. 4.86: Effect of nano-Zn and nano-Cu on pectin content (%) (0 DAS) in guava

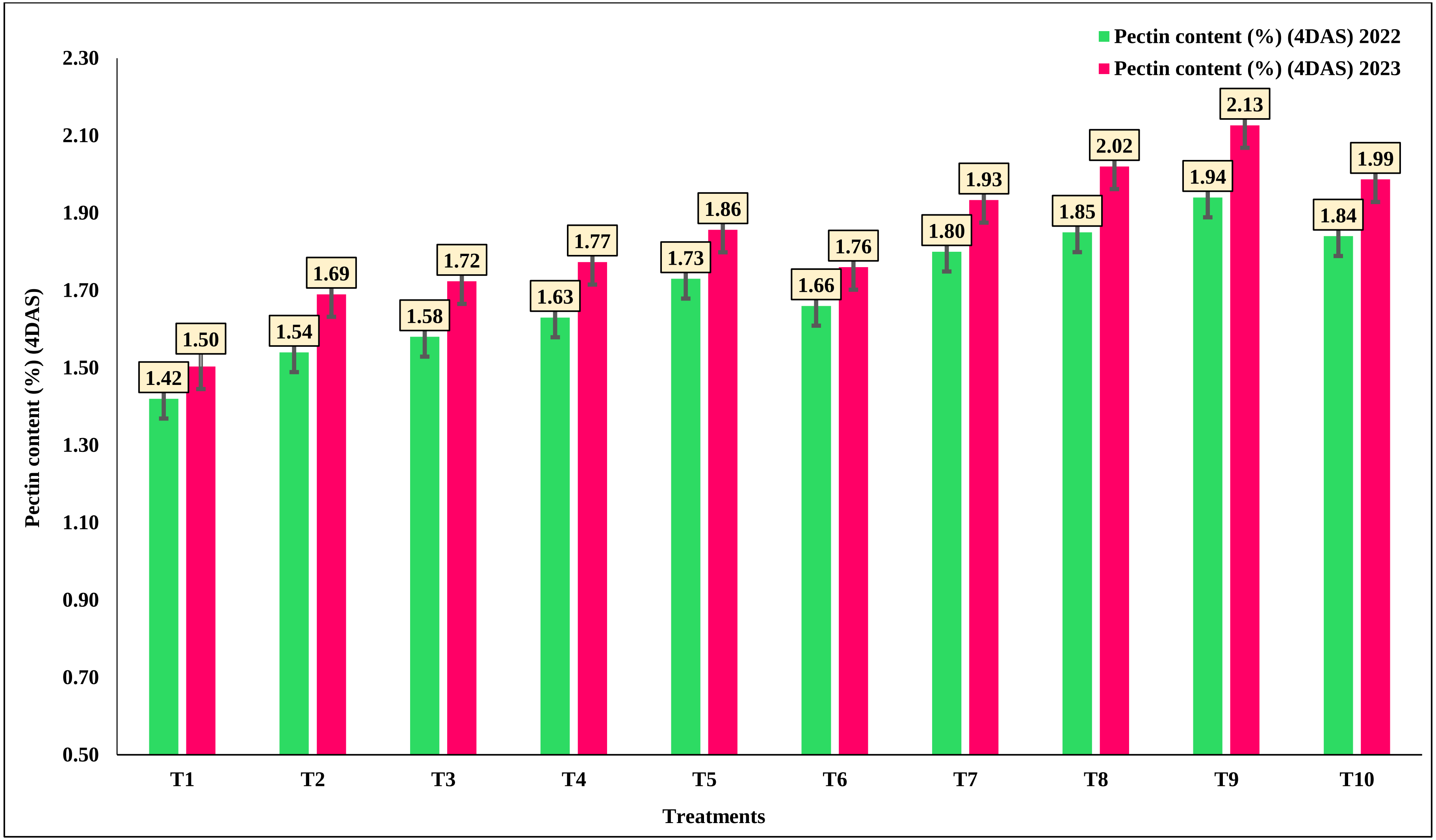

Fig. 4.87: Effect of nano-Zn and nano-Cu on pectin content (%) (4 DAS) in guava

Fig. 4.88: Effect of nano-Zn and nano-Cu on pectin content (%) (8 DAS) in guava

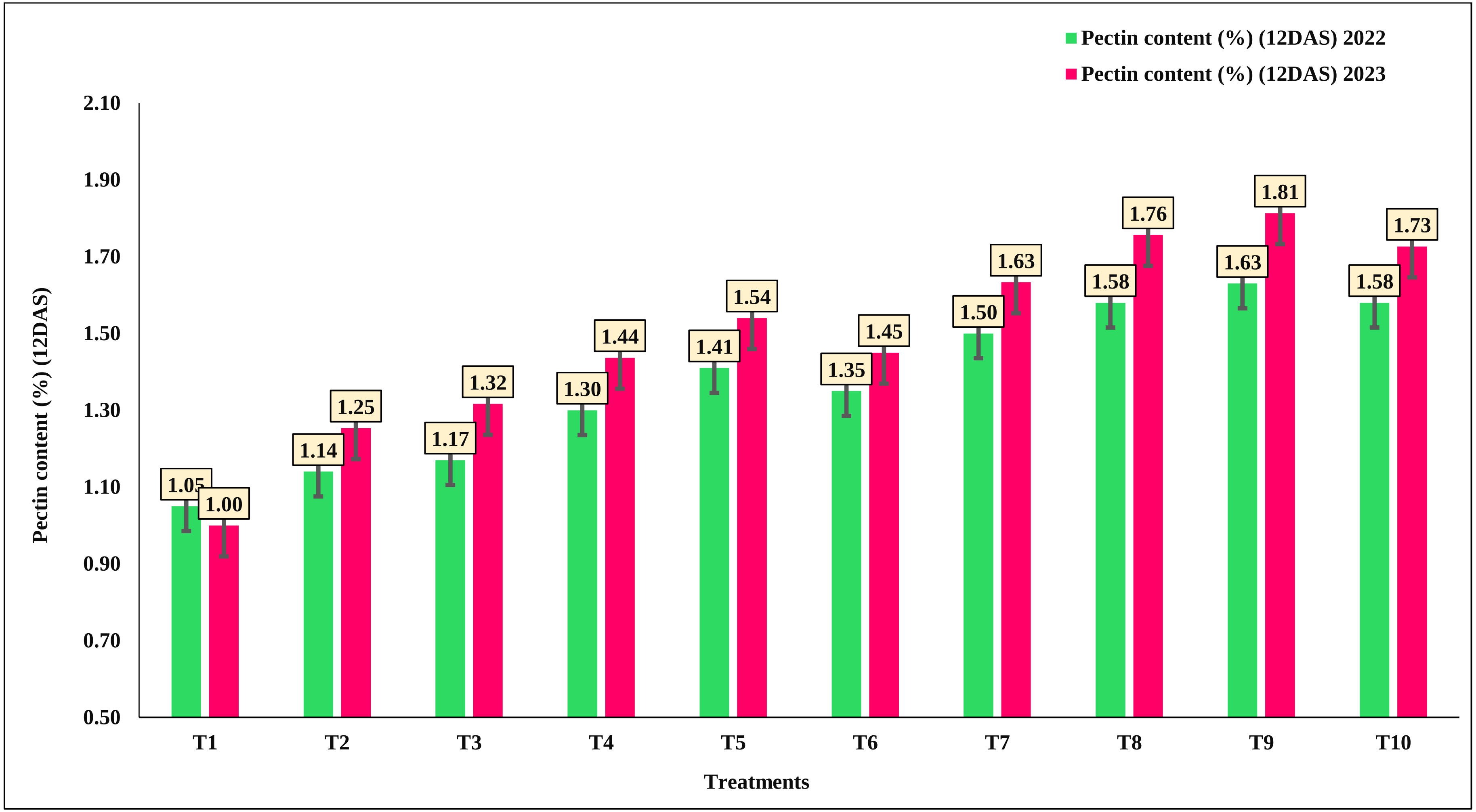

Fig. 4.89: Effect of nano-Zn and nano-Cu on pectin content (%) (12 DAS) in guava

4.6.41 Spoilage (%) (0 DAS)

Table no. 4.27 shows the data of the spoilage (%) on the zero day of storage during the two years of the experiment (2022 and 2023) along with the pooled data that there was no spoilage in any of the guava fruit at storage conditions, graphically presented in figure no.4.90.

4.6.42 Spoilage (%) (4 DAS)

Table no. 4.27 shows the data on the variation in the spoilage (%) on the fourth day of storage during the two years of the experiment (2022 and 2023) along with the pooled data. The findings shows substantial results of micronutrient foliar application on spoilage (%) of fruits at the fourth day in guava during both years of the experiment, graphically presented in figure no.4.91.

During the first year of the experiment (2022), the maximum spoilage (%) on the fourth day of shelf-life studies was under treatment T_1 where 20.83 % were noted it was substantially superior from other treatments. The minimum spoilage (%) on the fourth day of shelf-life studies was 0.00 % was noted in T_2, T_4, T_6, T_7, T_8, T_9, and T_{10}.

In 2023, statistically, treatments made a substantial impact on the spoilage (%) on the fourth day of shelf-life studies of guava fruit. The superior spoilage on the fourth day of shelf-life studies was in treatment T_1 (control) which was 16.67 % it is substantially superior from other treatments. The lowest spoilage % on the fourth day of shelf-life studies 0.00 % was in treatments T_4, T_5, T_6, T_7, T_8, and T_9.

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_1 gave the superior spoilage % on the fourth day of shelf-life studies, with a value of 18.75 % it was substantially maximum from other treatments. In contrast, treatments T_4, T_6, T_7, T_8, and T_9 had the lowest spoilage on the fourth day of shelf-life studies, with a value of 0.00 %.

4.5.43 Spoilage (%) (8 DAS)

Table no. 4.27 shows the data on the variation in the spoilage (%) on the eight days of storage during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments impact on spoilage (%) on the eight days of storage in guava during both years of the experiment, graphically presented in figure no.4.92.

During the first year of the experiment (2022), the superior spoilage (%) on the eight day of shelf-life studies was under T_1 where 70.83 % were noted at nominal with T_2, and T_3 with a value of 62.50 and 66.66 % respectively. The minimum spoilage on the eight day of shelf-life studies was 37.50 % which was noted in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] at nominal with T_7, and T_{10} with a value of 41.66 and 45.83 % respectively.

In the second trial year (2023), statistically, treatments made a substantial impact on the spoilage (%) on the eighth day of shelf-life studies of guava fruit. The superior spoilage on the eight day of shelf-life studies was noted on treatment T_1 which was 66.67 % at nominal with T_2, T_3, T_4, and T_6 ranging from 54.17 to 58.33%. The lowest spoilage on the eighth day of shelf-life studies was 37.50 % in Treatment T_1 and T_5 at nominal with T_7, T_8, and T_{10} ranging from 41.67 to 50.00 %.

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_1 gave the superior spoilage on the eighth day of shelf-life studies, with a value of 68.75 % it is substantially superior from other treatments. In contrast, treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the lowest spoilage percent on the eight days of shelf-life studies, with a value of 37.50 % at nominal with T_5 and T_7 with a value of 43.75 and 41.67 % respectively.

4.5.44 Spoilage (%) (12 DAS)

Table no. 4.27 shows the data on the variation in the spoilage (%) on the twelfth day of shelf-life studies during the two years of the experiment (2022 and 2023) along with the pooled data. Nano-micronutrient treatments impact on spoilage (%) on the twelfth day of shelf-life studies in guava during both years of the experiment, graphically presented in figure no.4.93.

During the first year of the experiment (2022), the superior spoilage (%) on the twelfth day of shelf-life studies was under T_1 (control) where 100 % was noted at nominal with T_2, T_3, and T_4 ranging from 87.50 to 95.83 %. The minimum spoilage (%) on the twelfth day of shelf-life studies was 62.50 % which was noted in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] at nominal with T_5, T_7, and T_{10} ranging from 66.66 to 75.00 %.

In the second trial year (2023), statistically, treatments made a substantial impact on the spoilage (%) on the twelfth day of guava fruit storage. The superior spoilage (%) on the twelfth day of shelf-life studies was recorded on treatment T_1 which was 100.00 % at nominal with the treatment T_2 with a value of 91.67 %. The lowest spoilage (%) on the twelfth day shelf-life studies was 62.50 % in treatment T_5 (Cu_2(30ppm)) at nominal with T_7 and T_9 with values of 66.67 and 70.83% respectively.

Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_1 (control) gave the superior spoilage % on the twelfth day of shelf-life studies, with a value of 100.00 % at nominal withs T_2 and T_3 with a value of 91.67 % for each of the treatments. In contrast, treatments T_9 and T_7 had the lowest spoilage (%) on the twelfth day of shelf-life studies, with a value of 66.67 % at nominal with T_5 with a value of 68.75%.

4.5.45 Spoilage (%) (16 DAS)

Table no. 4.27 shows the data of the spoilage (%) on the sixteenth day of storage during the two years of the experiment (2022 and 2023) along with the pooled data that there was 100.00% spoilage was recorded in all of the guava fruit at storage conditions, graphically presented in figure no.4.94.

In their 2018 study, Munde *et al*. investigated foliar micronutrient treatments' impact on guava fruit quality. They found that a combination of $CuSO_4$, $FeSO_4$, $ZnSO_4$, and borax minimized physiological weight loss during storage, with the lowest values observed on days two, four, six, and eight. This treatment extended fruit preservation to 7-10 days, contrasting with the control group's inferior quality maintenance and greater weight reduction.

The data presented in Table 4.27 illustrated the percentage of spoilage in guava fruits under different treatments and storage durations. Spoilage increased as the storage period progressed. However, the lowest spoilage rate (66.67%) was observed in trees treated with nano-Zn_2 (60ppm) + Cu_2 (30ppm), whereas the highest mean spoilage (100%) was noted in the control group on the twelfth day of storage.

Nano-Zn and Cu have been shown to have beneficial effects on various aspects of post-harvest fruit quality, including disease resistance, decay prevention, mitigation of oxidative stress, regulation of ethylene biosynthesis and action, modulation of fruit ripening, and regulation of respiration. These effects on fruit quality have also been investigated by Asgharia and Aghdam (2010). Similar studies have been conducted by Thirupathaiah *et al*. (2017) on sapota cv. Kalipati for a duration of 12 days.

Table no. 4.27: Effect of nano-Zn and nano-Cu on spoilage (%) at 0 DAS, 4 DAS, 8 DAS, 12 DAS, and 16 DAS of guava.

Treatments	Spoilage %														
	0(DAS)			4 (DAS)			8 (DAS)			12 (DAS)			16 (DAS)		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	0	0	0	20.83±4.16^{c}	16.67±4.16^{b}	18.75±3.60^{c}	70.83±4.16^{g}	66.67±4.16^{d}	68.75±3.60^{g}	100±0.00^{g}	100.00^{g}	100.00±0.00^{e}	100	100	100
T_2	0	0	0	0^{a}	4.17±4.16^{a}	2.08±2.08^{ab}	62.5±0.00^{efg}	54.17±4.16^{bcd}	58.33±2.08^{ef}	91.66±4.16^{efg}	91.67^{fg}	91.67±4.16^{de}	100	100	100
T_3	0	0	0	8.33±4.16^{b}	8.33±4.16^{a}	8.33±4.16^{b}	66.66±4.16^{fg}	58.33±4.16^{cd}	62.50±3.60^{ef}	95.83±4.16^{fg}	87.50^{ef}	91.67±0.00^{de}	100	100	100
T_4	0	0	0	0^{a}	0.00±0.00^{a}	0.00±0.00^{a}	58.33±4.16^{def}	54.17±4.16^{bcd}	56.25±3.60^{def}	87.5d±0.00^{efg}	79.17^{cde}	83.33±4.16^{cd}	100	100	100
T_5	0	0	0	4.16±4.16^{ab}	0.00±0.00^{a}	2.08±2.08^{ab}	50±0.00^{bcd}	37.50±0.00^{a}	43.75±00^{abc}	75±7.21^{abcd}	62.50^{a}	68.75±0.00^{ab}	100	100	100
T_6	0	0	0	0^{a}	0.00±0.00^{a}	0.00±00^{a}	58.33±4.16^{def}	58.33±4.16^{cd}	58.33±4.16^{ef}	83.33±4.16^{cdef}	83.33^{def}	83.33±4.16^{cd}	100	100	100
T_7	0	0	0	0^{a}	0.00±0.00^{a}	0.00±00^{a}	41.66±4.16^{ab}	41.67±4.16^{ab}	41.67±4.16^{ab}	66.66±4.16^{ab}	66.67^{ab}	66.67±4.16^{a}	100	100	100
T_8	0	0	0	0^{a}	0.00±0.00^{a}	0.00±00^{a}	54.16±4.16^{cde}	50.00±0.00^{abc}	52.08±2.08^{cde}	79.16±4.16^{bcde}	75.00^{bcd}	77.08±0.00^{bc}	100	100	100
T_9	0	0	0	0^{a}	0.00±0.00^{a}	0.00^{a}	37.5±0.00^{a}	37.50±0.00^{a}	37.50±00^{a}	62.5±0.00^{a}	70.83^{abc}	66.67±8.33^{a}	100	100	100
T_{10}	0	0	0	0^{a}	4.17±4.16^{a}	2.08^{ab}	45.83±4.16^{abc}	50.00±1.98^{abc}	47.92±4.16^{bcd}	70.83±4.16^{abc}	87.50^{ef}	79.17±0.00^{c}	100	100	100
S. Em (±)	0	0	0	1.33	1.18	1.18	2.11	1.98	1.93	2.45	2.29	2.29	0	0	0

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(Cu_1(20ppm)], T_5 [Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ Cu_2(30ppm)], T_{10} [$ZnSO_4$]

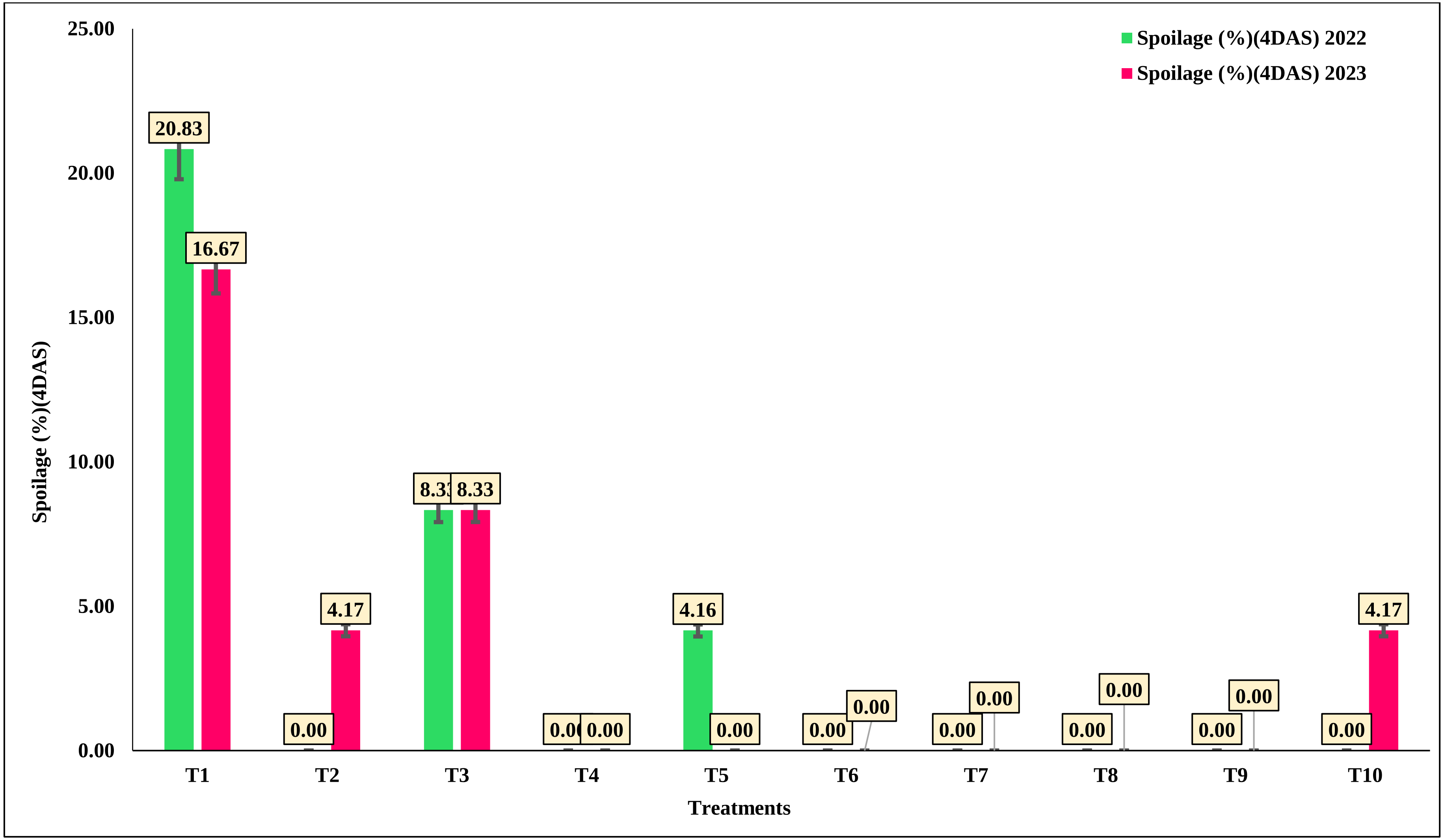

Fig. 4.90: Effect of nano-Zn and nano-Cu on spoilage (%) (4 DAS) in guava

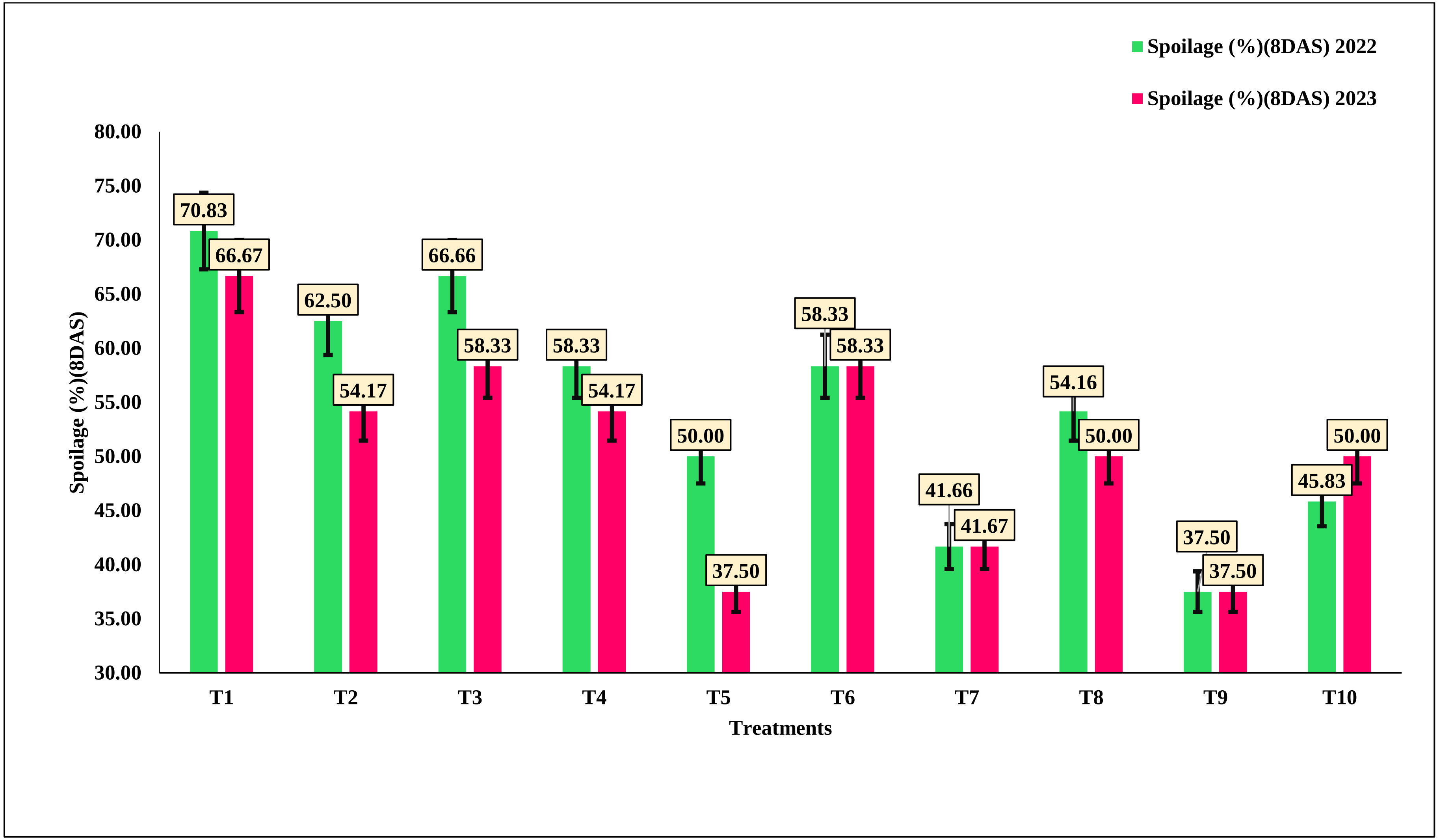

Fig. 4.91: Effect of nano-Zn and nano-Cu on spoilage (%) (8 DAS) in guava

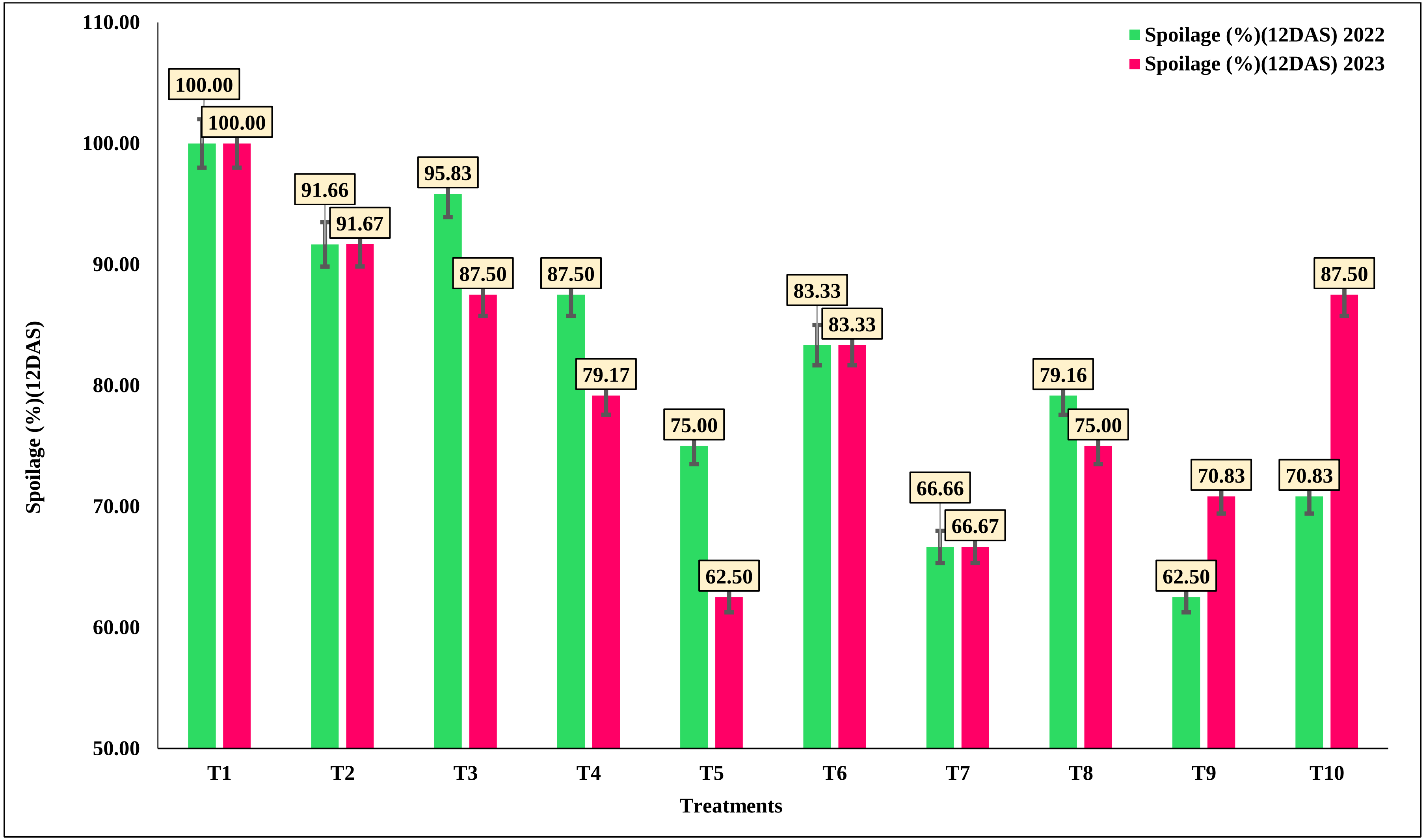

Fig. 4.92: Effect of nano-Zn and nano-Cu on spoilage (%) (12 DAS) in guava

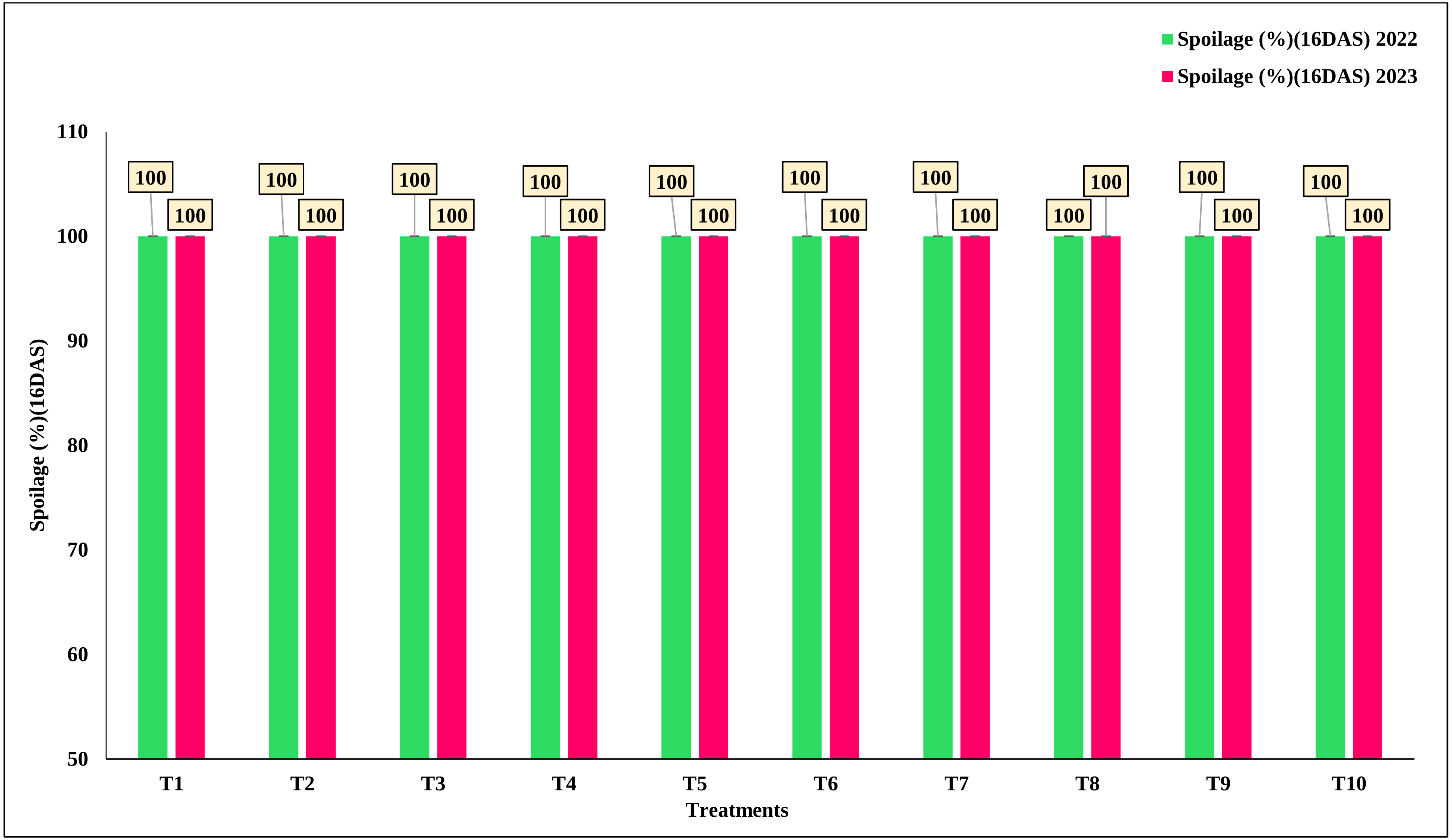

Fig. 4.93: Effect of nano-Zn and nano-Cu on spoilage (%) (16 DAS) in guava

The impact of applying nano-zinc (nano-Zn) and nano-copper (Cu) foliar on guava fruit quality has become an intriguing topic in horticultural research. The findings revealed a marked improvement in the quality of guava fruits when nano-Zn and Cu were applied through foliar application, both separately and in combination. Importantly, plants that were not treated produced smaller and lighter fruits by comparison. This robust improvement in fruit quality was corroborated by various analytical data in Tables no. 4.28.

Specifically, the combination of nano-Zn and Cu at concentrations of 60 ppm and 30 ppm respectively, resulted in a significant improvement in various parameters. Non-reducing sugars, which indicate fruit sweetness, increased to 3.32%, while total sugars, including both reducing and non-reducing sugars, rose to 8.74%. The ascorbic acid content, crucial for fruit nutrition, climbed to 268.90 mg/100 g of fruit, reflecting a marked enhancement in the fruit's health-promoting qualities (Sachin *et al.,* 2019). Additionally, reducing sugars, vital for sweetness and flavor, increased to 5.46%. These findings are consistent with those of Mahaveer and Sangma (2017), who reported similar positive effects in sweet oranges.

Investigations into the underlying mechanisms have shown that nano-Zn is crucial for oxidation-reduction reactions and acts as a catalyst in sugar metabolism. Its involvement in sugar metabolism affects the levels of total sugars, reducing sugars, and non-reducing sugars in treated plants. Zinc also impacts nucleic acid and starch metabolism, influencing various enzymes involved in these biochemical pathways. Similarly, when copper is applied alongside zinc, there is a positive correlation with the soluble solids content and total sugars in guava fruits, consistent with observations in tomato fruits reported by Hipólito *et al.* (2019).

Experimental studies delve into the intriguing realm of nanoparticles (NPs) and their absorption mechanisms in plants. It is suggested that NPs primarily infiltrate plants through stomata on leaf surfaces. Due to their minuscule size, they can interact with membrane transport proteins, enter plant cells, and influence plant physiology even at very low concentrations. Newly formed leaves, with their thinner wax layer and relative biological immaturity, are particularly efficient at nutrient absorption (S. *Singh et al*., 2023).

Furthermore, research indicates that NPs can move through vascular tissues, the epidermis, and the mesophyll in leaves exposed to NPs. These particles are not limited to foliage but can travel to other parts of the plant, including roots and newly formed leaves. Mechanisms for NP entry into plant cells include ion channels, endocytosis, and water molecular pathways, which may initiate redox reactions and other processes affecting NP morphology. Interestingly, some foliar NPs can create new entry points in plant cell walls, facilitating their entry into cells (Rajkumar, 2014).

4.6 Effect of nano-Zn and Cu on economics of cultivation of guava.

All treatments underwent an evaluation of the economic aspects of cultivation, and the data is shown in Table no. 4.28 and 4.29 and the Figure 4.84. Prevailing market prices served as the basis for determining the conclusive benefit-cost ratios. The interpretation of results employed common cost concepts rooted in agricultural economics. The inputs utilized in the cultivation of guava were classified into different components: cost of manure and fertilizers, cost of $ZnSO_4$, cost of nano-Zn and nano-Cu, expenses of Orchard management, Leased land rent and interest on rent. The costs associated with these components were calculated separately for different treatments. Orchard management cost include labour expenses, irrigation, and machinery or diesel consumption. Gross income was calculated by multiplying the total production per hectare per treatment by the prevailing market price.

During the first year of the experiment in 2022, the highest cultivation cost, amounting to Rs. 77,653, was noted in treatment T_9, involving the application of nano-Zn_2 (60 ppm) + nano-Cu_2 (30 ppm). Following closely was treatment T8 (nano-Zn_2 (60 ppm) + nano-Cu_1 (20 ppm)], with a total cultivation cost of Rs. 76,675. Conversely, the lowest cultivation cost, totaling Rs. 69062, was observed in treatment T_1 (Control).

Treatment T_9, consisting of nano-Zn_2 (60 ppm) + nano-Cu_2 (30 ppm), obtained the maximum gross returns of Rs. 3,01,362.01. This was followed by treatment T_8, which generated gross returns of Rs. 2,82,891.40. Instead, the lowest gross returns of Rs. 1,78,470.39 was recorded under treatment T_1, involving Control. The table further revealed that net returns were highest (Rs. 2,23,709.01) under treatment T_9 where plants were applied with nano-Zn_2 (60 ppm) + nano-Cu_2 (30 ppm) followed by net returns of Rs. 2,06,216.40 obtained under treatment T_8 (nano-Zn_2 (60 ppm) + nano-Cu_1 (20 ppm). Lowest net returns (Rs. 1,09,408.39) were obtained under treatment T_1 (Control).

The treatment T_9 (nano-Zn_2 (60 ppm) + nano-Cu_2 (30 ppm) yielded the maximum benefit-cost ratio of 1:2.88, indicating a favourable economic outcome. This was followed by treatment T_8 (nano-Zn_2 (60 ppm) + nano-Cu_1 (20 ppm) with a benefit-cost ratio of 1:2.69 and treatment T_{10} ($ZnSO_4$) with a benefit-cost ratio of 1:2.68. Instead, the lowest B:C ratio of 1:1.58 was observed under treatment T_1 (Control), indicating relatively lower economic returns compared to the investment.

In the experiment conducted in 2023, a similar trend was observed across all treatments regarding the economic aspects of cultivation, as detailed in Table 4.28. The highest cultivation cost, amounting to Rs. 77,653, was observed in treatment T_9, where nano-Zn_2 (60 ppm) + nano-Cu_2 (30 ppm) were applied. Following this was treatment T_8 (nano-Zn_2 (60 ppm) + nano-Cu_1 (20 ppm), with a total cultivation cost of Rs. 76,675. Conversely, the lowest cultivation cost, totaling Rs. 69,062, was observed under treatment T_1 (Control).

Maximum gross returns (Rs. 3,23,529.23) was obtained under treatment T_9 (nano-Zn_2 (60 ppm) + nano-Cu_2 (30 ppm), which was followed by gross returns of Rs. 292766.94 under treatment T_8. Minimum gross returns (Rs. 201467.72) were recorded under treatment T_1 (Control).

The analysis indicated that treatment T_9 (nano-Zn_2 (60 ppm) + nano-Cu_2 (30 ppm) recorded the maximum net returns of Rs. 245876.23, followed by treatment T_8 (nano-Zn_2 (60 ppm) + nano-Cu_1 (20 ppm) with net returns of Rs. 216091.94. The lowest net returns of Rs. 1,32,405.72 were observed under treatment T_1 (Control). Treatment T_9 (nano-Zn_2 (60 ppm) + nano-Cu_2 (30 ppm) displayed the highest B:C ratio of 1:3.17, indicating a favorable economic outcome which was substantially highest than T_1. This was followed by treatment T_{10} ($ZnSO_4$) and T_8 (nano-Zn_2 (60 ppm) + nano-Cu_1 (20 ppm) with benefit cost ratios of 1:3.00 and 1:2.82, respectively. Instead, treatment T_1 (Control) exhibited the lowest B:C ratio of 1:1.92, suggesting a relatively less favourable economic return. Treatment T_9 is suggested best in comparison to Treatment T_8 because only by spending one thousand more from T_8 (nano-Zn_2 (60 ppm) + nano-Cu_1 (20 ppm)) we can get a benefit of seven thousand more in income [treatment T_9 (nano-Zn_2 (60 ppm) + nano-Cu_2 (30 ppm)].

Analysis of the data from both consecutive years (2022-23), as illustrated in tables 4.28 and 4.29, along with figure 4.94, reveals that the highest overall return, net return, and benefit-to-cost (B:C) ratio were consistently achieved through foliar spraying of nano-Zn_2 (60ppm) + nano-Cu_2 (30ppm) (treatment T_9). These findings suggest that the application of nano-Zn + nano-Cu to guava plants via foliar spraying has the potential to improve both quantitative and qualitative aspects of production, resulting in greater financial profitability.

It was also seen by Mekawy (2021) in grape vine, Zagade *et al*. (2020) in guava, Kate *et al*. (2020) in guava, Patil *et al*. (2010) in tomato crop. In their findings they concluded that nano-Zinc and copper foliar application increase the Benefit cost ratio in horticultural crops.

Table no. 4.28: Effect of nano-Zn and nano-Cu on total cost of cultivation, gross income, net income and B:C ratio (in 2022) of guava.

Treatments	Manure and Fertilizer (Rs)	$ZnSO_4$ (Rs)	nano-Zn (Rs)	nano-Cu (Rs)	Orchard management (Rs)	Leased land rent (Rs)	Interest@ 12%	Total cost of cultivation (Rs)	Yield per ha (Kg)	Sale price (Rs)	Gross Income (Rs)	Net Income (Rs)	B:C Ratio
Control (T_1)	16802	0	0	0	9860	40000	2400	69062	5757.11	31	178470.39	109408.39	1.58
Zn_1 (T_2)	16802	0	3691	0	9860	40000	2400	72753	6707.99	34	228071.62	155318.62	2.13
Zn_2 (T_3)	16802	0	5537	0	9860	40000	2400	74599	6954.87	34	236465.51	161866.51	2.17
Cu_1 (T_4)	16802	0	0	2076	9860	40000	2400	71138	6765.04	34	230011.44	158873.44	2.23
Cu_2 (T_5)	16802	0	0	3054	9860	40000	2400	72116	6752.77	34	229594.20	157478.20	2.18
Zn_1+Cu_1 (T_6)	16802	0	3691	2076	9860	40000	2400	74829	7193.27	34	244571.25	169742.25	2.27
Zn_1+Cu_2 (T_7)	16802	0	3691	3054	9860	40000	2400	75807	7036.43	34	239238.75	163431.75	2.16
Zn_2+Cu_1 (T_8)	16802	0	5537	2076	9860	40000	2400	76675	7858.09	36	282891.40	206216.40	2.69
Zn_2+Cu_2 (T_9)	16802	0	5537	3054	9860	40000	2400	77653	8371.17	36	301362.01	223709.01	2.88
$ZnSO_4$ (T_{10})	16802	1045	0	0	9860	40000	2400	70107	7591.09	34	258097.07	187990.07	2.68

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(nano-Cu_1(20ppm)], T_5 [nano-Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+nano-Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ nano-Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ nano-Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ nano-Cu_2(30ppm)], T_{10} [$ZnSO_4$]

Table no. 4.29: Effect of nano-Zn and nano-Cu on total cost of cultivation, gross income, net income and B:C ratio (in 2023) of guava.

Treatments	Manure and Fertilizer (Rs)	$ZnSO_4$ (Rs)	nano-Zn (Rs)	nano-Cu (Rs)	Orchard management (Rs)	Leased land rent (Rs)	Interest @ 12%	Total cost of cultivation (Rs)	Yield per ha (Kg)	Sale price (Rs)	Gross Income (Rs)	Net Income (Rs)	B:C Ratio
Control (T_1)	16802	0	0	0	9860	40000	2400	69062	6498.96	31.00	201467.72	132405.72	1.92
Zn_1 (T_2)	16802	0	3691	0	9860	40000	2400	72753	7518.46	33.00	248109.33	175356.33	2.41
Zn_2 (T_3)	16802	0	5537	0	9860	40000	2400	74599	7613.60	33.00	251248.90	176649.90	2.37
Cu_1 (T_4)	16802	0	0	2076	9860	40000	2400	71138	7613.13	33.00	251233.21	180095.21	2.53
Cu_2 (T_5)	16802	0	0	3054	9860	40000	2400	72116	7424.71	33.00	245015.27	172899.27	2.40
Zn_1+Cu_1 (T_6)	16802	0	3691	2076	9860	40000	2400	74829	8095.74	34.00	275255.17	200426.17	2.68
Zn_1+Cu_2 (T_7)	16802	0	3691	3054	9860	40000	2400	75807	7911.33	34.00	268985.36	193178.36	2.55
Zn_2+Cu_1 (T_8)	16802	0	5537	2076	9860	40000	2400	76675	8610.79	34.00	292766.94	216091.94	2.82
Zn_2+Cu_2 (T_9)	16802	0	5537	3054	9860	40000	2400	77653	9515.57	34.00	323529.23	245876.23	3.17
$ZnSO_4$ (T_{10})	16802	1045	0	0	9860	40000	2400	70107	8242.48	34.00	280244.31	210137.31	3.00

T_1[Control], T_2[nano-Zn_1(40ppm)], T_3[nano-Zn_2(60ppm)), T_4[(nano-Cu_1(20ppm)], T_5 [nano-Cu_2(30ppm)], T_6 [nano-Zn_1(40ppm)+ nano-Cu_1(20ppm)], T_7 [nano-Zn_1(40ppm)+ nano-Cu_2(30ppm)], T_8 [nano-Zn_2(60ppm)+ nano-Cu_1(20ppm)], T_9 [nano-Zn_2(60ppm)+ nano-Cu_2(30ppm)], T_{10} [$ZnSO_4$]

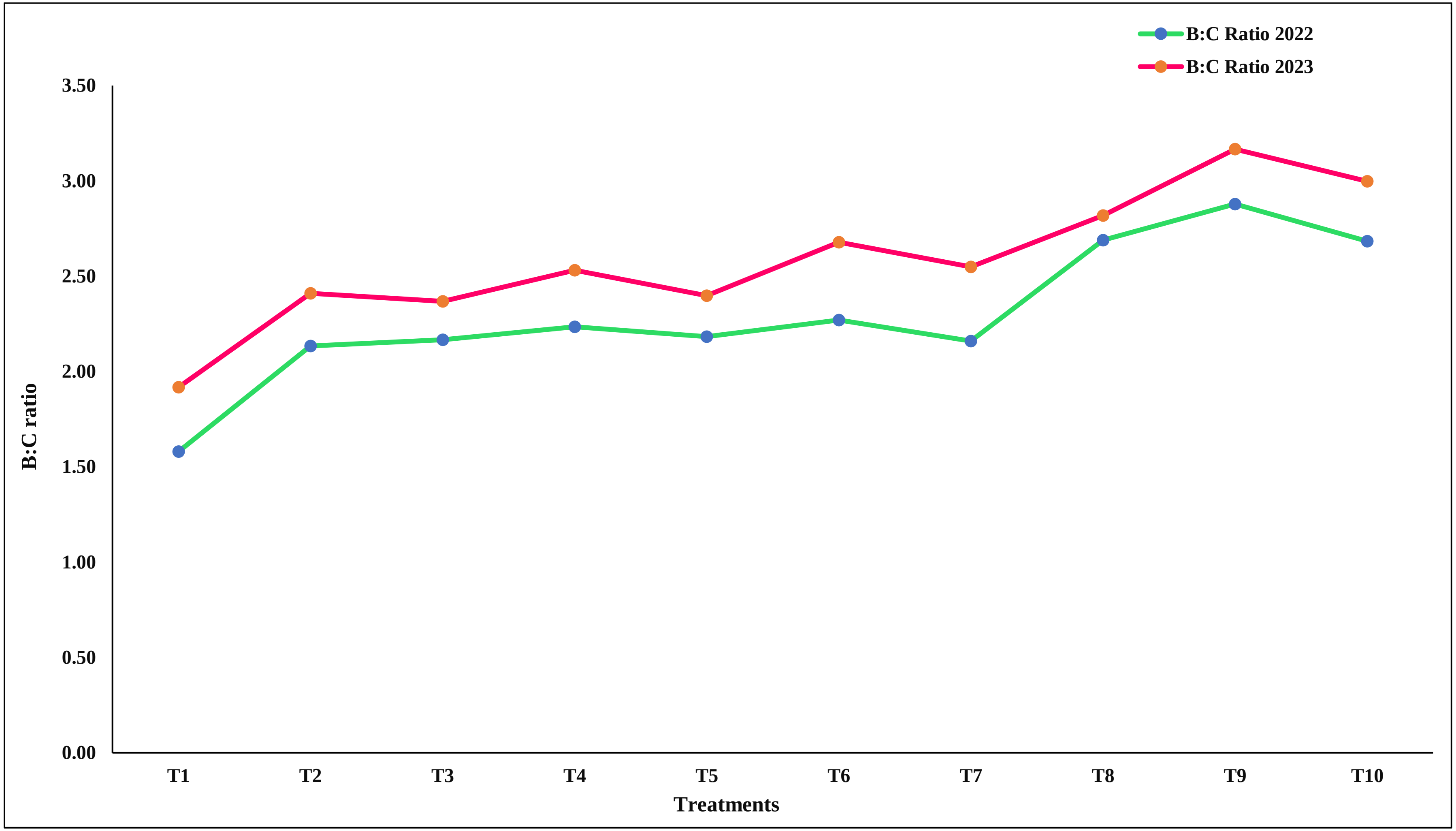

Fig. 4.94 Effect of nano-Zn and nano-Cu on B:C ratio in guava

Chapter-V

SUMMARY AND CONCLUSION

At the horticulture farms of the Department of Horticulture, Lovely Professional University, Punjab, the effects of nano zinc and nano copper on various growth and reproductive parameters of guava plants were assessed in both 2022 and 2023. The results of the study indicate a clear positive influence of nano micronutrients on growth and other relevant parameters. Additionally, treatments involving nano micronutrients resulted in improvements in leaf nutrient levels. This chapter provides a summary of the findings from the two-year (2022 and 2023) experimentation, along with the pooled data analysis.

5.1 Growth parameters

5.1.1 Increase in plant height (m)

- During 2022, max. increase in plant height (0.41m) was in Treatments T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)].
- In 2023, the highest increase in plant height, measuring 0.65 meters, was also observed in treatment T_8 [nano-Zn2(60ppm) + nano-Cu_1(20ppm)].
- Similar trend was observed in pooled estimates with maximum increase in plant height (0.53m) under the treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1 (20ppm)].

5.1.2 Plant spread (E-W) (N-S) (m)

- In the primary year of the experiment (2022), An increase in Plant spread (E-W) was observed during the study. Treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] showed the highest increase of 0.75m.
- In 2023, the study revealed findings about the increase in Plant spread (E-W). Treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] showed a maximum increase of 1.04 meters
- The combined data from the two years (2022 and 2023) of experimentation showed that treatment T_6 [nano-Zn_1(40ppm) + nano-Cu_1(20ppm)] had the maximum percent increase in Plant spread (E-W) (0.88 meters)
- In the experimental year 2022, An increase in plant spread (N-S) was found during the study. Treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] showed the highest plant spread of 0.70 meters.
- In 2023, results showed that the increase in Plant spread (N-S). Treatment T_8 [nano-

Zn_2(60ppm) + nano-Cu_1 (20ppm)] showed a maximum increase of 0.73 meters.

- The combined data from the two years (2022 and 2023) of experimentation showed that treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] had the maximum percent increase in Plant spread (N-S) (0.71 meters)

5.1.3 Increase in no. of leaves per shoot

- In 2022, treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] resulted in the maximum increase, with 18.13 leaves per shoot.
- During the 2023 trial, the treatment T_8, which included the application of nano-Zn_2(60ppm) + nano-Cu_1(20ppm), resulted in the highest increase in no. of leaves/shoot, with an increase of 19.16.
- The pooled data from the two years (2022 and 2023) of the experiment showed that treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] recorded the highest increase in the no. of leaves/shoot, with 18.64 leaves.

5.1.4 Chlorophyll content index

- During 2022, treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] was recorded with the highest Chlorophyll content index of 39.60.
- In the second-year trial (2023), the treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] resulted in the maximum Chlorophyll content index, which was 43.04.
- Aggregate data from both the years (2022 and 2023), shows that the treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] resulted in the maximum Chlorophyll content index, with a value of 41.32

5.1.5 Leaf area (cm^2)

- In an experiment performed in 2022, the treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] exhibited the maximum Leaf area (69.40 cm^2).
- In 2023, the treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] had a maximum Leaf area of 71.46 cm^2.
- Two years of data recorded the maximum Leaf area (70.43 cm^2) under the treatment T_8.

5.2 Flowering parameters

5.2.1 No. of flower/shoot

5.2.2 No. of flower/shoot (0 day)

- In 2022, any of the treatments was not found to be a substantial difference in the no. of

Flowers/shoot at starting of the experiment.

- In the 2023 trial, treatment T_5, involving the application of nano-Cu_2(30ppm) spray, registered the highest No. of flowers per shoot (1.94).
- The pooled data from the two years (2022 and 2023) of the experiment showed that treatment T_5 [nano-Cu_2(30ppm)] recorded the maximum No. of flowers per shoot (1.76).

5.2.3 No. of flowers per shoot (15 Day)

- In 2022, there were no noticeable differences found among any of the treatments regarding the No. of flowers per shoot after fifteen days.
- During the trial of 2023, the treatment T_3, which included the application of nano-Zn_2(60ppm), resulted in the maximum No. of flowers per shoot (3.11).
- The pooled data from both the years (2022 and 2023) of the experiment showed that treatment T_3 [nano-Zn_2(60ppm)] recorded the maximum No. of flowers per shoot (2.91).

5.2.4 No. of flowers per shoot (30 Day)

- In an experiment performed in 2022, the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] exhibited the maximum number of flowers with a substantial difference (5.92).
- In 2023, the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had a maximum number of flowers of 6.15.
- Two years of data recorded the maximum number of flowers (6.03) under the treatment T_9.

5.2.5 No. of flowers per shoot (45 Day)

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was recorded with the highest number of flowers of 13.96.
- In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum number of flowers, which was 14.23.
- Aggregate data from both the years (2022 and 2023), shows that the treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] resulted in the maximum number of flowers, with a value of 14.10

5.2.6 No. of flowers per shoot (60 Day)

- In the primary year of the experiment (2022), The number of flowers (at 60 day) was observed during the study. Treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] showed the highest number of flowers (5.83).
- In 2023, the study revealed findings about the number of flowers. Treatment T_8 [nano-

Zn$_2$(60ppm) + nano-Cu$_1$(20ppm)] showed a maximum number of 6.10.

- The combined data from the two years (2022 and 2023) of experimentation showed that treatment T$_9$ [nano-Zn$_2$(60ppm) + nano-Cu$_2$(30ppm)] had the maximum number of flowers (5.92)

5.2.7 No. of flowers per shoot (75 Day)

- In an experiment performed in 2022, the treatment T$_7$ [nano-Zn$_1$(40ppm) + nano-Cu$_2$(30ppm)] exhibited the maximum number of flowers 2.50.
- In 2023, the treatment T$_6$ [nano-Zn$_1$(40ppm) + nano-Cu$_1$(20ppm)] had a maximum number of flowers of 2.80.
- From the combined data of the two years (2022 and 2023), the experimental data revealed that the treatment T$_6$ exhibited the maximum number of flowers (2.64) each.

5.2.8 No. of flowers per shoot (90 Day)

- During 2022, observations were made regarding the maximum number of flowers. Treatment T$_{10}$ ($ZnSO_4$) exhibited a maximum number of flowers of 1.35.
- During 2023, the maximum number of flowers (1.58) was in T$_{10}$ ($ZnSO_4$).
- The combined data from both years (2022 and 2023) revealed that treatment T$_{10}$ ($ZnSO_4$) exhibited the maximum number of flowers of 1.46.

5.3 No. of fruit/shoot:

5.3.1 No. of fruit/shoot (0 Day)

- In 2022 and 2023, it was observed that no fruit has been settled on zero days of trial.

5.3.2 Number of fruits per shoot (15 Days)

- In both the experimental years (2022 and 2023), it was observed that a few fruits were settled on the fifteenth day of the trial. And found no substantial difference in the number of fruits per shoot in both years.

5.3.3 Number of fruits per shoot (30 Days)

- Throughout 2022, there was a notable absence of a significant number of fruits per shoot, with only a few fruits observed to have settled on the selected shoots.
- During 2023, the highest no. of fruits/shoot (1.79) recorded in T$_4$ [nano-Cu$_1$ (20ppm)].
- From the combined data of the two years (2022 and 2023), the experimental data revealed that treatment T$_4$ exhibited the maximum number of fruits (1.55).

5.3.4 Number of fruits per shoot (45 Days)

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was recorded with the highest number of fruits 3.09.
- In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum number of fruits, which was 3.22.
- Aggregate data from both the years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum number of fruits, with a value of 3.15

5.3.5 No. of fruits/shoot (60 Days)

- In 2022, The number of fruits (at 60 days) was observed during the study. Treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] showed the highest number of fruits (8.17).
- In 2023, the study revealed findings about the number of fruits per shoot. Treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] showed a maximum number of 8.30.
- The combined data from the two years (2022 and 2023) of experimentation showed that treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] had the maximum number of fruits per shoot (8.23)

5.3.6 Number of fruits per shoot (75 Days)

- In an experiment performed in 2022, the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] exhibited the maximum number of fruits (3.38).
- In 2023, the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had a maximum number of fruits of 3.57.
- From the combined data of the two years (2022 and 2023), the experimental data revealed that the treatment T_9 exhibited the maximum no. of fruits (3.48).

5.3.7 Number of fruits per shoot (90 Day)

- In an experiment performed in 2022, the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] exhibited the maximum number of fruits (1.57).
- In 2023, the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had a maximum number of fruits of 1.89.
- From the combined data of the two years (2022 and 2023), the experimental data revealed that treatment T_9 exhibited the maximum no. of fruits (1.73).

5.3.8 Total no. of flowers/shoot

- In the 2022 trial, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had the highest flowers per shoot (33.14).

- During the 2023 trial, flowers per shoot in guava followed a similar pattern. Treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] yielded the maximum flowers per shoot, reaching 34.93.
- The two-year (2022 and 2023) aggregated data also noted a trend similar to that observed in the two-year trial. Maximum flowers per shoot (34.03) were in T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)].

5.3.9 Total number of fruit set per shoot

- During 2022, the maximum total number of fruit set per shoot was under T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)], recording 18.01.
- In the subsequent year of the experiment (2023), observations were made regarding the total number of fruit sets per shoot variations. The treatment T_8, involving the application of nano-Zn_2(60ppm) + nano-Cu_1(20ppm), exhibited the highest total no. of fruit set/shoot (19.19).
- Combined data from both years (2022 and 2023), it was observed that the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] demonstrated highest total no. of fruit set/shoot (18.58)

5.3.10 Number of fruits harvested per shoot

- During 2022, the maximum number of fruits harvested per shoot was under T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] where 10.22 fruits were recorded.
- In 2023, statistically, treatments made a substantial impact on the no. of fruits harvested/shoot of guava fruits. The highest no. of fruits harvested/shoot (10.42)
- Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] gave the maximum number of fruits harvested per shoot, with a value of 10.32

5.3.11 Fruit set (%)

- During 2022, the maximum fruit set percent was in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] where 54.34 percent was recorded.
- In 2023, The maximum fruit set percent (56.55%) was recorded in treatment T_8, using nano-Zn_2(60ppm) + nano-Cu_1(20ppm).
- Data combined for two years (2022 and 2023) showed that treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] had the maximum fruit set percentage (55.29%).

5.3.12 Fruit retention (%)

- During 2022, the maximum fruit retention percent was in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] where 56.74 percent was recorded
- In 2023, The maximum fruit retention percent (54.41%) was recorded in treatment T_9, using nano-Zn_2(60ppm) + nano-Cu_2(30ppm).
- Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] had the maximum fruit retention percentage (55.57%).

5.3.13 Fruit drop percent

- In 2022, the highest percentage of fruit drop, amounting to 54.40%, was observed in treatment T1 (Control).
- In 2023, The maximum fruit drop percent (55.85%) was recorded
- Data combined for two years (2022 and 2023) showed that treatment T_1 (Control) had the maximum fruit drop percentage (55.13%)

5.4 Yield attributes

5.4.1 No. of fruits/plant

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] recorded with highest number of fruits per plant of 173.00
- In the second-year trail (2023), the same trend followed, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the highest number of fruits/plant, which was 176.72
- Aggregate data for the two years (2022 & 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum number of fruits per plant, with a value of 143.75

5.4.2 Fruit weight (g)

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] recorded with highest fruit weight of 174.68 g
- In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum fruit weight, which was 175.15 g
- Aggregate data for the two years (2022 and 2023), shows that the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum fruit weight, with a value of 174.92 g.

5.4.3 Fruit volume (cc)

- In an experiment performed in 2022, the treatment T_9 [nano-Zn_2(60ppm) + nano-

Cu_2(30ppm)] exhibited the maximum fruit volume (169.67 cc)

- In 2023, the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had the maximum fruit volume of 173.07cc
- Two years of data recorded maximum fruit volume (171.37cc) under the treatment T_9.
- From the combined data of the two years (2022 and 2023), the experimental data revealed that the treatments T_9 exhibited the maximum fruit volume, measuring 171.37cc.

5.4.4 Fruit yield per plant (kg/plant)

- During the first year of the experimentation (2022), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] produced the maximum fruit yield, with 30.22 kg per plant.
- In the second-year trial (2023), the fruit yield of guava trees followed a similar pattern. The maximum fruit yield of 34.35 kg per tree.
- The aggregated data from both years of the trial (2022 and 2023) revealed that the maximum yield per plant reached 34.35 kilograms.

5.4.5 Yield per hectare (kg/ha computed)

- In 2022, treatment T9 [nano-Zn2(60ppm) + nano-Cu2(30ppm)] recorded the highest yield per hectare, totaling 8371.17 kilograms.
- In 2023, The highest yield of fruits/hectare (9515.57 kg/ha) was calculated in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)].
- Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had the maximum fruit yield per hectare (8943.37 kg/ha).

5.5 Leaf nutrient status in guava

5.5.1 Boron content in leaves (ppm)

- In the first year (2022) experimentation, treatment T_1 (Control) exhibited the maximum boron content in leaves, measuring 67.85 ppm,
- Similar observations were made during the second year of experimentation (2023), where treatment T_1 (Control) demonstrated the maximum boron content in leaves, measuring 70.50 ppm.
- Pooled data for the two years also registered similar trend for boron content in leaves. Maximum boron in leaves (69.18 ppm) was recorded under the treatment T_1 (Control). Lowest boron content in leaves (37.61 ppm).

5.5.2 Zinc content in leaves (ppm)

- In the initial year (2022) of experimentation, the treatment T_9 [nano-Zn_2(60ppm) + nano-

Cu_2(30ppm)] showed the maximum zinc content in leaves, measuring 90.90 ppm.

- During the subsequent year (2023) of the experiment, similar pattern was observed regarding the zinc content in leaves among the treatments. Treatment T_9, involving the application of nano-Zn_2(60ppm) + nano-Cu_2(30ppm), displayed the maximum zinc content in leaves, measuring 28.50 ppm.
- Two-year pooled data (2022 and 2023) further confirmed a similar trend in the zinc content of leaves across the treatments. Treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] demonstrated the maximum zinc content in leaves, measuring 59.70 ppm.

5.5.3 Copper content in leaves (ppm)

- In the initial year (2022) of experimentation, the treatment T_5 (nano-Cu_2(30ppm)) showed the maximum copper content in leaves, measuring 13.93 ppm.
- During the subsequent year (2023) of the experiment, observation recorded regarding the copper content in leaves among the treatments. Treatment T_9, involving the application of nano-Zn_2(60ppm) + nano-Cu_2(30ppm) displayed the maximum copper content in leaves, measuring 15.53 ppm.
- Two-year pooled data (2022 and 2023) observed in the copper content of leaves across the treatments. Treatment T_5 [nano-Cu_2(30ppm)] demonstrated the maximum copper content in leaves, measuring 13.65 ppm.

5.5.4 Iron content in leaves (ppm)

- In the first year (2022) experimentation, treatment T_1 (Control) exhibited the maximum iron content in leaves, measuring 180.40 ppm.
- Similar observations were made during the second year of experimentation (2023), where treatment T_1 (Control) demonstrated the maximum iron content in leaves, measuring 173.50 ppm.
- pooled data for the two years also registered similar trend for iron content in leaves. Maximum iron in leaves (176.95 ppm).

5.5.5 Calcium content in leaves (ppm)

- In the initial year (2022) of experimentation, the treatment T_2 (nano-Zn_1(40ppm)) showed the maximum calcium content in leaves, measuring 22266.00 ppm.
- During the subsequent year (2023) of the experiment, observation recorded regarding the calcium content in leaves among the treatments. Treatment T_2, involving the application of nano-Zn_1(40ppm) displayed the maximum calcium content in leaves, measuring 21890.00

ppm

- Two-year pooled data (2022 and 2023) observed in the calcium content of leaves across the treatments. Treatment T_2 [nano-Cu_1(40ppm)] demonstrated the maximum calcium content in leaves, measuring 22078.00 ppm.

5.5.6 Nitrogen content in leaves (ppm)

- In the experiment's first year (2022), maximum nitrogen content in leaves was observed in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] with 17000 ppm recorded.
- Experiment conducted in 2023, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] once again displayed the maximum leaf nitrogen content (17450.00 ppm).
- Aggregated data from the two-year experiment (2022 and 2023), showed that the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] observed the maximum nitrogen content in leaves (17225.00 ppm).

5.5.7 Phosphorous content in leaves (ppm)

- In 2022 trial, the treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] resulted in the maximum phosphorous content in leaves, measuring 1557.00 ppm
- In an experiment performed in 2023, treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] exhibited the maximum phosphorous content in leaves, measuring 1553.00 ppm.
- Two-year aggregated data also recorded that the treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] exhibited the maximum phosphorous content in leaves, measuring 1251.00 ppm.

5.5.8 Potassium content in leaves (ppm)

- The experiment conducted in 2022, results were obtained regarding the potassium content in leaves. Treatment T_5 [nano-Cu(30ppm)] showed the maximum potassium content, measuring 6808.00 ppm.
- In the year 2023, treatment T1 (control) displayed the maximum potassium content in leaves, measuring 6592.00 ppm.
- The combined data from the two years (2022 and 2023) resulted that treatment T_5 [nano-Cu_2(30ppm)] observed the maximum potassium content in leaves, measuring 5950.50 ppm.

5.6 Self-life studies

5.6.1Total Sugars (%) (0 DAS)

- During 2022, the maximum total sugars (%) on the zero day was under treatment T_9 [nano-

Zn_2(60ppm) + nano-Cu_2(30ppm)] where 8.74% were recorded

- In 2023, statistically, treatments made a substantial impact on the total sugars (%) at the zero day of guava fruits storage. The Maximum total sugars at zero day 8.93 %.
- Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] gave the maximum total sugars at the zero day, with a value of 8.84%.

5.6.2 Total sugars (%) (4 DAS)

- During 2022, the maximum total sugars (%) on the fourth day of storage was under treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] where 8.90 % were recorded.
- In the second years trial year (2023), statistically, treatments made a substantial impact on the total sugars (%) on the fourth day of guava fruits storage. The maximum total sugars on the fourth day were in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 9.08 %.
- Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] gave the maximum total sugars on the fourth day, with a value of 8.99 %.

5.6.3 Total Sugars (%) (8 DAS)

- During 2022, the maximum total sugars (%) on the eight day of storage was under T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] where 9.29 %
- In 2023, statistically, treatments made a substantial impact on the total sugars (%) on the eighth day of guava fruit storage. The Maximum total sugars on the eight day of storage were recorded on treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 9.48 %
- Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] gave the maximum total sugars on the eight day, with a value of 9.39 %.

5.6.4 Total sugars (%) (12 DAS)

- During 2022, the maximum total sugars (%) on the twelfth day of storage was under T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] where 10.42 % were recorded.
- In 2023, statistically, treatments made a substantial impact on the total sugars (%) on the twelfth day of guava fruit storage. The Maximum total sugars on the twelfth day of storage were recorded on treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 10.61 %
- Aggregate data from both years (2022 and 2023) followed the same trend, it was found that

treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] gave the maximum total sugars on the twelfth day, with a value of 10.52 %.

5.6.5 Reducing sugars (%) (0 DAS)

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was recorded with the highest reducing sugars on the zero day of storage was 5.46 %.
- In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum reducing sugars on the zero nano-day of storage, which was 5.28%.
- When considering the combined data from the two years (2022 and 2023), it is evident that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] exhibited the highest reducing sugar content on the zero day of storage, measuring 5.37%.

5.6.6 Reducing sugars (%) (4 DAS)

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was recorded with the highest reducing sugars on the fourth day of storage was 5.57 %.
- In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum reducing sugars on the fourth day of storage, which was 5.39 %.
- The combined data from both years (2022 and 2023) indicates that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] yielded the highest level of reducing sugars on the fourth day of storage, measuring at 5.48%.

5.6.7 Reducing sugars (%) (8 DAS)

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was recorded with the highest reducing sugars on the eight day of storage was 5.68 %
- In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum reducing sugars on the eight day of storage, which was 5.50 %.
- When considering the combined data from both years (2022 and 2023), it is evident that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] yielded the highest level of reducing sugars on the eight day of storage, measuring at 5.59.

5.6.8 Reducing sugars (%) (12 DAS)

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was recorded with the highest reducing sugars on the twelfth day of storage was 6.16 %.
- In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum reducing sugars on the twelfth day of storage, which was 5.99 %.
- The combined data from both years (2022 and 2023) indicates that treatment T_9 [nano-

Zn_2(60ppm) + nano-Cu_2(30ppm)] yielded the highest level of reducing sugars on the twelfth day of storage, measuring at 6.08%.

5.6.9 Non-reducing sugars (%) (0 DAS)

- During 2022, the maximum non-reducing sugars on the zero day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 3.32 %.
- In 2023, The maximum non-reducing sugars on the zero day of storage were recorded in treatment T_9, using nano-Zn_2(60ppm) + nano-Cu_2(30ppm) that was 3.64 %.
- Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had the maximum non-reducing sugars on zero day of storage 3.48 %.

5.6.10 Non-reducing sugars (%) (4 DAS)

- During 2022, the maximum non-reducing sugars on the fourth day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 3.32 %.
- In 2023, The maximum non-reducing sugars on the fourth day of storage were recorded in treatment T_9, using nano-Zn_2(60ppm) + nano-Cu_2(30ppm) that was 3.69 %.
- Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had the maximum non-reducing sugars on the fourth day of storage at 3.51 %.

5.6.11 Non-reducing sugars (%) (8 DAS)

- During 2022, the maximum non-reducing sugars on the eight day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 3.68 %.
- In 2023, The maximum non-reducing sugars on the eight day of storage were recorded in treatment T_9, using nano-Zn_2(60ppm) + nano-Cu_2(30ppm) that was 3.97 %.
- Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had the maximum non-reducing sugars on the eight day of storage at 3.83 %.

5.6.12 Non-reducing sugars (%) (12 DAS)

- During 2022, the maximum non-reducing sugars on the eight day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 4.58 %.
- In 2023, The maximum non-reducing sugars on the twelfth day of storage were recorded in treatment T_3, using nano-Zn_2(60ppm) that was 4.73 %.

- Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had the maximum non-reducing sugars on the twelfth day of storage at 4.60.

5.6.13 TSS (^{0}B) (0 DAS)

- During 2022, the maximum TSS (^{0}B) on the zero day was under treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] where 9.89°B were recorded.
- In 2023, statistically, treatments made a substantial impact on the TSS (^{0}B) on the zero day of guava fruit storage. The Maximum TSS on the zero day was recorded under T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] 10.10°B recorded.
- The combined data from both years (2022 and 2023) consistently showed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] exhibited the highest total soluble solids (TSS) on the zero day of storage, measuring at 10.00°B.

5.6.14 TSS (^{0}B) (4 DAS)

- During 2022, the maximum TSS (^{0}B) on the fourth day of storage was under treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] where 10.81°B were recorded
- In 2023, statistically, treatments made a substantial impact on the TSS (^{0}B) on the fourth day of guava fruits storage. The Maximum TSS on the fourth day was in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 11.02°B.
- Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] gave the max. TSS (^{0}B) on the fourth day of storage, with a value of 10.92°B.

5.6.15 TSS (^{0}B) (8 DAS)

- During 2022, the maximum TSS (^{0}B) on the eight day of storage was under T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 11.74°B.
- In 2023, statistically, treatments made a substantial impact on the TSS on the eighth day of guava fruit storage. The Maximum TSS on the eight day of storage was recorded on treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 11.95°B.
- Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] gave the maximum TSS on the eight day, with a value of 11.85°B.

5.6.16 TSS (^{0}B) (12 DAS)

- During 2022, the maximum TSS (^{0}B) on the twelfth day of storage was under T_9 [nano-

Zn_2(60ppm) + nano-Cu_2(30ppm)] this was 12.86°B recorded

- In 2023, statistically, treatments made a substantial impact on the TSS (^{0}B) on the twelfth day of guava fruit storage. The Maximum TSS (^{0}B) on the twelfth day of storage was recorded on treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 13.07°B.
- Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] gave the maximum TSS (^{0}B) on the twelfth day, with a value of 12.97°B.

5.6.17 Titratable acidity (%) (0 DAS)

- During 2022, the maximum titratable acidity (%) on the zero day of storage was recorded in treatment T_1 (control) which was 1.23 %. The minimum titratable acidity (%) were observed in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)].
- In 2023, The maximum titratable acidity (%) on the zero day of storage was recorded in treatment T_3 (nano-Zn_2(60ppm)) was 1.40 %. Instead, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] recorded the minimum titratable acidity (%) on zero day of storage 1.05 %.
- Data combined for two years (2022 and 2023) showed that treatment T_2 (nano-Zn_1(40ppm)) had the maximum titratable acidity (%) on the zero day of storage 1.32 %. Instead, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the lowest titratable acidity (%) percentage on the zero day of storage, measuring 1.05 %.

5.6.18 Titratable acidity (%) (4 DAS)

- During 2022, The minimum titratable acidity (%) was observed in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] with a value of 0.74 %.
- In 2023, The treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] recorded the minimum titratable acidity (%) on the fourth day of storage was 0.86 %.
- Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the lowest titratable acidity (%) percentage on the fourth day of storage, measuring 0.80 %.

5.6.19 Titratable acidity (%) (8 DAS)

- During 2022, The minimum titratable acidity (%) was observed in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] with a value of 0.68%.
- In 2023, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] recorded the minimum titratable acidity (%) on the eight day of storage was 0.80 %.

- Data combined for two years (2022 and 2023) showed the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the lowest titratable acidity (%) percentage on the eight day of storage, measuring 0.74 %.

5.6.20 Titratable acidity (%) (12 DAS)

- During 2022, The minimum titratable acidity (%) were observed in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] with a value of 0.52 %.
- In 2023, The treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] recorded the minimum titratable acidity (%) on the twelfth day of storage was 0.65 %.
- Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the lowest titratable acidity (%) percentage on the twelfth day of storage, measuring 0.59 %.

5.6.21 TSS: Acid ratio (0 DAS)

- During 2022, the maximum TSS: Acid ratio on the zero day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 10.06.
- In 2023, The maximum TSS: Acid ratio on the zero day of storage was recorded in treatment T_9, using nano-Zn_2(60ppm) + nano-Cu_2(30ppm) that was 9.13.
- Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had the maximum TSS: Acid ratio on zero day of storage 9.13.

5.6.22 TSS: Acid ratio (4 DAS)

- During 2022, the maximum TSS: Acid ratio on the fourth day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 14.61.
- In 2023, The maximum TSS: Acid ratio on the fourth day of storage was recorded in treatment T_9, using nano-Zn_2(60ppm) + nano-Cu_2(30ppm) that was 12.78.
- Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had the maximum TSS: Acid ratio on the fourth day of storage was 13.70.

5.6.23 TSS: Acid ratio (8 DAS)

- During 2022, the maximum TSS: Acid ratio on the eight day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 17.26.
- In 2023, The maximum TSS: Acid ratio on the eight day of storage was recorded in treatment T_9, using nano-Zn_2(60ppm) + nano-Cu_2(30ppm) that was 14.90.

- Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had the maximum TSS: Acid ratio on the eight day of storage was 16.08

5.6.24 TSS: Acid ratio (12 DAS)

- During 2022, the maximum TSS: Acid ratio on the eight day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 24.41.
- In 2023, The maximum TSS: Acid ratio on the twelfth day of storage was recorded in treatment T_9, using nano-Zn_2(60ppm) + nano-Cu_2(30ppm) that was 20.13.
- Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had the maximum TSS: Acid ratio on the twelfth day of storage was 22.27.

5.6.25 Ascorbic acid (mg/100g) (0 DAS)

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was recorded with the highest ascorbic acid on the zero day of storage was 268.90mg/100g.
- In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum ascorbic acid on the zero day of storage, which was 271.12 mg/100g.
- Data compiled from both years (2022 and 2023) indicate that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] yielded the highest concentration of ascorbic acid (Vitamin C) on the zero day of storage, measuring at 270.01 mg/100g.

5.6.26 Ascorbic acid (mg/100g) (4 DAS)

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was recorded with the highest ascorbic acid on the fourth day of storage was 262.84 mg/100g.
- In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum ascorbic acid (mg/100g) on the fourth day of storage, which was 265.05 mg/100g.
- Combined data from both 2022 and 2023 reveal that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] exhibited the highest concentration of ascorbic acid (Vitamin C) on the fourth day of storage, measuring at 263.95 mg/100g.

5**.6.27 Ascorbic acid (mg/100g) (8 DAS)**

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was recorded with the highest ascorbic acid on the eight day of storage was 255.73 mg/100g.

- In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum ascorbic acid on the eight day of storage, which was 257.95 mg/100g.
- The combined data from both 2022 and 2023 demonstrates that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] yielded the highest concentration of ascorbic acid (Vitamin C) on the eight day of storage, measuring at 256.84 mg/100g.

5.6.28 Ascorbic acid (mg/100g) (12 DAS)

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was recorded with the highest ascorbic acid on the twelfth day of storage was 237.73 mg/100g.
- In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum ascorbic acid (mg/100g) on the twelfth day of storage, which was 237.73 mg/100g.
- The combined data from both 2022 and 2023 indicates that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] yielded the highest concentration of ascorbic acid (Vitamin C) on the twelfth day of storage, measuring at 237.73 mg/100g.

5.6.29 Antioxidants (%) (0 DAS)

- During 2022, the maximum antioxidants (%) on the zero day was under treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] where 48.35% were recorded.
- In 2023, statistically, treatments made a substantial impact on the antioxidants (%) on the zero day of guava fruit storage. The maximum antioxidant (%) on the zero day was 49.31 % was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)].
- Across both years (2022 and 2023), the combined data consistently revealed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] exhibited the highest level of antioxidants (%) on the zero day of storage, reaching a value of 48.84%.

5.6.30 Antioxidants (%) (4 DAS)

- During 2022, the maximum antioxidants (%) on the fourth day of storage was under treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] where 47.28 %.
- In the second year's trial year (2023), statistically, treatments made a substantial impact on the antioxidants (%) on the fourth day of guava fruit storage. The maximum antioxidants on the fourth day were in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 48.24 %.
- Aggregate data from both years (2022 and 2023) followed the same trend, it was found that

treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] gave the maximum antioxidants (%) on the fourth day, with a value of 47.77 %.

5.6.31 Antioxidants (%) (8 DAS)

- During 2022, the maximum antioxidants (%) on the eight day of storage was under T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] where 42.39 % were recorded.
- In 2023, The maximum antioxidants on the eight day of storage were recorded on treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 43.34%.
- Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] gave the maximum antioxidants (%) on the eight day, with a value of 42.87 %.

5.6.32 Antioxidants (%) (12 DAS)

- During 2022, the maximum antioxidants (%) on the twelfth day of storage was under T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] where 37.51% were recorded.
- In 2023, The maximum antioxidants (%) on the twelfth day of storage were recorded on treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 38.47%.
- Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] gave the maximum antioxidants (%) on the twelfth day, with a value of 38.00 %.

5.6.33 Firmness (kg/in^2) (0 DAS)

- During 2022, the maximum firmness (kg/in^2) on the zero day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + Cu_2(30ppm)] and T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] which was 5.71kg/in^2.
- In 2023, The maximum firmness (kg/in^2) on the zero day of storage was recorded in treatments T_5 and T_7, with the same value of 5.95 kg/in^2.
- Data combined for two years (2022 and 2023) showed that treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] had the maximum firmness (kg/in^2) on the zero day of storage was 5.80 kg/in^2.

5.6.34 Firmness (kg/in^2) (4 DAS)

- During 2022, the maximum firmness (kg/in^2) on the fourth day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 5.50 kg/in^2.

- In 2023, The maximum firmness (kg/in^2) on the fourth day of storage was recorded in treatment T_7, using nano-Zn_1(40ppm) + nano-Cu_2(30ppm) was 5.82 kg/in^2.
- Data combined for two years (2022 and 2023) showed that treatment T_8 [nano-Zn_2(60ppm) + nano-Cu_1(20ppm)] had the maximum firmness (kg/in^2) on the fourth day of storage was 5.60 kg/in^2.

5.6.35 Firmness (kg/in^2) (8 DAS)

- During 2022, the maximum firmness (kg/in^2) on the eight day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 5.00 kg/in^2.
- In 2023, The maximum firmness (kg/inc^{2}h) on the eight day of storage were recorded in treatment T_7, using nano-Zn_1(40ppm) + nano-Cu_2(30ppm) was 5.68 kg/in^2.
- Data combined for two years (2022 and 2023) showed that treatment T_7 [nano-Zn_1(40ppm) + nano-Cu_2(30ppm)] had the maximum firmness (kg/in^2) on the eight day of storage was 5.26 kg/in^2.

5.6.36 Firmness (kg/in^2) (12 DAS)

- During 2022, the maximum firmness (kg/in^2) on the eight day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] which was 4.48 kg/in^2.
- In 2023, The maximum firmness (kg/in^2) on the twelfth day of storage was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was 4.30 kg/in^2.
- Data combined for two years (2022 and 2023) showed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had the maximum firmness (kg/in^2) on the twelfth day of storage was 4.39 kg/in^2.

5.6.37 Pectin content (%) (0 DAS)

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was recorded with the highest pectin content (%) on the zero day of storage was 2.13 %.
- In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum pectin (%) on the zero day of storage, which was 2.31 %.
- The combined data from both 2022 and 2023 indicates that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] yielded the highest percentage of pectin on the zero day, with a value of 2.22%.

5.6.38 Pectin content (%) (4 DAS)

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was recorded with the highest pectin content (%) on the fourth day of storage was 1.94 %.

- In the second-year trial (2023), the treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] resulted in the maximum pectin content (%) on the fourth day of storage, which was 2.13 %.
- The combined data from both 2022 and 2023 indicates that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] yielded the highest percentage of pectin on the fourth day, with a value of 2.04%.

5.6.39 Pectin content (%) (8 DAS)

- In 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] exhibited a pectin content (%) of 1.84% on the eight day of storage.
- During the second-year trial (2023), treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] exhibited the highest pectin content (%) on the eighth day of storage, reaching 2.02%.
- The combined data from both years (2022 and 2023) revealed that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] yielded the highest pectin content (%) on the eight day, measuring at 1.93%.

5.6.40 Pectin content (%) (12 DAS)

- During 2022, treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] was recorded with the highest pectin content (%) on the twelfth day of storage was 1.63 %.
- During the trial in the second year (2023), treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] achieved the highest pectin content (%) on the twelfth day of storage, reaching 1.81%.
- Combined data from both 2022 and 2023 indicates that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] yielded the highest pectin content (%) on the twelfth day, measuring at 1.72%.

5.6.41 Spoilage (%) (0 DAS)

5.6.42 Spoilage (%) (4 DAS)

- During 2022, no spoilage was recorded on the fourth day of storage except treatment T_1 (control) where 20.83 % were recorded.
- In the second year's trial year (2023), same trend was followed no spoilage was recorded in the treated plant`s fruits, the spoilage on the fourth day was recorded in treatment T_1 (control) which was 16.67 %
- Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_1 (control) gave the maximum spoilage % on the fourth day, with a value of

18.75 %

5.6.43 Spoilage (%) (8 DAS)

- During 2022, The minimum spoilage on the eight day of storage was 37.50 % which was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)].
- In 2023, treatments made a substantial impact on the spoilage (%) on the eight day of guava fruit storage. The lowest spoilage on the eight day was 37.50 % in T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)].
- Aggregate data from both years (2022 and 2023) followed the same trend, it was found that treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)] had the lowest spoilage percent on the eight day, with a value of 37.50 %

5.6.44 Spoilage (%) (12 DAS)

- During 2022, The minimum spoilage (%) on the twelfth day of storage was 62.50 % which was recorded in treatment T_9 [nano-Zn_2(60ppm) + nano-Cu_2(30ppm)].
- In 2023, The lowest spoilage (%) on the twelfth day was 62.50 % in treatment T_5 (nano-Cu_2(30ppm)).
- Aggregate data from both years (2022 and 2023) treatments T_9 and T_7 had the lowest spoilage (%) on the twelfth day, with a value of 66.67 %.

5.6.45 Spoilage (%) (16 DAS)

- The lowest spoilage rate, recorded at 66.67%, was observed in trees treated with nano-Zn_2(60ppm) + nano-Cu_2(30ppm), while the highest spoilage rate, reaching 100%, was observed in the control group on the twelfth day of storage.

5.7 Effect of nano micro nutrients (nano-Zn and Cu) on economics of Cultivation of Guava.

- During 2022, the maximum Benefit-Cost ratio 1:2.88 was observed in treatment T_9, where the application of nano-Zn_2(60 ppm) + nano-Cu_2 (30 ppm) was done.
- The experiment conducted in 2023, similar pattern was observed among all treatments in terms of the economic aspects of cultivation, benefit cost ratios of 1:3.17 was observed in treatment T_9, where the application of nano-Zn_2(60 ppm) + nano-Cu_2 (30 ppm) was done.
- According to the data of both subsequent years (2022-23) as presented benefit cost ratio were finally obtained by foliar nano-Zn_2(60 ppm) + nano-Cu_2 (30 ppm) spraying (treatment T_9). Based on the results of this investigation, applying nano-Zn+ nano-Cu, foliarly to guava plants may enhance production both numerically and qualitatively, leading to a greater financial gain.

In conclusion, the application of nano zinc (Zn) and nano copper (Cu) micronutrients on guava plants has shown significant improvements in both growth and reproductive parameters over two years (2022 and 2023). Treatments with higher concentrations, particularly T_9 (nano-Zn_2 at 60 ppm and nano-Cu_2 at 30 ppm) and T_8 (nano-Zn_2 at 60 ppm and nano-Cu_1 at 20 ppm), demonstrated notable enhancements across various metrics, including plant height, leaf area, leaf nutrient levels, and the number of fruits per shoot.

The study found that nano-Zn and nano-Cu not only contributed to physical growth parameters, such as increased plant spread and chlorophyll content index, but also supported reproductive outcomes like the number of flowers and fruits per shoot. The results showed that treatment T_9 produced the highest fruit yield per plant and yield per hectare, suggesting that these nano-micronutrient treatments support better crop productivity.

The economic analysis supports these findings, with T_9 treatments yielding the highest benefit-cost ratios (1:2.88 in 2022 and 1:3.17 in 2023). These ratios indicate the potential of nano-Zn and nano-Cu treatments to increase guava yield and quality economically, thus promising financial advantages for guava cultivation when adopting these foliar applications.

In summary, foliar application of nano-Zn and nano-Cu to guava plants appears to be an effective practice to improve both yield and economic returns, offering a promising approach for sustainable and enhanced guava production.

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APPENDICES

Appendix I

Standard Meteorological Data for the year 2022

Date	Max Temp (°C)	Min Temp (°C)	RH% (max.)	RH (min.)	Wind speed (km/hr)	Rain Fall (mm)	Evaporation (mm)
01-06-2022	32	31	40	37	4	0	12.6
02-06-2022	38	30	42	36	0	0	14.5
03-06-2022	40	31	34	38	22	0	16
04-06-2022	41	32	32	42	8	0	12.4
05-06-2022	43	30	32	40	0	0	8.5
06-06-2022	40	32	29	42	4	0	12.5
07-06-2022	40	31	30	43	5	0	13.8
08-06-2022	48	34	27	42	6	0	14.4
09-06-2022	38	32	28	40	12	0	18.5
10-06-2022	39	34	26	38	14	0	20.4
11-06-2022	40	33	62	48	26	0	14.5
12-06-2022	38	28	60	45	17	0	13.2
13-06-2022	39	34	27	36	6	0	32.6
14-06-2022	40	35	28	34	0	0	18.6
15-06-2022	36	30	52	58	21	0	3.5
16-06-2022	40	30	50	55	12	0	10.5
17-06-2022	38	34	40	37	11	0	5.5
18-06-2022	44	35	44	49	9	0	6.3
19-06-2022	40	31	42	36	13	0	2.1
20-06-2022	34	29	44	48	0	65.4	0
21-06-2022	38	29	44	49	24	5.2	4.1
22-06-2022	42	28	42	51	12	0	2.6
23-06-2022	40	27	44	50	26	0	10.8
24-06-2022	40	28	42	52	16	0	18.6
25-06-2022	41	30	44	49	0	0	24.8
26-06-2022	40	32	52	55	5	0	15.5

27-06-2022	38	34	48	49	1	0	38.6
28-06-2022	43	34	50	56	32	0	12.4
29-06-2022	44	32	52	58	12	0	18.2
30-06-2022	40	30	50	56	14	0	6.4
01-07-2022	38	32	58	64	40	0	18.1
02-07-2022	42	30	61	55	14	0	14.6
03-07-2022	44	32	57	58	18	35.2	11.2
04-07-2022	44	29	56	62	4	4.2	13.2
05-07-2022	42	32	60	67	10	0	14.4
06-07-2022	43	31	63	58	8	0	0
07-07-2022	45	32	62	67	0	0	0
08-07-2022	44	32	64	69	4	0	4.8
09-07-2022	40	33	62	64	0	0	4.7
10-07-2022	39	30	60	60	10	0	3.2
11-07-2022	36	33	64	62	18	0	4.7
12-07-2022	37	33	65	60	4	0	2
13-07-2022	37	30	60	60	20	0	0
14-07-2022	38	32	58	61	26	0	4.6
15-07-2022	32	32	54	61	4	6.2	2.4
16-07-2022	37	30	56	58	2	0	4.8
17-07-2022	36	31	54	56	0	4.7	4.6
18-07-2022	35	32	57	62	4	2.6	2.7
19-07-2022	36	32	56	67	10	8.4	2.9
20-07-2022	34	31	80	69	23	47.4	0.9
21-07-2022	29	25	86	70	8	142.6	0.8
22-07-2022	35	26	72	64	18	0	0.8
23-07-2022	36	28	78	68	9	0	1
24-07-2022	37	27	76	65	12	0	1.6
25-07-2022	34	27	64	62	14	0	2.8
26-07-2022	37	28	70	64	9	0	3.2
27-07-2022	37	27	77	69	9	1.4	3
28-07-2022	37	25	73	69	5	1	3.2
29-07-2022	30	26	74	61	13	0.5	2.9

30-07-2022	29	25	72	64	8	0.9	2.6
31-07-2022	34	24	76	65	4	0.7	2.5
01-08-2022	35	24	75	62	11	0	7.4
02-08-2022	36	26	78	68	1	0	7.2
03-08-2022	36	27	79	67	13	0	7.5
04-08-2022	35	26	78	68	11	0	7.6
05-08-2022	34	25	77	65	9	0	7.1
06-08-2022	34	26	78	62	4	0.1	6.6
07-08-2022	35	26	74	67	4	0	0
08-08-2022	36	25	73	62	9	0	0
09-08-2022	39	28	72	62	5	0	7.3
10-08-2022	39	29	78	62	5	0	6.2
11-08-2022	26	24	76	63	16	8.3	7.5
12-08-2022	37	25	70	61	5	0	7
13-08-2022	35	26	72	60	10	0	8.1
14-08-2022	35	27	71	68	9	4.6	0
15-08-2022	29	25	73	64	18	3.2	0
16-08-2022	34	25	72	64	3	0	7.4
17-08-2022	34	26	78	69	15	0	7.5
18-08-2022	33	26	78	68	8	0	7.5
19-08-2022	35	28	75	60	5	1.2	6.3
20-08-2022	34	27	77	61	3	0.5	6.1
21-08-2022	35	25	72	67	5	0.5	0
22-08-2022	33	26	78	64	5	1.4	0
23-08-2022	33	26	78	63	10	3.3	7.1
24-08-2022	35	26	71	60	10	0.8	7.3
25-08-2022	33	25	74	68	6	0.7	7.6
26-08-2022	34	26	77	64	8	0.1	7.4
27-08-2022	34	25	78	68	5	0	7.2
28-08-2022	34	25	78	69	7	0	7.5
29-08-2022	34	27	76	65	6	1.6	0
30-08-2022	35	25	72	61	9	1.7	0
31-08-2022	37	26	77	61	9	0.1	7.1

01-09-2022	36	27	77	62	9	0	4
02-09-2022	36	26	76	64	7	1	6
03-09-2022	36	26	74	62	6	0.1	6
04-09-2022	36	26	71	68	4	0	0
05-09-2022	38	25	70	61	11	0	0
06-09-2022	37	25	68	61	12	0	5.2
07-09-2022	38	25	72	64	10	0	5.5
08-09-2022	38	26	70	61	11	0	6
09-09-2022	39	26	67	60	12	0	4.3
10-09-2022	38	25	73	61	1	0	4.2
11-09-2022	38	26	78	73	10	0	4
12-09-2022	35	25	77	64	9	0.2	0
13-09-2022	36	23	72	64	12	0.5	0
14-09-2022	36	24	69	62	11	0	0
15-09-2022	33	25	70	67	8	0.4	4.5
16-09-2022	32	24	71	68	11	1.4	6
17-09-2022	33	21	68	61	19	2.6	4
18-09-2022	38	24	78	64	13	0	6.3
19-09-2022	38	24	74	61	17	0	0
20-09-2022	37	25	70	63	10	0	0
21-09-2022	39	25	70	62	14	0	4
22-09-2022	35	25	72	64	10	0.5	4
23-09-2022	34	23	71	62	14	0.1	6.2
24-09-2022	30	23	77	64	10	2.1	6.2
25-09-2022	23	21	76	63	9	2.4	4
26-09-2022	35	20	67	60	12	0	4
27-09-2022	35	22	70	61	10	0	2
28-09-2022	35	23	72	67	12	0	4.5
29-09-2022	36	23	74	60	9	0	5.5
30-09-2022	37	23	70	67	12	0	5.5
01-10-2022	37	23	55	46	6	0	5.1
02-10-2022	36	23	59	43	12	0	4.5
03-10-2022	37	23	54	45	12	0	4

04-10-2022	37	22	52	41	10	0	4.8
05-10-2022	37	21	54	42	7	0	4.6
06-10-2022	34	22	50	42	9	0	5
07-10-2022	32	21	55	46	8	0	5.2
08-10-2022	32	21	59	43	9	0	3.5
09-10-2022	32	21	54	44	8	0	3.8
10-10-2022	30	19	67	53	3	0	3.6
11-10-2022	31	20	62	55	2	0	4.1
12-10-2022	36	24	50	42	6	0	4.8
13-10-2022	32	23	59	43	2	0	4
14-10-2022	32	20	54	44	2	0	4.2
15-10-2022	36	24	56	47	4	0	4.8
16-10-2022	34	20	52	41	2	0	5
17-10-2022	32	23	54	46	4	0	4.4
18-10-2022	32	20	54	44	0	0	4.8
19-10-2022	32	21	56	45	2	0	4.4
20-10-2022	31	20	56	46	2	0	4.2
21-10-2022	31	19	54	41	3	0	4.6
22-10-2022	30	19	50	41	2	0	4.4
23-10-2022	30	20	56	44	2	0	4.5
24-10-2022	30	19	57	42	2	0	4.6
25-10-2022	29	18	57	46	3	0	4.7
26-10-2022	30	18	51	43	8	0	5.2
27-10-2022	29	18	53	43	3	0	4.5
28-10-2022	30	19	52	47	3	0	4.4
29-10-2022	29	16	54	41	2	0	4.5
30-10-2022	29	19	51	42	0	0	4
31-10-2022	30	19	51	42	2	0	4.2
01-11-2022	30	19	51	45	4	0	3.5
02-11-2022	28	18	52	47	2	0	3.4
03-11-2022	28	19	58	48	6	0	3.4
04-11-2022	29	17	54	42	2	0	3.3
05-11-2022	27	18	55	44	2	0	3.4

06-11-2022	29	18	56	42	2	0	3.5
07-11-2022	29	16	51	48	2	0	3.4
08-11-2022	28	14	56	46	0	0	3.5
09-11-2022	28	14	53	44	2	0	3.4
10-11-2022	27	14	52	44	3	0	3.4
11-11-2022	27	16	54	41	3	0	3.5
12-11-2022	27	13	52	44	2	0	3.6
13-11-2022	27	13	56	47	2	0	3.2
14-11-2022	27	14	54	46	2	0	3.3
15-11-2022	26	14	58	47	4	0	3.5
16-11-2022	27	13	57	48	2	0	3.4
17-11-2022	26	14	58	48	2	0	3.3
18-11-2022	27	14	57	47	2	0	3.2
19-11-2022	26	14	58	48	3	0	3.1
20-11-2022	25	13	59	49	3	0	3.3
21-11-2022	24	14	58	41	2	0	3.2
22-11-2022	24	12	59	48	4	0	3.2
23-11-2022	23	12	56	44	2	0	3.3
24-11-2022	24	15	54	46	0	0	3.4
25-11-2022	24	14	55	47	2	0	3
26-11-2022	21	12	56	48	0	0	2
27-11-2022	21	10	55	44	0	0	1.7
28-11-2022	22	10	52	41	0	0	1.9
29-11-2022	22	10	56	44	0	0	2
30-11-2022	23	11	54	42	0	0	1.8
01-12-2022	25	11	89	77	0	0	1.5
02-12-2022	24	13	89	79	2	0	2
03-12-2022	26	14	80	68	5	0	1.7
04-12-2022	28	12	79	65	8	0	1.5
05-12-2022	27	13	80	61	2	0	2
06-12-2022	27	8	100	54	0	0	1.3
07-12-2022	27	9	89	60	4	0	1.8
08-12-2022	26	9	89	61	4	0	1.5

09-12-2022	28	11	89	53	0	0	1.5
10-12-2022	28	14	90	63	10	0	1.3
11-12-2022	29	13	89	57	12	0	1.7
12-12-2022	27	11	80	55	4	0	1.5
13-12-2022	27	12	90	77	10	0	1.5
14-12-2022	26	10	89	79	8	0	1.3
15-12-2022	25	10	97	65	10	0	1.5
16-12-2022	25	10	89	75	5	0	1.8
17-12-2022	27	10	90	85	5	0	1.2
18-12-2022	26	10	89	70	2	0	1
19-12-2022	25	11	88	75	4	0	0.5
20-12-2022	23	10	90	80	6	0	0.3
21-12-2022	25	10	89	79	5	0	0
22-12-2022	24	9	90	79	5	0	0.1
23-12-2022	22	9	97	75	5	0	0.1
24-12-2022	23	7	98	70	5	0	0.2
25-12-2022	19	7	98	74	6	0	0.1
26-12-2022	21	9	93	78	5	0	0.2
27-12-2022	22	9	96	78	10	0	0
28-12-2022	23	8	93	86	10	0	0.5
29-12-2022	21	9	98	88	6	2	0
30-12-2022	22	12	89	79	6	0	0
31-12-2022	22	8	89	77	10	0	0

Appendix II

Standard Meteorological Data for the year 2023

Date	Max Temp (°C)	Min Temp (°C)	RH% (max.)	RH (min.)	Wind speed (km/hr)	Rain Fall (mm)	Evaporation (mm)
01-06-2023	32	20	90	49	5	9.8	0
02-06-2023	31	21	87	49	4	1.2	0
03-06-2023	34	20	86	46	4	0	6
04-06-2023	36	23	86	40	5	0	6
05-06-2023	38	22	84	35	7	0	8
06-06-2023	38	20	58	30	8	22.8	8
07-06-2023	32	20	82	41	9	0.4	0
08-06-2023	38	20	90	32	3	0	3.4
09-06-2023	40	24	80	33	2	0	9
10-06-2023	41	26	76	31	3	0.4	6
11-06-2023	34	23	83	47	4	12	3.6
12-06-2023	38	24	87	41	2	0	12
13-06-2023	39	27	83	40	4	0	5
14-06-2023	38	21	78	44	4	23	8
15-06-2023	32	21	84	60	4	6.2	0
16-06-2023	35	25	87	49	3	0	0
17-06-2023	38	25	89	40	4	0	6
18-06-2023	37	27	85	50	2	0	8
19-06-2023	39	26	75	42	6	0	7
20-06-2023	39	26	82	40	2	0	10
21-06-2023	40	29	72	49	2	0	7
22-06-2023	36	27	84	66	2	16.2	6
23-06-2023	37	29	83	56	2	0	0
24-06-2023	37	29	85	58	2	0	5.4
25-06-2023	34	28	81	66	5	0	5.2
26-06-2023	33	27	81	62	3	0.2	5.8
27-06-2023	37	27	85	49	2	0	3.2
28-06-2023	35	27	81	57	3	2.2	5.5

29-06-2023	38	27	87	51	2	0	2.5
30-06-2023	37	27	83	54	2	0	6
01-07-2023	36	26	81	54	1	0	5
02-07-2023	37	27	82	52	1	0	4.2
03-07-2023	38	29	83	54	2	0	5.1
04-07-2023	34	25	84	60	2	5.4	6
05-07-2023	30	24	92	77	2	70	0
06-07-2023	32	23	89	74	2	14	0
07-07-2023	34	25	86	64	2	0	0
08-07-2023	30	24	91	78	10	63.8	
09-07-2023	28	24	91	80	12	8.2	0
10-07-2023	30	24	85	72	9	0.2	2
11-07-2023	36	25	92	60	2	0	3
12-07-2023	36	28	89	63	7	0	3.6
13-07-2023	34	24	88	64	8	3	2.9
14-07-2023	34	28	84	66	5	0	7.4
15-07-2023	37	28	90	58	6	0	8.3
16-07-2023	34	26	86	74	5	14.8	5.2
17-07-2023	37	26	89	60	7	8.6	0
18-07-2023	34	29	87	77	6	0.2	1.6
19-07-2023	32	28	84	73	7	0	4.9
20-07-2023	38	29	76	60	3	0	1.4
21-07-2023	37	29	90	63	6	0.4	5.1
22-07-2023	30	25	93	83	6	26.2	5.3
23-07-2023	35	27	89	63	4	0	0
24-07-2023	34	26	93	74	6	40.8	3.6
25-07-2023	34	28	90	80	3	1.6	0
26-07-2023	32	27	90	76	6	0	2.4
27-07-2023	34	27	90	68	2	0	2.7
28-07-2023	33	27	92	77	5	17.6	2.1
29-07-2023	33	27	92	71	4	0	1.7
30-07-2023	34	28	92	66	6	4.2	0.8
31-07-2023	35	28	92	66	7	0	4

01-08-2023	36	28.1	92	70	4	26.4	1.2
02-08-2023	37	28	92	72	5	0	0.9
03-08-2023	36	26	86	64	5	9.8	6.2
04-08-2023	35	28	90	73	7	6	1.6
05-08-2023	35	27	92	70	5	14.2	0.8
06-08-2023	35	28	89	65	5	0	3.2
07-08-2023	34	26	87	75	5	0	5
08-08-2023	34	27	92	75	4	0	3.2
09-08-2023	33	25	89	77	4	5.8	3.9
10-08-2023	34	27	91	72	3	0	0.5
11-08-2023	35	27	92	77	3	0	2.8
12-08-2023	35	28	92	70	6	0	4
13-08-2023	34	28	89	71	6	0.2	4.1
14-08-2023	32	27	90	80	6		4.8
15-08-2023	35	27	91	74	9	0.2	3.2
16-08-2023	36	26	90	76	5	0.2	5
17-08-2023	35	28	91	68	6	0.4	5
18-08-2023	36	28	93	66	3	0	4
19-08-2023	35	27	90	70	4	1.8	2.3
20-08-2023	38	28	92	58	3	0.2	1.7
21-08-2023	35	28	92	78	3	0	4.5
22-08-2023	36	28	92	70	7	0.8	2
23-08-2023	31	27	92	83	7	0.6	3.1
24-08-2023	35	26	92	71	3	0.2	2.5
25-08-2023	35	27	92	64	3	0.4	2.5
26-08-2023	33	24	92	66	5	0	2.4
27-08-2023	34	25	93	61	6	0	3.4
28-08-2023	29	20	92	70	5	11	2
29-08-2023	33	28	92	64	3	0	0
30-08-2023	35	30	91	62	4	0	3.6
31-08-2023	34	30	90	70	4	0	3.2
01-09-2023	35	26	92	59	6.5	0.2	4.6
02-09-2023	35	26	92	64	7.6	0	5.3

03-09-2023	34	26	92	65	7.6	0	4.6
04-09-2023	34	25	93	61	6.8	0	5
05-09-2023	34	25	90	64	4.7	0	4.5
06-09-2023	35	24	92	55	4.7	0	4.8
07-09-2023	36	24	93	59	3	0	5.1
08-09-2023	36	26	93	58	3.6	0	4
09-09-2023	34	24	91	64	6	0	4.4
10-09-2023	33	25	90	69	4	0	3.7
11-09-2023	33	25	88	67	4	0	3.8
12-09-2023	34	26	92	68	3.6	0	2.5
13-09-2023	35	27	92	68	5.4	0	2.9
14-09-2023	37	28	91	71	3.2	0	3.5
15-09-2023	34	26	92	83	5.76	2.4	2.8
16-09-2023	34	25	92	64	4	1.6	0.5
17-09-2023	29	24	91	83	3.24	3	3.6
18-09-2023	31	24	91	73	5.04	5.7	1
19-09-2023	27	24	90	84	3.24	7.2	0
20-09-2023	35	24	93	54	3.6	0.6	4.1
21-09-2023	35	25	93	65	5.4	0.2	3.6
22-09-2023	34	25	93	68	1.44	0	3.7
23-09-2023	31	22	93	71	5.76	0.4	2.4
24-09-2023	33	22	93	70	4.32	1	3.2
25-09-2023	33	22	94	59	2.16	1	3
26-09-2023	34	22	93	61	3.24	0	3.5
27-09-2023	33	21	93	59	6.12	0	3.4
28-09-2023	34	20	93	66	3.6	0	4.2
29-09-2023	35	20	93	52	3.96	0	3.6
30-09-2023	34	21	92	55	7.2	0	3.2
01-10-2023	33.59	18.10	92.72	42.7	4.32	0.4	1.6
02-10-2023	33.31	17.22	92.39	43.53	5.4	0	1
03-10-2023	33.20	17.43	92.44	49.8	7.92	0	0.2
04-10-2023	34.02	17.61	92.53	48.75	6.12	0.2	0.4
05-10-2023	34.03	17.42	92.38	51.33	5.76	0.2	0.6

06-10-2023	33.58	18.23	92.89	52.6	5.76	0	0.3
07-10-2023	34.82	18.51	92.25	50.64	5.04	0.2	0.3
08-10-2023	34.66	20.49	90.39	54.09	3.96	0	4.3
09-10-2023	34.13	21.68	92.19	58.31	2.52	0	3.7
10-10-2023	30.53	19.58	91.5	56.88	6.48	6.6	0.6
11-10-2023	31.30	16.94	91.07	50	4.68	0.2	3.9
12-10-2023	32.51	16.32	92.81	45.53	4.32	0	3.3
13-10-2023	32.48	16.75	93.25	50.4	2.88	0.2	3.8
14-10-2023	30.67	19.17	92	57.28	6.48	0	2.5
15-10-2023	29.34	17.93	91.52	51.45	3.24	2	2.5
16-10-2023	25.87	18.62	92.1	58.99	7.92	0.4	3.8
17-10-2023	25.22	17.08	90.24	59.57	6.12	0.2	5.4
18-10-2023	28.13	14.74	91.24	50.47	5.76	0.4	1.4
19-10-2023	28.31	13.12	92.79	51.68	5.04	0.8	2.4
20-10-2023	30.32	13.38	93.42	48.6	2.88	0	2.5
21-10-2023	30.15	13.32	92.76	44.61	3.6	0.4	2.3
22-10-2023	29.13	16.11	92.75	55.81	5.4	0.4	2.5
23-10-2023	29.82	14.92	92.25	45.50	6.84	0	2.5
24-10-2023	30.52	13.56	92.70	49.10	4.32	0	4.7
25-10-2023	30.34	13.33	92.37	43.76	6.12	0	2.6
26-10-2023	31.16	12.36	92.95	35.87	6.12	0	2.7
27-10-2023	30.85	11.82	92.23	45.13	4.32	0	2.5
28-10-2023	30.10	13.84	92.86	54.22	4.68	0	2.6
29-10-2023	30.52	15.66	93.55	50.89	2.16	1	2.6
30-10-2023	30.96	14.16	93.61	39.86	3.24	0	2.5
31-10-2023	31.12	13.97	93.17	43.85	2.52	0	2.9
01-11-2023	30.4	14.5	92.7	48.7	2.88	0	1.5
02-11-2023	31.3	13.3	94.0	45.8	3.24	0	1.5
03-11-2023	28.6	14.0	93.7	50.0	5.04	0	1.6
04-11-2023	29.0	13.4	93.3	47.6	4.68	0	1.6
05-11-2023	29.7	11.3	94.0	40.4	6.48	0	2.0
06-11-2023	29.6	11.8	92.7	49.1	3.24	0	2.0
07-11-2023	28.2	12.9	93.3	53.1	5.04	0	1.9

08-11-2023	29.0	13.9	92.2	47.0	4.32	0	2.0
09-11-2023	29.1	13.6	93.2	47.2	4.32	0.6	1.6
10-11-2023	19.0	15.9	86.8	82.0	9	0.4	1.0
11-11-2023	23.8	11.3	92.4	59.0	6.12	0	1.8
12-11-2023	25.7	10.7	94.3	54.0	7.92	0	1.6
13-11-2023	27.6	10.0	94.6	62.2	2.52	0	2.0
14-11-2023	26.6	9.8	93.5	50.3	6.12	0	1.8
15-11-2023	27.2	10.6	93.6	48.3	6.48	0	1.8
16-11-2023	27.1	10.2	93.8	49.3	4.32	0	2.0
17-11-2023	27.9	9.9	93.6	42.3	5.4	0	2.0
18-11-2023	27.7	9.1	93.4	43.0	2.52	0	2.0
19-11-2023	28.1	8.4	93.6	44.7	1.8	0	2.0
20-11-2023	26.8	11.6	92.6	57.0	3.6	0	2.0
21-11-2023	25.77	19.15	93.23	45.07	8.64	0	1.6
22-11-2023	25.46	8.76	92.39	44.05	7.2	0.2	1.1
23-11-2023	26.7	7.38	92.48	40.96	3.24	0.2	2.7
24-11-2023	25.67	6.45	92.7	47.58	6.12	0	2.2
25-11-2023	24.84	7.55	94.78	49.2	2.88	0	1.8
26-11-2023	24.45	10.92	92.05	49.6	2.88	0	0.9
27-11-2023	21	11.65	91.6	69.72	2.52	0	2.3
28-11-2023	25.97	10.71	92.84	51.16	6.12	0	0.7
29-11-2023	26.9	11.39	92.69	50.23	3.6	0	1.5
30-11-2023	19.1	14.59	87.05	82.58	7.2	6.6	0.6
01-12-2023	22.7	10.1	91.2	59.7	6.48	0.2	0.3
02-12-2023	24.5	8.85	93.5	55.08	2.88	0	1.2
03-12-2023	24.28	8.67	93.6	61.8	1.8	0	1.3
04-12-2023	23.5	10.3	94.7	55.3	3.24	0	1.2
05-12-2023	23.04	9.52	95.15	54.7	5.76	0	0.9
06-12-2023	24.18	7.55	95.3	45.9	6.12	0	1.5
07-12-2023	23.8	8.97	94.27	42.8	6.84	0	1.4
08-12-2023	23.48	5.78	94.15	47.58	2.88	0	1.5
09-12-2023	22.57	5	95.17	59.13	5.76	0	1.6
10-12-2023	21.88	5.38	94.08	46.88	7.92	0	1.5

11-12-2023	23.11	5.33	93.58	52.6	2.52	0	1.6
12-12-2023	22.19	5.04	94.16	57.34	1.8	0	1.2
13-12-2023	22.26	3.47	94.15	37.47	3.6	0	0.9
14-12-2023	22.16	4.1	93.48	50.03	6.48	0	1.5
15-12-2023	21.47	5.2	94.3	55.48	1.08	0	1.4
16-12-2023	21.1	2.68	93.88	51.66	2.88	0	0.9
17-12-2023	20.81	5.97	93.87	55.72	5.4	0	1
18-12-2023	20.63	4.03	94.57	55.87	7.2	0	1.5
19-12-2023	20.96	2.73	95.62	50	6.84	0	1.6
20-12-2023	22.81	2.46	94.45	52.83	1.08	0	1.3
21-12-2023	20.71	2.72	93.92	52.85	3.6	0	0.9
22-12-2023	19.45	3.54	95.03	68.31	2.52	0	1
23-12-2023	23.23	8.89	92.34	54.06	2.88	0	0.9
24-12-2023	22.9	5.66	93.66	67.12	3.6	0	0.5
25-12-2023	19.75	5.96	95.21	65.54	5.4	0	1.2
26-12-2023	18.71	6.31	96.01	79.36	1.44	0.4	0.7
27-12-2023	20.2	6.56	95.87	72.15	1.56	0	0.5
28-12-2023	21	7.6	94.3	68.9	2.5	0	0.8
29-12-2023	17.4	9.8	95	66	2.3	0	0.6
30-12-2023	12.6	8.5	90	70	2.1	0	0.5
31-12-2023	11.4	9.2	94	76	2.5	0	0.8

List of Publications

S. No.	Journal indexing (Scopus/UGC/Web of Science)	Status of Paper (Submitted/ Accepted/ published)	Type of paper (Research/ Review)	Journal Name	Title of the Paper	Volume, Issue Number & page number	ISSN Number, Impact Factor/SJR	Weather this is thesis work (Yes/No)	Log Request ID on UMS
1	Scopus	Published	Research	Journal of Applied and Natural Science	Impact of foliar spray of nano-Zn and nano-Cu on biochemical characteristics of guava cv. Allahabad Safeda	16(1), 239-244	0974-9411 (Print), 2231-5209 (Online)	Yes	65875

List of Conferences

S. No.	Oral/ Poster Presentation	Conference Name	Topic	National/ International	Organizing Committee
1	Oral	“Sustainable Development through Agriculture Production, Protection and Policy Landscape for Crop Care	Role of nano-fertilizers in fruit crops	National	AEEFWS Society MNV University, Palwal and Just Agriculture Education Group, at MNV University, Palwal (Haryana)
2.	Oral and Poster	Global Indian Young Scientist Research and Innovation Conference 2023	Effect of foliar-applied nano-fertilizer and its impact on guava plant: Absorption and translocation	International	GIST, NASC, New Delhi