EFFECT OF NANO-ZnO AND FeO ON GROWTH, YIELD, QUALITY AND SHELF LIFE OF STRAWBERRY (*Fragaria × ananassa* Duch.) Cv. WINTER DAWN UNDER OPEN AND PROTECTED CONDITIONS

Thesis Submitted for the Award of the Degree of

DOCTOR OF PHILOSOPHY

in

Fruit Science

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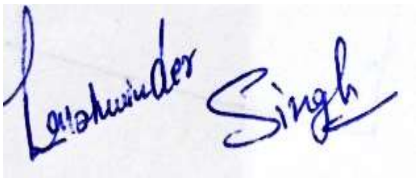
2024

DECLARATION

I, hereby declared that the presented work in the thesis entitled **"Effect of Nano- ZnO and FeO on growth, yield, quality and shelf life of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open and protected conditions"** in fulfilment of degree of **Doctor of Philosophy (Ph.D.)** is outcome of research work carried out by me under the supervision of Dr. Ramesh Kumar Sadawarti, working as Dean (School of Agriculture), 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-I

This is to certify that the work reported in the Ph. D. thesis entitled **"Effect of Nano-ZnO and FeO on growth, yield, quality and shelf life of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open and protected conditions"** submitted in fulfilment of the requirement for the award of degree of **Doctor of Philosophy (Ph.D.)** in the Department of Horticulture, School of Agriculture, is a research work carried out by Mr. Lakhwinder Singh, 12109678, is Bonafede 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.

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CERTIFICATE-II

This is to certify that the thesis entitled **"Effect of Nano- ZnO and FeO on growth, yield, quality and shelf life of Strawberry (*Fragaria × ananassa* Duch.) cv. Winter Dawn under open and protected conditions"** submitted by Lakhwinder Singh (Registration No. 12109678) to the Lovely Professional University, Phagwara in partial fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY (Ph.D.) in the discipline of Horticulture (Fruit Science) has been approved by the Advisory Committee after an oral examination of the student in collaboration with an external examiner.

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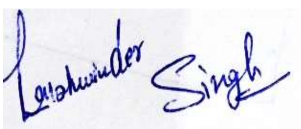

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LIST OF ABBREVIATIONS

Abbreviations	Description
% :	Percentage
@ :	at the rate
°C:	Degree celcius
C.D.:	Critical difference
CV:	Co-efficient of Variation
Cm :	Centimeter
cm^2 :	centimeter square
DPPH :	2,2-diphenylpicrylhydrazyl
et al. :	et alii (Co-workers)
RBD :	Randomized Block Design
Fig . :	Figure
g or gm :	Gram
ha :	Hectare
i.e; :	That is
kg :	Kilogram
L. :	Linneous
m :	Meter
mg :	Milligram
mg/g :	milligram per gram
No. :	Number
NS :	Non-significant

ppm :	Parts per million
SE(d) :	Standard error deviation
SE(m) :	Standard error mean
TSS :	Total soluble solids
ZnO :	Zinc oxide
FeO:	Iron oxide
B :	Boron
nano-Zn :	Nano Zinc
nano-Cu :	Nano Copper
N :	Nitrogen
P :	Phosphorous
K :	Potassium
Cu :	Copper
RH :	Relative Humidity

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Abstract

Title: Effect of Nano- ZnO and FeO on growth, yield, quality and shelf life of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open and protected conditions.

Abstract:

The studies entitled, "Effect of Nano- ZnO and FeO on growth, yield, quality and shelf life of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open and protected conditions" were carried out at the teaching and research farm, School of Agriculture lovely Professional University during the year 2021-22 and 2022-23. The experiments comprises of 16 treatments of ZnO and FeO and their various combination, such as T_0 (Control 100% RDF), T_1 Z_1(50ppm ZnO NPs), T_2 Z_2(100 ppm ZnO NPs), T_3 Z_3(150 ppm ZnO NPs),T_4 F_1(50 ppm FeO NPs), T5F2(100 ppm FeO NPs), T_6 F_3(150 ppm FeO NPs), T_7 Z_1 F_1(50ppm ZnO NPs + 50ppm FeO NPs), T_8 Z_1 F_2(50pm ZnO NPs + 100ppm FeO NPs), T_9 Z_1 F_3(50ppm ZnO NPs+ 150ppm FeO NPs), T_{10} Z_2F_1(100ppm ZnO NPs + 50ppm FeO NPs), T_{11} Z_2 F_2(100ppm ZnO NPs+ 100ppm FeO NPs), T_{12} Z_2 F_3(100ppm ZnO NPs + 150ppm FeO NPs), T_{13} Z_3F_1(150ppm ZnO NPs + 50ppm FeO NPs), T_{14} Z_3F_2(150ppm ZnO NPs + 100ppm FeO NPs), T_{15} Z_3F_3 (150ppm ZnO NPs + 150ppm FeO NPs) replicated 3 times in randomised block design. Among the various treatments evaluated, T_{15} (150 ppm ZnO + 150 ppm FeO) significantly improved the plant height (12.1 cm protected, 11.4 cm open), leaf area index (72.36 cm^2 in both conditions), chlorophyll content (54.86 mg/µmol protected, 53.10 mg/µmol open) at 110 DAT, highest number of flowers (8.50 protected, 7.67 open) at 100 DAT with superior yield (197.63 g protected, 201.30 g open) and quality attributes, such as total soluble solids (6.30 °Brix protected, 6.33 °Brix open) and ascorbic acid (51.70 mg/100g protected, 51.08 mg/100g open), further validated T_{15}'s effectiveness. T_{10} (100 ppm ZnO + 100 ppm FeO) performed well, ranking second in effectiveness for

growth and yield attributes. For shelf life, treatments T_{13} (150 ppm ZnO + 50 ppm FeO) and T_7 (50 ppm ZnO + 50 ppm FeO) demonstrated commendable results, with T_{13} offering the longest shelf life across multiple day intervals (0, 3, 6, 9 days). Overall, this study confirms that integrated applications of Nano-ZnO and FeO, particularly treatments T_{15} and T_{13}, provide an environmentally sustainable strategy to enhance strawberry cultivation in Punjab. These findings highlight optimized nano-fertilization as a promising approach for productive and quality-driven strawberry farming.
Keywords: *ZnO, FeO, Winter Dawn, Growth, Yield, Quality, Shelf life, protected field, Open Field.*

Chapter I

INTRODUCTION

The cultivated strawberry (*Fragaria × ananassa* Duch.) belongs to the Rosaceae family and originates from a natural hybridization between two wild species, *Fragaria chiloensis* and *Fragaria virginiana*, which are native to North America, respectively. Most cultivated strawberry varieties are octaploid, possessing 56 chromosomes (2n=8x=56) (Kazemi et al., 2014). The strawberry species predominantly cultivated in India is *Fragaria × ananassa*, commonly known as the garden strawberry. Other species, such as *F. vesca Duch.* (2n=14) and *F. moschata Duch.* (2n=42), are also grown, but to a lesser extent (Nasrin et al., 2017). In India, Strawberry was first introduced by the ICAR, NBPGR, Regional Research Station, Shimla (H.P.) in the early sixties. Global production of strawberries is about 14.5 million tonnes (FAOSTAT, 2021-22). China leads with the production of strawberries of about 3.3 million tonnes after the USA with the production of 1.3 million tonnes of strawberries. In India, Strawberry covers about 13.52 thousand tonnes of production (NHB Database 2021-22, 1st Advance Estimate). In which Punjab and Haryana covers 4.26 thousand tonnes production. However, an early effort was made to famous its cultivation inside of Himachal Pradesh as well as in the state of Uttar Pradesh. Cultivars like sweet Charlie, Chandler, Belrubi, Pusa Early Dwarf, Fern, Selva, Pajaro, Winter Dawn, Camarosa, Red Coat, Addie, Swiss, Gorella, Jucunda, Sweet Heart, Mecharenj, Red Gro Florida-90, Elsanta, Brighton, Dilpans, Florida Go are the common cultivars being grown in tropical and sub-tropical northern India. However, some cultivars like Sweet Charlie, Chandler, and Selva have also shown promising results under Lucknow conditions (Bialy *et al.,* 2023).

One such innovative variety is the "Winter Dawn" strawberry (*Fragaria x ananassa*). This variety has gained substantial attention in the agricultural community for its ability to thrive in colder climates and produce high-quality fruit during the winter season. In India, it is generally cultivated on the hills (mainly in the Nainital as well as the Dehradun districts of state Uttarakhand, Kashmir valley of Jammu and Kashmir, Himachal Pradesh (HP), also the Nilgiri hills), a plateau-like West Bengal (Kalimpong), and to some extent in the plains areas like Uttar Pradesh, Maharashtra

(Mahabaleshwar), Karnataka (Bangalore), Delhi, Haryana, and Punjab. It is cultivated in Gurdaspur, Ludhiana, Amritsar, Jalandhar, Bathinda, and many other places in Punjab at small scales (Anonymous et al., 2021).

Strawberries contain minerals, vitamins, and an anti-cancer component called ellagic acid. Strawberries are a rich source of vitamin C, providing 40-120 mg per 100 g of fruit, along with essential nutrients such as protein and minerals like potassium, phosphorus, calcium, and iron. The iron content in strawberries can be particularly beneficial for individuals with anemia. Additionally, strawberries offer a modest amount of vitamin A, with about 60 IU per 100 g of the edible portion. The fruit is also notable for its high-quality pectin content (0.55%), primarily in the form of calcium pectate, which makes it ideal for jelly production. Beyond fresh consumption, strawberries are in demand for use in processed products like jams, ice creams, syrups, quick-frozen foods, and canned items. Due to their high nutrient content and appealing flavor, strawberries have gained popularity as a table fruit enjoyed by millions worldwide. They are regarded as one of the most flavorful, appealing, and nutritious soft fruits globally (Kher et al., 2010). Strawberry fruits have a fair amount of natural antioxidants, which are found to help relieve oxiDAPive stresses (Sharma and Thakur., 2008). They are using strawberries to prevent several kinds of cancer and heart diseases. This fruit is also reported to be beneficial in reducing inflammation and obesity-related disorders. The demand for strawberries rises day by day and increases due to their charming colours, gratifying flavour, and several functions. (Naderi *et al.,* 2013). The first domestic hybrids were created in Europe. The pH range of soil is about 4.6-6.5 for the production of Strawberries (Kouloumprouka *et al.,* 2024).

The genetic makeup of strawberries is a complex puzzle that has intrigued scientists for decades. With advancements in genomics, researchers have made significant strides in unravelling the strawberry genome. The diploid nature of cultivated strawberries, with two sets of chromosomes, has presented unique challenges in deciphering their genetic code. The publication of the first strawberry genome in 2010 marked a significant milestone (Song *et al.,* 2024). This breakthrough provided insights into the genetic diversity, evolutionary history, and potential for breeding improvements in strawberries. Understanding the genetic underpinnings of strawberry traits, such as fruit size, flavour, and disease resistance, has opened doors to targeted breeding programs to create superior cultivars with desirable characteristics (Amrish *et al.,* 2014).

Additionally, micronutrients like zinc, iron, and manganese aid in various metabolic processes, ensuring healthy plants. Optimal fertilizer management promotes increased fruit yield and influences fruit quality (Adhikari *et al.,* 2015). Properly balanced fertilization can lead to larger, sweeter, and more flavourful strawberries with desirable nutritional profiles. Furthermore, fertilizers can contribute to longer shelf life by bolstering the plant's resistance to diseases and stressors. However, applying fertilizers judiciously, considering soil nutrient levels, plant needs, and environmental sustainability is crucial to reap the full benefits while minimizing potential drawbacks (Lilay *et al.,* 2024). Zinc (Zn) and Iron (Fe) are crucial micronutrients that play vital roles in the growth, development, yield, and shelf life of strawberries. These micronutrients support various physiological processes within the plant, contributing to its overall health and enhancing productivity (Akram et al., 2024). Below, we explore the roles of zinc and iron in strawberries and their internal mechanisms: Zinc is crucial for various enzymatic activities within the plant, including the synthesis of growth hormones and DNA replication. It is essential for photosynthesis and the formation of chlorophyll, which directly impacts the plant's ability to produce energy through photosynthesis. Strawberry plants absorb zinc as Zn^{2+} ions. Once inside the plant, it is transported to different plant tissues, especially the young leaves and meristematic regions, where it is utilized in enzyme synthesis and metabolic processes (Kumar *et al.,* 2024). Zinc is involved in the synthesis of auxins, hormones that regulate plant growth. Iron, on the other hand, is a key element of chlorophyll, the pigment responsible for photosynthesis. It plays a critical role in electron transport within chloroplasts, aiding in energy production and carbon assimilation. Iron also plays a role in nitrogen metabolism and enzyme activation. Strawberry roots primarily absorb iron as Fe^{2+} ions, especially in slightly acidic to neutral soils. The plant employs various strategies to increase iron uptake in iron-deficient conditions, including releasing iron-chelating compounds known as siderophores. Once absorbed, iron is transported through the xylem to various plant tissues, primarily the leaves, where it is incorporated into chlorophyll molecules (Tanin *et al.,* 2024; Asif *et al.,* 2024). In summary, zinc and iron are indispensable micronutrients when used as nanoparticles play pivotal roles in the growth, development, yield, and, indirectly, the shelf life of strawberries. Understanding their internal mechanisms and ensuring their availability through proper fertilization and soil management practices is crucial for maximizing strawberry production and quality (Ekka *et al.,* 2024). Additionally, zinc oxide (ZnO) and iron oxide (FeO) are indispensable micronutrients for strawberry plants. Adequate levels of these micronutrients used as nanofertilizers, achieved through proper soil management and fertilization practices, are essential for maximizing strawberry production and maintaining high-quality fruit (Vishwakarma *et al.,* 2024).

Nano-fertilizers can significantly influence the growth and development of strawberry plants, promoting more vital root systems, increased vegetative growth, and enhanced flowering. As a result, they often lead to higher fruit yields with improved size and quality (Eman *et al.,* 2007). Furthermore, the controlled release of nutrients from nano-fertilizers can contribute to stress tolerance in strawberries, making them more resilient to adverse environmental conditions and diseases. This resilience can indirectly extend the shelf life of harvested strawberries by reducing post-harvest deterioration (Al Tawaha *et al.,* 2024). Nevertheless, careful and responsible application of nano-fertilizers is essential to harness these benefits while addressing potential concerns related to nanoparticle toxicity and environmental impact. (Channab *et al.,* 2024).

Nano ZnO and FeO have very limited research endeavours about the strawberry crop. Thus, this research study is being carried out to discover the desired outcomes including nano ZnO and nano FeO.

Keeping in view the present investigation entitled **"Effect of Nano- ZnO and FeO on growth, yield, quality and shelf life of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open and protected conditions"** was executed with the succeeding objectives:

1. To study the influence of Nano-fertilizers on the growth parameters of Strawberry.
2. To find out the impact of nano-fertilisers on flowering and yield parameters of strawberries.

3. To analyse the biochemical constituents affecting the fruit quality with the application of nano-fertilisers.

4. To study the effects of nano-fertilisers on the shelf life of fruit.

Chapter II

REVIEW OF LITERATURE

Nano-fertilizers have the potential to significantly imrove the growth, development, and yield of strawberry plants by enhancing root development, vegetative growth, and flowering. They are considered valuable tools for improving plant growth traits, flower production, yield, quality, and extending the shelf life of the crop.

This chapter reviews previous research related to the application of nano-fertilizers in various crops. Evidence from studies on other crops is included to provide a broader context for interpreting the results. The current study, titled "Effect of Nano-ZnO and FeO on Growth, Yield, Quality, and Shelf Life of Strawberry (*Fragaria × ananassa* Duch.) Cv. Winter Dawn under Open and Protected Conditions," was conducted. A summary of relevant research on the use of nano-fertilizers, particularly in crop production, is provided.

2.1 Efficiency of Nano-fertilizers on the growth and floral attributes.

2.2 Efficiency of Nano-fertilizers on the yield attributes.

2.3 Efficiency of Nano-fertilizers on the quality and shelf-life attributes.

2.1 Efficiency of Nano-fertilizers on the growth and floral attributes.

The application of 0.4% zinc sulfate and 0.2% ferrous sulfate resulted in notable improvements in several growth parameters of strawberry plants. Treated plants exhibited an increased number of leaves (29.93 and 23.24), higher flower production (2.22 and 3.33), and greater plant height (18.85 and 18.28 cm). Furthermore, the highest number of runners was observed in plants treated with 0.4% zinc sulfate. These growth enhancements were likely due to increased photosynthetic activity and the role of carbonic anhydrase in the leaves (Ram et al., 2008). The effects of different concentrations (3, 4.5, 6, and 9 ml) of liquid nano NPK on cucumber growth and yield were compared to conventional mineral fertilizers. The nano NPK treatments significantly improved plant height, leaf number per plant, chlorophyll content, yield, and NPK levels in both leaves and fruits. Specifically, the application of 6 ml of nano NPK resulted in a yield increase of 4.84% and 53.42% in the first and second seasons, respectively. Additionally, this treatment exhibited the lowest weight loss and decay percentage after 21 days of storage at 5°C. Conversely, the control NPK treatment showed higher firmness and total soluble solids (TSS) values. These findings suggest that nanofertilizers can effectively enhance plant growth providing a promising alternative to traditional mineral fertilizers. (Merghany *et al.*, 2019).

The effects of foliar applications of nano fertilizers containing N, P, and K, as well as Humic and Fulvic acid, were investigated at two critical stages: just before the pink bud stage and just before the pea size stage. This study aimed to optimize fertilizer application for maximum yield in both conventional and organic orchards. In conventional orchards, the highest yields were achieved with the application of N at 300 ppm, resulting in 28.15 tons/ha and 29.89 tons/ha in the two respective years of the study. Conversely, in organic apple cultivation, the application of Humic acid at 0.15% led to the highest yields of 19.96 tons/ha and 20.97 tons/ha in the same year. The economic evaluation highlighted that the application of P nano fertilizer at 50 ppm provided the highest net Benefit-to-Cost (B: C) ratio of 6.31 in the conventional system, whereas in the organic system, the application of Humic acid at 0.15% resulted in the highest B: C ratio of 5.51. These findings suggest that the strategic use of nano-fertilizers in conventional orchards and Humic and Fulvic acid in organic orchards can significantly increase both yield and economic returns (Khan *et al.,* 2009).

Nitrogen and calcium fertilization (nanofertilizers) altered sugars, organic acids, volatile, and phenolic contents in strawberry fruits. Higher doses of nitrogen and calcium increased the content of unpleasant aroma aldehydes such as hexanal (up to 3.8-fold) and (E)-2-hexenal (up to 3.7-fold). The content of fruity esters was highest in fruits fertilized with the nano-fertilizer Lithovit (up to 2.3-fold). However, fertilization with N and Ca decreased the strength of ketone and terpenoid fruity aromas. The highest content of total phenols, as well as all individual hydroxycinnamic and hydroxybenzoic acid derivatives, was obtained in the Lithovit nano-fertilizer treatment. While nitrogen fertilization mostly had a negative impact on strawberry flavor, nano-fertilization with Lithovit improved strawberry phenolic content and aroma (Weber *et al.,* 2021).

The impact of both nitrogen and calcium fertilization on strawberry fruit composition was highlighted in a study, which revealed changes in sugars, organic acids, volatile, and phenolic contents. Higher doses of nitrogen and calcium increased unpleasant aroma aldehydes like hexanal (up to 3.8-fold) and (E)-2-hexenal (up to 3.7-fold), while fruity esters were most abundant in fruits treated with the nano-fertilizer Lithovit (up to 2.3-fold). However, the fertilization with N and Ca diminished the strength of ketone and terpenoid fruity aromas. The Lithovit nano-fertilizer treatment resulted in the highest total phenol content, as well as the greatest amounts of individual hydroxycinnamic and hydroxybenzoic acid derivatives. While nitrogen fertilization largely had a negative effect on strawberry flavour, nano-fertilization with Lithovit improved the phenolic content and aroma of the strawberries (Saini *et al.,* 2021).

Kumar *et al.,* (2017) conducted a study and observed that nano zinc application at a concentration of 150 ppm, combined with iron oxide nanoparticles (NPs) at the same concentration, in strawberry cv. Chandler yielded remarkable results. This treatment exhibited the highest height of plant, no. of leaves, petiole length, weight of fruit, fruit diameter, and maximum fruit number. These findings highlight that NPs Zn at 150 ppm significantly enhance the growth and productivity of strawberries. Rajkumar *et al.,* (2014) investigated the effect of Zn & B @ 1 per cent each through foliar mode, which made a significant impact on quality traits like TSS, sugars, pectin content, and vitamin C were observed with the maximum combined dose of Zinc and Boron. These secondary nutrients reduced titratable acidity. It also had a significant impact on increased fruit volume (117.75 cm3), fruit weight (148.75 g), higher fruit yield (135.10 kg/plant), fruit set, retention of fruit (72.55%) and less fruit drop (27.45%) in guava cv. Prabhat pants.

2.2 Efficiency of Nano-fertilizers on the yield attributes.

Significant improvements in various fruit-related parameters were observed in the low-chilling custard apple cv. Arka Sahan , following foliar spray treatments containing boron, zinc, iron, and their combinations. The treatment $ZnSo_4$ and H_3BO_3 in combination at the concentration of 0.5%, increased fruit retention, enhanced fruit diameter, volume, length, and firmness, and resulted in higher average fruit weight and overall fruit yield in peaches (Sharma *et al.,* 2014).

The application of nano zinc sulfate (0.5%), along with Azotobacter and phosphate-solubilizing bacteria (PSB), led to the highest plant height, plant diameter, and leaf count. These treatments also accelerated flowering, reducing the time to the first bloom and the height at which it appeared, while shortening the days to maturity. Furthermore, they enhanced several fruit attributes, including greater fruit length, width, weight, yield per plant, and extended shelf life (Razzaq et al., 2013).

Zinc and boron at 1% each via foliar mode had significant effects on yield traits in guava cv. Prabhat. This included increased fruit volume (117.75 cm^3), fruit weight (148.75 g), higher fruit yield (135.10 kg/plant), improved fruit set, fruit retention (72.55%), and reduced fruit drop (27.45%). These studies collectively underscore the positive impacts of micronutrient and nano-fertilizer applications on enhancing growth parameters and yield characteristics across different fruit crops (Yadav *et al.,* 2013; Srivastava *et al.,* 2014; Rajkumar *et al.*, 2014).

The application of $ZnSO_4$ and H3BO_3 at 0.4% each, along with iron sulfate at 0.2%, had significant effects on various parameters in pomegranate cv. Sindhuri. This treatment increased plant height by 11.52%, spread in the North-South direction by 7.93%, fruit set by 54.17%, fruits per plant by 23.67, and leaf chlorophyll content by 0.62 mg/g. Additionally, zinc sulfate and H_3BO_3 at 0.4% each resulted in the maximum spread in the East-West direction (7.83%) and total canopy volume (29.91%). The combined use of 0.4% zinc sulfate, boric acid, and iron sulfate resulted in an increase in fruit weight, fruit volume, aril count per fruit, and yield, reaching up to 5 kg per plant in pomegranates. Similarly, the impact of micronutrient application on Acid lime (cv. Kagzi lime) was significant in terms of flowering, fruiting, and yield. The application of $FeSO_4$ (0.4%), $ZnSO_4$ (0.5%), and Borax (0.4%) resulted in various positive outcomes. These included an increased number of flowers (22.37), higher fruit set, more fruits per shoot (8.53), a higher number of fruits per plant (925), reduced fruit drop incidence (24.33%), increased fruit volume (29.67 ml), weight (42.67 g), length (4.80 cm), girth (13.20 cm), and enhanced fruit yield (27.07 kg per plant and 74.97 kg per hectare) in Acid lime. These findings from studies conducted by Yadav et al., (2014) and Sutanu et al., (2017) highlight the significant positive impacts of micronutrient applications on growth parameters and yield characteristics in pomegranate and Acid lime.

The impact of applying $ZnSO_4$ through foliar mode at various concentrations on strawberries was examined, revealing significant improvements in multiple fruit-related parameters when zinc sulfate was applied at a rate of 0.5%. This treatment led to increases in fruit weight, length, width, number of fruits per plant, yield per plant, and yield per hectare. Moreover, this concentration outperformed other levels of zinc sulfate as well as the control group. The second most effective concentration was observed at 0.1% of $ZnSO4$, according to the study by Waskela et al., (2013).

Mn and Zn on various traits of pomegranate through foliar application revealed several positive outcomes when Zn at 3.00% was combined with Mn at 60 mg/L. This treatment increased fruit set by 50.55%, reduced fruit cracking by 15.60%, boosted yield to 26.77 kg per tree, and enhanced total soluble solids (TSS) to 13.77^{o}brix in pomegranate cv. Salemey. These findings highlight the potential of this specific foliar application combination for improving the productivity and quality attributes of pomegranate, as demonstrated by Obaid *et al.*, (2013).

Nano-Zn applied at concentrations of 0.4 ppm, 0.8 ppm, and 1.2 ppm on Flame Seedless grapes, revealed the notable findings. The highest bunch weight was observed with nano zinc applied at 0.4 ppm, while the maximum number of berries was recorded at 1.2 ppm. The application of 0.4 ppm of nano zinc resulted in increased leaf area and fresh weight, whereas 1.2 ppm significantly elevated total carbohydrate content, leaf concentration of Fe, cluster number, and cluster weight. Furthermore, nano zinc at all three concentrations (0.4 ppm, 0.8 ppm, and 1.2 ppm) significantly increased yield compared to traditional fertilizers.

The impact of nano zinc on strawberries was explored by applying nano ZnO at both 50% and 100% of the recommended dose. Surprisingly, the application of nanoparticles at 100% of the recommended dose was more effective than conventional zinc oxide, particularly in enhancing crop yield. The researchers observed a remarkable increase in total soluble solids (TSS), vitamin C, and reduced sugar content when nano zinc was applied at a concentration of 0.01%, compared to the effects of conventional ZnO on strawberry cv. San Andreas. These studies by El-Hak *et al.,* (2019) and Carlesso *et al.,* (2018) highlight the potential benefits of nano zinc in improving the productivity and quality of Flame Seedless grapes and strawberries.

The impact of nano zinc on Mango plants was investigated, revealing that foliar application at 1 g/L significantly increased yield in mango cv. Ewasy. Additionally, nano zinc applied at both 0.5 g/L and 1 g/L resulted in the highest fruit weight and fruit length. These findings underscore the potential of nano zinc for promoting growth and enhancing fruit production in mango plants, as demonstrated by the study.

Applying nano zinc at a concentration of 150 ppm, combined with iron oxide nanoparticles (NPs) at the same concentration, to strawberry cv. Chandler resulted in exceptional outcomes. This treatment achieved the highest benefit ratio and positively influenced several yield-related traits, including the duration to first flowering and first harvesting, number of fruits, fruit weight, fruit diameter, and fruit yield per plant. Furthermore, the use of zinc oxide nanoparticles at 150 ppm led to increased plant height, number of leaves, petiole length, fruit weight, fruit diameter, and maximum fruit number. These findings highlight the significant enhancement in the growth and productivity of strawberries with the application of NPs Zn at 150 ppm (Kumar *et al.,* 2015).

Application of boron, zinc, and urea to guava resulted in significant increases in yield compared to the control group. The highest yields were achieved for guava variety Lalit at 17.78 kg/tree, 18.92 kg/tree, and 19.59 kg/tree, and for variety Shweta at 16.55 kg/tree, 17.73 kg/tree, and 18.32 kg/tree, with optimal treatments being boron and zinc at 0.6% each, and urea at 1% concentration. Conversely, the control group showed lower fruit retention. The use of boron, zinc, and urea also significantly enhanced fruit retention, with the highest percentages observed in variety Lalit (61.76%, 62.25%, and 62.51%) and variety Shweta (59.70%, 60.15%, and 60.50%) under the same treatments, while the control group exhibited the lowest retention (Chander *et al.,* 2017).

Maurya *et al.,* (2016) evaluated the substantial improvement in fruit characteristics and yield in aonla cv. NA-6 through the synergistic application of calcium nitrate, potassium sulphate, and $ZnSO_4$. Notably, this combined treatment (Ca+Zn+K) led to increased fruit volume, measuring 41.4 cm3, as well as enhanced fruit weight, measuring 44.3 g. Moreover, a remarkable yield of 61.8 kg/tree was observed, indicating the positive response combined sprays of these specific nutrients on productivity and quality of aonla. Gurung *et al.,* (2016) researched Darjeeling Mandarin and examined the effects of foliar application consisting of the micronutrients as well as the growth regulators. They found GA_3 (15 ppm) + Zn (0.5%) + boron (0.1%) resulted in significant improvements across various performance parameters. Notably, this treatment led to increased plant height (3.82 m), trunk girth (33.95 cm), canopy area (455.31 m2), shoot length (4.51 cm), flowering intensity (83.89), and fruit set (21.31%), while also reducing the incidence of fruit drop (23.66%). Additionally, the fruits from this treatment exhibited superior physical and chemical attributes, including increased fruit weight (66.24 g), segment number (10.33), juice content (33.83%), TSS (10.36 °B), total sugars (10.15%), reducing sugar (4.11%), ascorbic acid (29.94 mg/100 gram), and lower value of titrable acidity (0.66%) in mandarins. These results highlight the positive impact of the specific combination of GA_3, and secondary nutrients on various parameters of Darjeeling mandarin.

Micronutrients through foliar mode on fruit production were studied in guava Cv. L-49, revealing that specific micronutrient combinations had a positive effect. The highest number of fruits per shoot (3.6) was achieved with a mixture of 0.5% zinc sulfate, 0.5% ferrous sulfate, and 0.3% borax. Additionally, the lowest fruit drop percentage (53.6%) was recorded with a treatment of 0.5% ferrous sulfate and 0.3% borax. These results underscore the significance of micronutrient foliar sprays in optimizing fruit yield and reducing fruit drop (Meena *et al.*, 2020).

Application of foliar sprays containing zinc at 0.5% and boron at 0.1% led to notable improvements in banana Cv. poovan. Higher plant height, increased leaf count, and better flowering rates were observed, particularly in high-density plant populations. The application of these micronutrients significantly enhanced growth and yield characteristics, including planting density, height, flower number, and leaf count (Bhoyar *et al.*, 2016)

Singh et al. (2015) investigated the impact of applying 0.4% zinc via foliar spray after the fruit set stage in mango trees. This treatment led to a notable improvement in fruit retention, an increased number of fruits per shoot, and a reduction in fruit drop. Specifically, fruit retention increased by 10.27%, the number of fruits per shoot reached 7.60, and the fruit drop rate decreased to 89.73%. These results demonstrate the effectiveness of foliar zinc sulfate application in enhancing fruit retention and minimizing fruit drop in mango trees.

Response of various treatments including various combinations of vermicompost, biofertilizers and nanofertilizers on strawberry crop growth and yield was examined, observed that the combination of vermicompost at 10 tons/ha, Azotobacter at 7 kg/ha, PSB at 6 kg/ha, and Zn at 0.1% resulted in the highest yield, with an average of 311.26 g/plant. In comparison, the control plot yielded the lowest average at 136.59 g/plant. This treatment also led to significant improvements in tree height, canopy width, no. of leaves, and area of leaves per strawberry plant (Singh *et al.,* 2012).

Gurjar *et al.,* (2015) studied the effect of zinc and boron through a foliar application on Kinnow mandarin, using a combination of 0.2% boric acid and zinc sulphate 0.5%, resulting in the highest retention of fruit and the lowest fruit drop rates of when compared to the control group. Furthermore, the treated group exhibited the highest fruit volume, diameter and fruit number/plant in comparison to the control group. Research conducted by Chandra and Singh demonstrated that the application of zinc, magnesium, and copper at the concentration of 0.5% resulted in improvement in various fruit yield parameters. This treatment led to increased fruit weight (32.5 g), pulp-to-stone ratio (19.70), and total yield (59.7 kg/tree) (Chandra and Singh 2019).

Application of $ZnSO_4$ and $H3BO_3$ at 0.4% each, along with iron sulfate at 0.2%, significantly impacted various parameters in pomegranate cv. Sindhuri. This treatment increased fruit set to 54.17%, the no. of fruits per plant to 23.67, and leaf chlorophyll content to 0.62 mg/g. It also achieved the maximum canopy volume at 29.91%. Additionally, the combination of $ZnSO_4$, boric acid, and iron sulfate at 0.4% each resulted in increased weight, volume of fruits, no. of arils and a yield of 5 kg/plant (Yadav *et al.,* (2014).

An investigation was conducted from 2008 to 2010 to evaluate the effectiveness of Zn and Cu, both individually and in combination, on various strawberry growth parameters. The combination of Zn and Cu at 100 ppm showed a significant impact compared to the control group, leading to increased fruit yield, a higher number of crowns, and more runners in the strawberry plants (Tripathi *et al.,* 2014).

By applying Zn and B at 1% each through foliar mode significantly impacted guava yield. The combination of Zn and B resulted in the highest no. of fruits per plant, increased fruit volume (117.75 cm^3), fruit weight (148.75 g), fruit yield (135.10 kg/plant), and improved fruit set and retention (72.55%) while reducing fruit drop to 27.45% in guava cv. Prabhat (Rajkumar *et al.,* 2014).

Kazemi *et al.,* (2014) investigated the effect of calcium, zinc sulphate and iron on strawberry's reproductive development, yield, and quality parameters. In response to three concentrations of $ZnSO_4$, three concentrations of iron, two concentrations of calcium (5 and 10 mM), and distilled water served as treatments. The outcomes showed that the fruits treated with zinc sulphate at 150 mg/L had the highest levels of TSS, titratable acidity, and vitamin C, while the control had the lowest.

Applying zinc and urea fertilizers to guava leaves resulted in the highest retention of fruit, fruit weight, and no. of fruits per tree. Specifically, treatments using 1.5% urea and 0.6% zinc were superior in most parameters compared to other treatments. The impact of applying nutrients and growth regulators via foliar application was examined on kinnow mandrin. The results indicated that the combination of $ZnSO_4$ at 0.5% and 2,4-D achieved the lowest fruit drop rate at 53.5%, alongside boost in yield, fruit size along with quality (Jat and Laxmidas 2014).

Waskela *et al.,* (2013) examined the impact of the application of $ZnSO_4$ through foliar mode at various concentrations on guava fruits. The researchers found that applying zinc sulphate at a rate of 0.75% resulted in significant improvements in multiple fruit-related parameters. Notably, this treatment led to an increase in fruit wt., length, width, no. of fruits per plant, weight, yield per plant, and yield per hectare. Moreover, this treatment outperformed other levels of zinc sulphate as well as the control group. The second most effective concentration was observed at 0.50% of $ZnSO_4$.

Razzaq *et al.,* (2013) conducted research to assess the impact of foliar applications of Zn on the productivity, growth, and yield of the fruit of Kinnow mandarin. The results indicated that trees treated with 0.6% zinc sulphate exhibited notable improvements in various parameters. These included increased fruit length (71.60 mm), fruit width (83.74 mm), peel content (32.50%), and rag content (26.05%). Furthermore, the treatment resulted in increased fruit weight (194.50 g), juice content (39.60%), and total yield (59.60 kg per tree). Sheikh and Manjula (2012) applied boric acid at a concentration of 0.2% yielded notable outcomes in terms of total yield, with an average of 34.05 kg per plant. This treatment demonstrated a substantial reduction in fruit cracking incidence, which was observed at 3.33%. However, when considering individual fruit weight, the concentration of boric acid (0.4%) resulted in greater fruit weight.

Nitin *et al.,* (2012) in their study demonstrated that $ZnSO_4$ at conc. of 0.6 per cent and H_3BO_3 at conc. of 0.5% on guava, both before & after the fruit set, yielded remarkable results in various fruit parameters. The treated fruits exhibited maximum fruit radial diameter at 7.52 cm, higher fruit weight at 162.01 g, increased fruit yield at 46.41 kg per tree, polar diameter at 7.91 cm, higher fruit volume at 195.27 cc, and specific gravity at 1.024 g/cc.

Modi *et al.,* (2012) performed a research study and found the impact of micronutrients on the growth of the papaya crop, quality as well as the yield of papaya cv. Madhu Bindu. The findings demonstrated that the individual application of $ZnSO_4$ at a concentration of 0.5% and borax at a concentration of 0.3% had significant effects on the weight of fruit, no. of fruits, and overall yield in papaya. Research conducted by Khan *et al.,* (2012) observed that sprays of H_3BO_3 at conc. 0.3 per cent and $ZnSO_4$ at conc. 0.5 per cent yielded significant improvements in various parameters of Feutrell's early mandarin trees. The treated trees exhibited increased tree height at 43.80 cm and stem girth at 4.82 cm. Additionally, the fruits showed increased fruit length at 53.34 mm, diameter at 64.57 mm, and fruit weight at 145.30 g.

The impact of zinc on yield of fruit and chemical traits in pomegranate was studied with applications at concentrations of 0.1%, 0.3%, and 0.6%, applied twice. The use of foliar sprays containing manganese and zinc significantly improved fruit-related attributes, resulting in a fruit yield of 8.1 kg per tree, a weight of 33.5 g for 100 arils, and a fruit diameter of 8.20 cm (Hasani *et al.,* 2012).

Arvind *et al.,* (2012) researched to examine the response of potassium, boron, calcium & zinc on fruits of mango. It was found that trees sprayed with borax @0.5percent showed maximum fruit yield, TSS, sugars and vitamin C in mango. Other quality traits like sugars and vit. C content were maximum maintained by borax, calcium and potassium treatments. The findings indicated that the application of 0.5%

borax through foliar spray resulting highest yield in mango.

Shukla *et al.*, (2011) investigated a study and demonstrated the influence of Ca (Calcium) as well as B (Bororn) on the growth and quality of Aonla. Calcium carbonate along with borax at a concentration of 0.4% resulted in the highest yield recorded (158.6 kg/tree), whereas the control group yielded the lowest (105.2 kg/tree). Singh *et al.*, (2010) examined the impact of varying levels of B and Zn & combined effect on the yield of papaya cv. Ranchi. The application of 0.50% borax combined with 0.25% Zn was determined to be the most effective treatment. This particular treatment resulted in the highest yiled (37.20 kg per plant). In their 2010 study, Mitra *et al.* in 2010 examined how various organic substances, micronutrients and biofertilizers influenced the fruit quality & fruit yield of guava CV. Sardar. They concluded that the application of NPK 50:40:50 gm/tree/year +ZnO (50 ppm) neem cake @5 kg/tree/year, resulted in the maximum yield.

2.3 Efficiency of Nano-fertilizers on the quality and shelf-life attributes

The impact of pre-harvest nano-fertilization on the quantitative traits of Red Delicious apples was studied by applying calcium chloride (0%, 1.5%, and 2.0%) and nano-calcium (0%, 1.5%, and 2.0%) sprays on apple trees at two-week intervals, starting 70 days after full bloom until 30 days before commercial maturity. The findings revealed that nano-calcium had a more pronounced effect on fruit quality and yield compared to conventional calcium chloride, with the 2.0% nano-calcium treatment showing the greatest improvements. This treatment led to notable increases in total acidity (TA), total phenolic content (TPC), total antioxidant activity (TAA), fiber, and starch content. However, both calcium chloride and nano-calcium treatments resulted in a reduction in total soluble solids (TSS), total sugars, and anthocyanin levels compared to untreated control fruits. The study underscores the potential of nano-calcium for improving the quality and nutritional value of apples (Ranjbar et al., 2020).

Singh *et al.*, (2007) discovered in their investigation that the application of a mixture containing zinc (0.5%), copper (0.4%), and NAA @10 ppm resulted in maximum weight of fruit, pulp weight, and yield in the 'Narendra Aonla 10' variety of aonla. Additionally, this treatment combination significantly improved various quality attributes of the fruit, including reduced acidity, increased TSS, elevated levels of vitamin C, reduced sugars and non-reducing sugars also total sugars as well as total phenols including the juice content and fiber content.

Ghosh *et al.,* (2009) found that $ZnSO_4$ @0.5% resulted in increased fruit weight (31.3 g), higher pulp content (95.2%), elevated TSS (8.4°B), greater total sugar content (4.9%), and enhanced vitamin C levels (540 mg/100 g) in the study. Additionally, the application of borax at 0.4% significantly improved the total yield (36.2 kg/plant). The study found a positive impact of $ZnSO_4$ on fruit quality attributes, while borax application had a significant effect on total yield.

Khan *et al.,* (2009) in their study concluded that $ZnSO_4$ and Thiourea proved to be highly effective in improving various growth and yield parameters in the aonla cultivar 'Narendra Aonla-6'. The combined spray also enhanced fruit yield (46.54 kg/tree) and improved quality attributes, such as higher total soluble solids (TSS) content (12.7°B), increased ascorbic acid levels (680 mg/100 g pulp), elevated phenolic content (168.4), higher sugars content (5.97%), and lower titratable acidity (1.75%). Furthermore, ZnSO4 (0.5%) specifically resulted in a high initial fruit set (75.05%) in the 'Narendra Aonla-6' cultivar. Lal *et al.,* (2010) had done application of micronutrients on litchi which resulted in enhanced fruit yield and quality parameters such as TSS, vitamin C, total sugars, & juice percentage. Among the micronutrients tested, 1.0% borax resulted in the highest improvement in these quality attributes. Additionally, the treatment at the concentration of 400 ppm SADH led to maximum percentage of edible fruits and the lowest percentage of non-edible fruits. Furthermore, trees that were sprayed with 1.5% potassium nitrate and 2.0% calcium nitrate exhibited the maximum weight of fruit, measuring 20.41 g and 20.37 g, respectively.

Application of foliar Zn, Cu, and B at different concentrations (0.2%, 0.3%, and 0.4%) both individually and in various combinations in guava and observed that application of zinc @0.4% had a significant impact on several parameters. It notably improved the total soluble solids (TSS) at 11.78°Brix, total sugar content at 6.36%, sugar-acid ratio at 15.91, and seed weight at 2.02 mg. On the other hand, the application of boron (0.4%) demonstrated notable effects on vitamin C content, which increased to 137.56 mg/100 g pulp, and pectin content, which increased to 1.65%, in the L-49 guava fruits. These findings highlight the specific benefits associated with zinc and boron by foliar method of application, respectively, in enhancing the quality and nutritional composition of guava fruits (Rawat *et al.,* 2010).

The influence of secondary nutrients on the yield and growth characteristics of Washington cultivar of papaya was examined. was investigated by Chandra and his colleagues revealed that a combination of copper sulfate, manganese sulfate, and borax significantly influenced several fruit parameters. This treatment resulted in notable improvements including fruit length, fruit width, and yield, with a yield of 40.40 kg per tree. Additionally, the fruit exhibited higher total sugar content (9.72%), vitamin C content (58.32 mg/100 g), and total soluble solids (TSS) at 9.60°Brix. The specific combination of these micronutrients was found to enhance both the quality and nutritional composition of papaya fruits (Chandra *et al.,* 2010).

The effect of iron, boron, and zinc on mango fruit cv. Dashehari was observed, resulting in the highest levels of total soluble solids (TSS) at 27.90°Brix, ascorbic acid content at 150.3 mg/100ml, reducing sugar at 19.92%, non-reducing sugar at 8.83%, total sugar at 49.92%, and the lowest acidity level at 0.178%. Compared to the control group, the application of 0.4% iron, 0.8% boron, and 0.8% zinc significantly improved the quality attributes of mango (Anees *et al.,* 2011).

Singh *et al.,* (2010) observed in their research impact of varying levels of B and Zn & combined effect on the yield of papaya cv. Ranchi. The application of 0.50% borax combined with 0.25% Zn was determined to be the most effective treatment. This particular treatment resulted in maximum yield (37.20 kg per plant) and exhibited elevated levels of TSS, sugars, vitamin C, beta carotene, & high TSS: acid in papaya as comparison with the other treatments.

Pathak *et al.,* (2011) investigate the impact of $FeSO_4$ @0.5% + $ZnSO_4$ @0.5% at 3rd, 5th, and 7th months after planting had notable effects on various parameters in banana cv. Martaman. They observed that this combination showed improvements in quality parameters such as sugar-to-acid ratio (47.70), non-reducing sugar content (10.04%), and minimum titratable acidity (0.36%). However, when FeSO4 (0.5%) was applied alone, significant improvements were observed in total soluble solids (25.53°B), reducing sugar (6.57%), and total sugar (17.24%) of the fruits.

Shukla *et al.,* (2011) investigated in their study observed the influence of Ca (calcium) as well as B (boron) on the growth also the quality in the case of Aonla and observed that by applying calcium carbonate along with borax at the concentration of 0.4% increased vitamin C (626.49 mg/100g). Furthermore, the fruits treated with calcium carbonate and borax at 0.4% exhibited larger sizes and slightly higher total soluble solids (TSS) levels (16.5%) at the time of harvest compared to the fruits in the control group (15.1%). Arvind *et al.,* (2012) outbased response of potassium, boron, calcium & zinc on fruits of mango. It was found that trees sprayed with borax @0.5percent showed maximum fruit yield, TSS, sugars and vitamin C in mango. Other quality traits like sugar and ascorbic acid content were best maintained by borax, calcium and potassium treatments. Additionally, borax treatment exhibited significant improvements in sugars, TSS and vitamin C in mango fruits. Moreover, the treatments involving borax, calcium, and potassium were found to be effective in maintaining sugar and ascorbic acid levels, contributing to overall fruit quality and fruit yield. Gupta and Tripathi (2012) conducted trials from 2009 to 2011 to investigate the application of biofertilizers on strawberry plants. The results showed that Azotobacter @7kg/ha & vermicompost@30tonnes/ha had significant effects on various characteristics. The treated plants exhibited maximum berry length, width, weight, volume at 6.12 cc and 5.82 cc, total soluble solids (TSS) at 10.31 ^{o}Brix and 9.29 ^{o}Brix, total sugars at 9.73% and 8.74%, and ascorbic acid content at 56.52 mg/100gpulp and 54.53 mg/100gpulp, with minimum titratable acidity at 0.52% and 0.47%, respectively. Application of Azotobacter and vermicompost on the quality and growth of strawberry plants, compared to untreated plants.

Foliar application of zinc at various concentrations was applied to pomegranate to evaluate the fruit yield and chemical traits and observed that, using concentrations of 0%, 0.3%, and 0.6% significant effects were recorded in parameters such as juice content, total soluble solids, ratio of TSS/TA, and leaf area. The most suitable combination for these characteristics, under the prevailing conditions, was the spray of zinc at a rate of 0.3%. Additionally, foliar spray of manganese and zinc showed positive and significant effects on various fruit-related attributes, including the arils per peel ratio (1.88%), TSS (15.73 °B), juice content of arils (68.2%), and anthocyanin index (0.328) (Hasani *et al.*, 2012).

Mir *et al.,* (2012) conducted a study and their findings indicated that with the application of nutrients Zn, B, and Mn exhibited superiority in terms of biochemical characteristics, specifically TSS (15.85 °B), total sugars (9.78%), vitamin C (13.48 mg/100ml), and anthocyanin content (20.36 mg/100ml) in pomegranate fruits. Nitin *et al.,* (2012) demonstrated that ZnSO4 at conc. of 0.6 per cent and $H3BO_3$ at conc. of 0.5% on guava, results in various fruit parameters. The treated fruits exhibited maximum fruit radial diameter at 7.52 cm, higher fruit weight at 162.01 g, polar diameter at 7.91 cm, higher fruit volume at 195.27 cc, and specific gravity at 1.024 g/cc.

Sajid *et al.,* (2012) experimented and recorded that with the application of growth nutrients like zinc (Zn) and boron (B) significantly improved the quality of sweet orange fruits, enhancing factors such as fruit juice content, total soluble solids (TSS), vitamin C, and non-reducing sugars. Specifically, higher levels of TSS, fruit juice, and vitamin C were observed when fruit was treated with a 1% zinc solution combined with a low concentration of boron at 0.02%.

The application of 0.6% $ZnSO_4$ to strawberry cv. Chandler plants resulted in significant outcomes, with the highest total soluble solids (TSS) content at 8.31^0B and the highest amount of ascorbic acid. Additionally, the TSS: acid ratio was notably elevated at 11.70, while the acidity level was the lowest at 0.716% (Kumar *et al.,* 2017). The effects of integrated nutrient management (INM) on the quality characteristics of papaya cultivar Madhubindu were studied. Applying ½ RDF in combination with Azotobacter at a rate of 50 g per plant and phosphate-solubilizing bacteria (PSB) at a rate of 2.5 g per square meter resulted in the highest levels of sugars and TSS (Bakshi *et al.,* 2013).

The application of micronutrients and GA_3 through foliar mode positively impacted guava fruit yield and quality, as disclosed in an investigation by Gaur et al., 2014. The study revealed that a 0.4% borax solution resulted in the highest total soluble solids (TSS) value, measuring 11.7°Brix, and minimal acidity at 0.30%. Additionally, foliar application of borax at this concentration led to higher total sugar content and the highest vitamin C content in guava fruits. Similarly, Kazemi (2014) studied the quality parameters of strawberries in response to calcium, zinc sulphate and application of borax at this concentration resulted in increased total sugar and vitamin C content in guava fruits. In a similar vein, Kazemi (2014) investigated the effects of calcium, zinc sulfate, and iron on the quality attributes of strawberries. Treatments included three concentrations of $ZnSO_4$, three concentrations of iron, two concentrations of calcium (5 and 10 mM), and distilled water. The results showed that strawberries treated with 150 mg/L of zinc sulphate had the highest levels of TSS, titratable acidity, and vitamin C, while the control group had the lowest (Kazemi *et al.*, 2014).

Meena et al. (2014) found that spraying 6-year-old Anola plants of cultivar NA-7 with calcium, boron, and zinc at concentrations of 0.6%, 0.4%, and 0.8%, respectively, resulted in improved fruit retention, and increased fruit volume, length, and diameter. The combined spray of calcium, boron, and zinc made a higher contribution in sugars, juice content, vitamin C and TSS. Fruit weight increase (45.2g), and fruit thickness (1.41 cm) but with qualities such as reduced acidity, maximum TSS, ascorbic acid and juice content, were found to be significant using calcium nitrate+borax+zinc sulphate. A research by Rajkumar *et al.,* (2014) on the application of zinc & boron @ 1 per cent each through foliar mode, made a significant impact on quality traits like TSS, sugars, pectin content, and vitamin C were observed with the maximum combined dose of Zinc and Boron. These secondary nutrients reduced titratable acidity. It also had a significant impact on increased fruit volume (117.75 cm3), and fruit weight (148.75 g) of guava cv. Prabhat pants.

Applying zinc, magnesium, and copper at a 0.5% concentration significantly improved several quality attributes of guava fruit. This treatment led to higher levels of total soluble solids (TSS), vitamin C, and various sugars (total, reducing, and non-reducing), while reducing titratable acidity (Chandra and Singh, 2015). Additionally, research exploring different doses of farmyard manure (FYM) combined with various biofertilizers and nano-fertilizers found that applying half the recommended fertilizer dose (225 g N2O, 195 g P2O5, 150 g K2O) along with 50 kg of FYM and Azospirillum inoculated per tree, plus 0.5% zinc sulfate, notably improved guava fruit quality parameters, including TSS, vitamin C, total sugars, TSS/acid ratio, and pectin. These improvements were consistent across both the rainy and winter seasons (Goswami *et al.,* 2014).

A study on Darjeeling Mandarin was investigated to find out the impact of foliar treatments with micronutrients and growth regulators. The combination of GA_3 (15 ppm), Zn (0.5%), and boron (0.1%) resulted in significant improvements across various performance parameters. This treatment led to the highest juice content (33.83%), TSS (10.36 °B), total sugars (10.15%), reducing sugar (4.11%), and ascorbic acid (29.94 mg/100 grams), along with the lowest value of titratable acidity (0.66%) in mandarins. These results highlight the positive impact of this specific combination of GA_3 and secondary nutrients on various parameters of Darjeeling Mandarin (Gurung *et al.*, 2016).

Chapter III

MATERIALS AND METHODS

The present investigation entitled "Effect of Nano-ZnO and FeO on growth, yield, quality, and shelf life of Strawberry (*Fragaria* × *ananassa* Duch.) Cv. Winter Dawn under open and protected conditions" was carried out at the experimental farm of the Department of Horticulture, Lovely Professional University (Phagwara) during the years 2022 to 2024. The experimental site is located in Phagwara, Punjab, at approximately 237 meters (768 feet) above sea level. Its geographical coordinates are approximately 31.2232°N latitude and 75.7670°E longitude, with an annual rainfall of about 816 mm. The experiment was conducted in a polytunnel with a total area of 500 m^2. The polytunnel was equipped with rolling side curtains that allowed for natural ventilation, ensuring optimal airflow and temperature control. This setup provided a controlled environment for strawberry cultivation, protecting the plants from extreme weather while maintaining adequate ventilation for healthy growth.

3.1 Experimental details

Design and layout of the experiment

The details of the experimental plan employed in the present investigation are as follows:

Name of crop: Strawberry

Botanical name: *Fragaria* × *ananassa* Duch.

Family: Rosaceae

Variety: Winter Dawn

Design of experiment: RBD (Randomised Block Design)

Number of replications: 3

Number of treatments: 16

Total Number of Plots (Protected): 45

Total Number of Plots (Open): 45

Total Number of Plants per Plot: 8

Number of Plants per Treatment: 8

Row to row distance: 60cm

Plant to plant distance: 30 cm

Size per plot: 1^2m (m x m)

Conditions: Open and Polytunnel

Site of the experiment: Experimental Farm of Horticulture Department, School of Agriculture, LPU (Phagwara) Punjab

Treatment details:

Treatments	Doses Nano-Zno (Zinc oxide), Nano-Feo (Iron oxide)
T_0	Control (100% RDF)
T_1	Z_1 (50ppm ZnO NPs)
T_2	Z_2 (100 ppm ZnO NPs)
T_3	Z_3(150 ppm ZnO NPs),
T_4	F_1(50 ppm FeO NPs)
T_5	F_2(100 ppm FeO NPs)
T_6	F_3(150 ppm FeO NPs)
T_7	Z_1 F_1(50ppm ZnO NPs + 50ppm FeO NPs),
T_8	Z_1 F_2(50pm ZnO NPs + 100ppm FeO NPs)
T_9	Z_1F_3(50 ppm ZnO NPs + 150 ppm FeO NPs)
T_{10}	Z_2F_1(100 ppm ZnO NPs + 50 ppm FeO NPs)
T_{11}	Z_2F_2(100 ppm ZnO NPs + 100 ppm FeO NPs)
T_{12}	Z_2F_3(100 ppm ZnO NPs + 150 ppm FeO NPs)
T_{13}	Z_3F_1(150 ppm ZnO NPs + 50 ppm FeO NPs)
T_{14}	Z_3F_2(150 ppm ZnO NPs + 100 ppm FeO NPs)
T_{15}	Z_3F_3(150 ppm ZnO NPs + 150 ppm FeO NPs)

Plate-I

Bed Preparation

Transplanting of Strawberry Runners

Plate-II

Transplanting of Strawberry runners under Polytunnel

Nano Zinc Oxide (ZnO) and Nano Iron Oxide (FeO)

<u>**Plate-III**</u>

Weighing of Nano-fertilizers

<u>**Foliar application of Nano-ZnO & FeO on Crop**</u>

Plate-IV

Strawberry Fruits after Harvesting

Biochemical Parameters of Fruits

3.3 Agronomical practices

3.3.1 Preparation of field:

The experimental field was prepared by ploughing and harrowing to achieve a fine tilth. The experimental site was divided into small plots.

3.3.2 Application of manures:

Suggested amounts of manure i.e. farmyard manure, Vermicompost, and compost were applied before transplanting the runners of strawberry var. Winter Dawn.

3.3.3 Planting of runners:

The strawberry plants were spaced 60 cm between rows and 30 cm between individual plants, and they were planted during the evening hours. Following planting, light irrigation was applied to ensure adequate soil moisture for the young plants.

3.3.4 Aftercare:

To maintain a consistent plant population in each plot, gap-filling was carried out by replacing dead runners with new ones of the same age. This practice of gap filling was performed until the 15th day after planting to ensure uniformity in plant distribution across all plots.

3.3.5 Weeding and hoeing:

Throughout the growth period, the plots were meticulously maintained weed-free through regular intervals of weeding. The initial weeding took place 30 days after planting, followed by subsequent sessions as needed to ensure optimal growth conditions for the plants.

3.3.6 Irrigation:

Immediately after planting, the strawberry plants were initially watered using a drip irrigation system. Ongoing irrigation was then adjusted according to the moisture requirements of the soil during the growth period, with drip irrigation continuing to ensure efficient water use for the crop.

3.3.7 Plant protection:

Initially, the plants exhibited signs of dryness, and red termites were observed in the soil. To eliminate the red termites from the field, neem oil was applied at the recommended dosage. This treatment was administered twice to effectively manage the termite infestation and ensure the health of the plants.

3.3.8 Harvesting:

The fruits were harvested once they reached more than 75% of their colouration. Harvesting was conducted over more than one month, picking the fruits at various stages of ripeness to ensure optimal quality and yield.

3.4 Recorded Observations:

Three plants chosen at random from each treatment were carefully monitored to assess the effects of the treatments on the growth, development, yield, and quality of the strawberry crop. All recorded observations were subjected to rigorous statistical analysis. Key parameters such as plant height, leaf count, plant spread, leaf area index, and chlorophyll content, alongside various yield and quality attributes, were recorded from five randomly selected plants within each replication for each treatment.

3.4.1 Vegetative growth parameters:

3.4.1.1 Plant height (cm):

Plant height was measured from the base of each plant to the tip of the main stem using a ruler, with readings recorded in centimeters. Measurements were taken from five different plants at 30, 60, 90, and 120 days after planting (DAP). The average heights were calculated and analyzed statistically to assess the growth trends over time.

3.4.1.2 Stem girth (cm):

Stem girth (mm) was measured with the vernier scale.

3.4.1.3 Number of leaves:

The number of fully expanded leaves was counted on five randomly selected plants at various stages of growth until harvest. These counts were averaged and analyzed to monitor leaf development throughout the growth period.

3.4.1.4 Leaf Length:

The length of leaves was measured with the help of a scale (cm).

3.4.1.5 Petiole length (cm)

The length of the petiole was measured with the help of a scale (cm).

3.4.1.6 Leaf area index (LAI):

The youngest fully expanded matured leaf was observed with the use of a leafarea meter.

3.4.1.7 Plant spread (cm):

The spread of each plant was measured in both the East-West and North-South directions. Averages for each direction were calculated from the recorded measurements. This Data provided insights into the overall spatial distribution and growth pattern of the plants within the experimental plots.

3.4.1.8 Number of crowns:

After the fruiting season, the average number of crowns per plant was recorded and expressed as the mean number of crowns per plant. This measurement provided valuable Data on the reproductive growth and development of the strawberry plants under study.

3.4.2 Flowering and fruiting parameters:

3.4.2.1 Days to first flowering:

The number of days to first flowering was determined by recording the time from planting to the first appearance of flowers (anthesis). This parameter served to assess the flowering onset and developmental timing of the strawberry plants in the study.

3.4.2.2 Number of flowers per plant:

The number of flowers per plant was recorded for selected plants at 60, 80, 100, and 115 days after planting (DAP). The average number of flowers per plant was then calculated based on these observations. This provided a comprehensive view of the flowering dynamics and productivity of the strawberry plants throughout their growth period.

3.4.2.3 Duration of flowering:

The duration of flowering was recorded from the onset of ten per cent flowering to the attainment of eighty per cent flowering in each treatment. This Data collection method aimed to capture the full span of the flowering period and assess the flowering duration across different experimental conditions.

3.4.2.4 Berry set (%):

Percentage fruit set refers to the proportion of blossoms that ultimately develop into fruits. It is a measure used to quantify the efficiency of fruit production relative to the total number of blossoms on a plant or within a specific area under study.

3.4.2.5 Days taken for fruit maturity:

The number of days to fruit maturity was calculated by recording the time from planting to when the first fruit reached maturity. This parameter provides essential information about the growth and developmental timeline of the strawberry plants about their fruit production cycle.

3.4.2.6 Number of fruits per plant:

At the time of harvest, the total amount of fruit was calculated for each plot, and then the ratio was determined by dividing the total number of fruits by the number of plants in each plot. This method allowed for an assessment of the average yield per plant, providing insights into the productivity of the strawberry plants in the experimental plots.

3.4.2.7 Yield per plant:

Total yield per plant per treatment was determined by weighing the total amount of fruits harvested and multiplying it by the average weight of fruits recorded at each harvesting event. This calculation provided the yield of fruits per plant in grams (gm), offering a quantitative measure of fruit production per plant under each treatment condition.

3.4.2.8 Fruit length (cm):

The length of fully developed berries was measured using a vernier caliper and recorded in centimeters. This precise measurement method ensured accurate documentation of berry dimensions, contributing to the assessment of fruit morphology and quality in the study.

3.4.2.9 Fruit diameter (cm):

The diameter of fully developed berries was measured using a vernier caliper and recorded in centimeters. This method ensured precise measurement of berry dimensions, providing valuable Data on fruit morphology and size in the study.

3.4.2.10 Fruit weight (cm):

The weight of fruits was measured using an electric weighing machine. This approach ensured accurate and consistent measurement of fruit weight, providing essential Data for evaluating fruit yield and quality in the research study.

3.4.2 Quality parameters:

3.4.3.1 Fruit TSS (ºBrix)

The total soluble solids (TSS) content in the fruits was measured using a hand-held refractometer with a range of 0-30%. A few drops of fruit juice were placed on the refractometer's prism, and the TSS percentage was read directly from the device and recorded. These values were adjusted to 20°C as per the guidelines outlined in the AOAC (Association of Official Analytical Chemists) 2010 standard method. This method ensured accurate determination of TSS levels, providing crucial information on fruit quality and maturity.

3.4.3.2 Acidity

To determine the acidity of the fruit juice, a known volume of juice was diluted with distilled water and titrated with a 0.1N NaOH solution, using phenolphthalein as an indicator. The titration was stopped when a faint pink color persisted. The acidity was then expressed as a percentage of citric acid, according to the AOAC (Association of Official Analytical Chemists) 2010 standard method. The acidity was calculated using the formula provided in the standard method. This method allowed for accurate quantification of acidity levels in the fruit juice, essential for assessing fruit quality and flavor characteristics.

$$\text{Acidity (\%)} = \frac{0.0064 \text{ X Volume of } 0.1\text{N (ml) NaOH}}{\text{Volume of the juice taken (ml)}} \times 100$$

(1 ml of N NaOH=0.0064 g of citric acid)

3.4.3.3 Total sugars

Lane and Eynon method were used to estimate the total sugars and reducing sugars, as described by Ranganna (1986).

Sample preparation: Twenty grams of fruit tissue was macerated and homogenized with distilled water for 5 minutes. The resulting homogenate was transferred into a 250 ml volumetric flask. It was neutralized using 1.0 N NaOH. Subsequently, 2 ml of 45% lead acetate solution was added, followed by thorough shaking, and then allowed to stand undisturbed for 10 minutes. Afterwards, 2 ml of 22% potassium oxalate was used to de-lead the solution, and the volume was adjusted up to 250 ml. The solution was then filtered using Whatman No. 4 filter paper, and the resulting filtrate was labelled as 'Solution-A'. This process was performed to prepare the sample for further analysis according to the specified methodology.

To estimate reducing sugars, solution (A) was utilized. For the determination of total sugars, 50 ml of solution (A) was inverted in a 250 ml titration flask, hydrolyzed with 5 ml of concentrated hydrochloric acid (HCl), and left to stand overnight. The resulting solution was then neutralized with 5.0 N NaOH and adjusted to a final volume of 250 ml with distilled water. This prepared solution was labelled as 'Solution B'. This process was undertaken to facilitate the analysis of total sugar content as per the prescribed methodology.

Titration: For the titrimetric estimation of reducing and total sugars, Fehling's solutions (A) and (B) were employed. Five millilitres each of Fehling's solution (A) and Fehling's solution (B) were placed in a conical flask containing 25 ml of distilled water. These solutions were then titrated against 'Solution-A' for reducing sugars and 'Solution-B' for total sugars until a brick-red colour appeared. Following this, a few drops of methylene blue indicator were added, and the titration continued until a brick-red precipitate was observed. Throughout the process, the flask was heated on a heat source to maintain the boiling of the contents. The percentages of reducing and total sugars were subsequently calculated based on the titration results. This method allowed for accurate determination of sugar content in the samples as per the experimental protocol.

$$\text{Reducing/total sugars (\%)} = \frac{\text{Ff x Vd}}{\text{Tv x Ws}} \times 100$$

Where, Ff = Fehling's factor; Vd = volume made up; Tv = titrated value; Ws =weightof sample taken.

The value of non-reducing sugars was calculated by following formula and expressed as a percentage on a fresh fruit weight basis.

Non-reducing sugars (%) = Total sugars (%) – Reducing sugars (%) x 0.95

3.4.3.4 Reducing sugars

The Lane-Eynon titration method was to measure reducing sugars of the sample. It involves titrating the sugar solution with Fehling's solution, where reducing sugars reduce copper (II) ions to copper (I), forming a brick-red precipitate. The endpoint is indicated by the color change, and the amount of reducing sugars is calculated based on the volume of the sugar solution used.

3.4.3.5 Non-reducing sugars

Non reducing sugars= Total sugars (%) – Reducing Sugars (%)

3.4.3.6 Ascorbic acid

The ascorbic acid content was determined titrimetrically using 2,6-dichlorophenol indophenol dye, following a modified procedure outlined in the A.O.A.C. (Association of Official Agricultural Chemists) guidelines (Anon., 1960). The quantity of ascorbic acid obtained from the analysis was expressed as milligrams per 100 grams of fresh fruit. This method provided a reliable measurement of the ascorbic acid concentration in the fruit samples, crucial for assessing their nutritional quality.

3.4.3.7 Total flavonoid

The total flavonoid content was determined using the aluminium chloride colorimetric assay, following the methodology outlined by Kamtekar *et al.*, (2014). The ethanolic extract necessary for the assay was prepared according to the procedure described by Kowitcharoen *et al.,* (2021). This approach ensured accurate quantification of flavonoid levels in the sample, providing valuable information about their antioxidant properties and potential health benefits.

Reagents preparations

Quercetin solution (1000 μg ml^{-1})

1000 μg/ml stock solution was prepared by dissolving 100 mg of quercetin in 100 ml of absolute alcohol.

Working standard 10 ml of stock solution to 90 ml with absolute alcohol (100µg/ml) 5% Sodium nitrite 5 g Sodium nitrite was dissolved in 100 ml of distilled water in volumetric flask 10 % Aluminium chloride 10 g Aluminium chloride was dissolved in 100 ml of distilled water in volumetric flask 1 M Sodium hydroxide 4 g Sodium nitrite was dissolved in 100 ml of distilled water in volumetric flask.

Procedure

Briefly, 1 gram of samples was homogenized with 10 ml of 80% ethanol (v/v) and centrifuged at 12,000× g for 20 minutes to obtain the extract. For the assay, 1 ml aliquots of the microgreens extract and 1 ml of standard quercetin solution (200, 400, 600, 800, 1000 µg/ml) were placed into test tubes. To each tube, 4 ml of distilled water and 0.3 ml of 5% sodium nitrite solution were added. After 5 minutes, 0.3 ml of 10% aluminium chloride was added, followed by 2 ml of 1 M sodium hydroxide at the 6th-minute mark. The volume was adjusted to 10 ml with distilled water and thoroughly mixed. Absorbance was measured at 510 nm using a spectrophotometer, with distilled water used as the blank. The total flavonoid content of the samples was quantified and expressed as milligrams of quercetin equivalents per 100 grams of fresh weight basis. This method allowed for the accurate determination of flavonoid levels in the microgreen extract.

3.4.3.8 Total phenols

For the estimation of total phenols, 1 ml of each extract was mixed with Folin-Ciocalteu's phenol reagent and water in a 1:1:20 (v/v) ratio, followed by an incubation period of eight minutes. Subsequently, 10 ml of 7% (w/v) sodium carbonate solution was added, and the mixture was left to stand for two hours. The absorbance of each sample was measured at 750 nm using a spectrophotometer. The concentration of total phenols in the extracts was determined by comparing their absorbance values to a standard calibration curve prepared with gallic acid. The results were expressed as micrograms of gallic acid equivalents per gram of fresh weight (GAE/g fw), providing a quantitative measure of total phenolic content in the samples.

3.4.3.9 TSS/acid ratio

The TSS/acid ratio was calculated by dividing the total soluble solids (TSS) value by the titratable acidity. This ratio provides a quantitative assessment of the balance between sugar content (represented by TSS) and acidity in the fruit or sample under study. It serves as an important parameter in determining fruit maturity, flavour profile, and overall quality.

3.4.3.10 Anthocyanin Content

The anthocyanin content in selected microgreen families was measured using a spectrophotometric method. To begin, 0.1 g of fresh, homogenized sample was mixed with 5 mL of a methanol: HCl: H2O solution (90:1:9) in glass tubes. The mixture was vortexed and incubated in the dark at room temperature for 1 hour. After incubation, the tubes were centrifuged at 2000 rpm for 5 minutes, and the supernatant was collected for analysis. Absorbance was recorded at wavelengths of 534, 643, and 661 nm using a spectrophotometer, with the methanol: HCl: H2O solution serving as the blank. The anthocyanin content in the microgreen extracts was determined using the appropriate equations provided in the methodology by Martínez-Ispizua *et al.,* (2022).

Anthocyanin Content (µmol/g FW) =(0.0821 × Abs534 - 0.00687 × Abs643 - 0.002426 × Abs661) × (Volume made up)/(1000×Weight of sample)

The anthocyanin concentration was expressed as µmol/g FW.

3.4.3.11 Soluble proteins

Two grams of fresh berry pulp were macerated in 10 ml of 0.1 M phosphate buffer (pH 7.4) in an ice-cold pestle and mortar. The extract was then pressed through a double-layer cheesecloth. Later, it was centrifuged at 5000 rpm for 15 minutes at 4 degrees Celsius. From the clarified supernatant, the proteins were estimated by the method described by Lowery *et al.,* (1951) at 700 nm on spectronic-20 colorimeter.

3.4.3.12 PLW (%)

Mass loss during storage was calculated by subtracting the final sample weight from its initial recorded weight and expressing this difference as a percentage of the initial weight. This calculation is represented by the formula:

This method provides a quantitative measure of the amount of mass lost over the storage period, essential for assessing the post-harvest characteristics and shelf life of the samples.

$$\text{Mass loss (\%)} = \frac{\text{Fruit initial weight (g) - fruit final weight (g)}}{\text{Fruit initial weight (g)}}$$

3.4.3.13 Spoilage (%)

The process involved separating decayed fruits, weighing them individually, and then calculating their weight as a percentage of the total weight for each replicate. This method provided a quantitative assessment of fruit decay relative to the overall sample weight in each experimental replicate.

Chapter IV

RESULTS AND DISCUSSION

The current study entitled "Effect of Nano-ZnO and FeO on growth, yield, quality and shelf life of Strawberry (*Fragaria × ananassa* Duch.) Cv. Winter Dawn under open and protected conditions" was carried out during 2022-24 under protected and open field conditions. The Data have been presented in figures as well as in tabular form. The Data were statistically analyzed. The results of the experiment are summarised below:

4.1 Vegetative growth parameters

4.1.1 Plant height:

The study of Table 4.1a and Figure 4.1a revealed that, significant variations exist on plant height across all treatments at 30^{th}, 60^{th}, 90^{th}, and 110^{th} days after planting with the application of different levels of Nano-ZnO and Nano-FeO. Maximum (5.59 cm) plant height was recorded during (2022-23) at 110^{th} DAP under treatment T_{15} (150 ppm ZnO + 150 ppm FeO), followed by 5.35 cm under T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (4.55 cm) plant height was noted in control (T_0). Similarly, at 30^{th}, 60^{th}, 90^{th} DAP for the first year of trial. In the second-year trial, maximum (11.92 cm) plant height was observed in treatment T_{15} (150 ppm ZnO + 150 ppm FeO) at 120^{th} DAP with the height of, followed by 11.79 cm under T_9 (50 ppm ZnO + 150 ppm FeO) and minimum (9.73 cm) height was recorded in T_0 (Control) for the second year trial. These observations highlight the effects of different treatments on plant height throughout the growth stages of the experiment, emphasizing the influence of zinc oxide (ZnO) and iron oxide (FeO) combinations on plant growth.

Combining the Data from both years (2022-23 and 2023-24), the analysis revealed that produced the tallest (12.08 cm) plants at 120^{th} DAP under was recorded treatment T_{15} (150 ppm ZnO + 150 ppm FeO), followed by 11.71 cm was noticed T_{11} (100 ppm ZnO + 100 ppm FeO). Minimum (9.80 cm) plant height was observed under control (T_0). The increase in plant height observed with the application of zinc sulphate can be attributed to the higher concentration of auxin, which leads to enhanced apical growth. This connection is explained by the requirement of zinc for tryptophan synthesis, which serves as a precursor for auxin, as highlighted by Kumar et al., (2015). These results also align with the study by Rathore and Chandra (2003), who noted that zinc is involved in tryptophan synthesis, serving as a precursor for the synthesis of IAA. This, in turn, promotes tissue growth and development, as noted by Swietlik (2010).

For open field condition, Data present in Table 4.1b indicates that, during (2022-23) for first year trial, at 120th DAP, the utmost (12.30 cm) plant height was noticed under treatment T_{15} (150 ppm ZnO + 150 ppm FeO) while the least (9.60 cm) was recorded in the control treatment (T_0). During (2023-24), For the second year trial, at 120th DAP maximum (10.40 cm) plant height was noticed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 10.10 cm under T_9 (50 ppm ZnO + 150 ppm FeO). The minimum (9.10 cm) plant height was recorded under the treatment control (T_0) similar trend was noticed at 30th, 60th and 90th DAP. Pooling the Data for both the years (2022-23 and 2023-24) revealed the utmost (11.36 cm) plant height at 120th DAP was noticed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 11.20 cm under T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (9.35 cm) plant height was recorded under the treatment (T_0).

The zinc significantly facilitates cell division, meristematic growth in apical tissues, and cell enlargement, while actively contributing to the synthesis of new cell walls which ultimately resulting better growth of plant and it is also linked to its role in auxin concentration, enzymatic processes, and cellular development. Similarly, iron plays a crucial role in various enzymatic reactions within the plant, contributing to the synthesis of essential compounds and the regulation of plant growth hormones, ultimately leading to an increase in overall plant height. The observed increase in vegetative growth parameters in the current studies, resulting from the foliar application of iron and zinc, is align with earlier research findings by Dawood *et al.,* (2001); Hafeez *et al.,* (2013); Bakshi *et al.,* (2013); Prasad *et al.,* (2014); Reddy *et al.,* (2021); Raliya *et al.,* (2013) and Nair *et al.,* (2016).

Table 4.1a: Effect of Nano- ZnO and FeO on plant height (cm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions.

Plant Height (cm) (Protected)												
	30 DAP			60 DAP			90 DAP			110 DAP		
Treatments	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_0	3.1	3.2	3.2	4.5	4.1	4.3	6.7	6.7	6.7	9.9	9.7	9.8
T_1	3.8	3.6	3.7	4.7	4.5	4.6	6.9	7.0	7.0	10.5	10.4	10.5
T_2	3.1	3.1	3.1	4.7	4.6	4.7	7.0	6.9	7.0	11.0	10.7	10.9
T_3	3.9	3.9	3.9	4.8	4.5	4.7	7.1	7.2	7.2	11.1	10.6	10.9
T_4	3.8	3.8	3.8	4.9	4.7	4.8	7.1	7.1	7.1	11.5	10.5	11.0
T_5	3.2	3.1	3.2	5.0	4.6	4.8	7.2	7.1	7.2	10.8	10.9	10.9
T_6	3.8	3.7	3.8	4.8	5.0	4.9	6.9	6.9	6.9	10.5	10.8	10.7
T_7	3.8	3.5	3.7	5.4	5.1	5.3	7.0	7.0	7.0	10.9	10.9	10.9
T_8	3.5	3.4	3.5	4.5	5.0	4.8	6.6	6.6	6.6	10.0	10.6	10.3
T_9	3.8	3.8	3.8	5.1	4.9	5.0	6.6	6.6	6.6	11.6	11.7	11.7
T_{10}	4.0	3.9	4.0	5.0	5.2	5.1	6.5	6.5	6.5	10.5	11.1	10.8
T_{11}	3.2	3.5	3.4	5.3	4.9	5.1	7.2	7.2	7.2	11.7	11.5	11.6
T_{12}	3.9	3.6	3.8	4.9	4.8	4.9	6.7	6.7	6.7	10.9	11.0	11.0
T_{13}	3.9	3.4	3.7	4.9	4.3	4.6	6.6	6.6	6.6	10.9	10.8	10.9
T_{14}	3.5	3.6	3.6	4.6	4.8	4.7	6.6	6.6	6.6	10.8	10.8	10.8
T_{15}	3.7	3.4	3.6	5.5	4.9	5.2	7.3	7.4	7.4	12.2	11.9	12.1
C.D.	0.177	0.523	0.400	0.563	0.523	0.543	0.467	0.472	0.470	1.024	0.796	0.910
SE(m)	0.096	0.180	0.138	0.194	0.180	0.187	0.161	0.163	0.162	0.353	0.274	0.314
SE(d)	0.135	0.255	0.195	0.275	0.255	0.265	0.227	0.230	0.229	0.499	0.388	0.444
C.V.	4.548	3.535	4.032	3.781	4.535	4.158	4.053	4.098	4.076	5.593	4.347	4.970

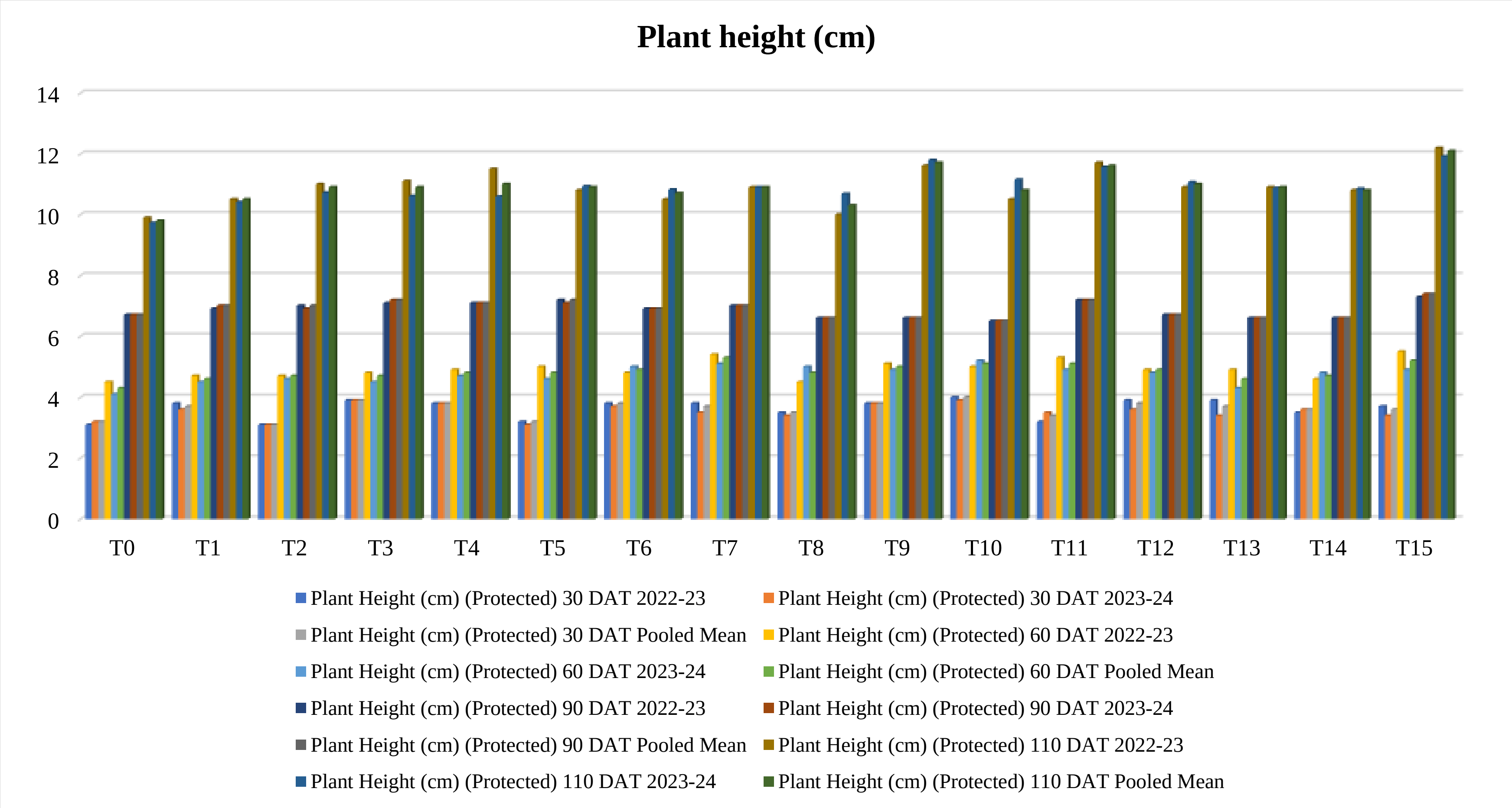

Figure 4.1a: Effect of Nano- ZnO and FeO on plant height (cm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions.

Table 4.1b: Effect of Nano- ZnO and FeO on plant height (cm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions.

Plant Height (cm) (Open field)												
Treatments	30 DAP			60 DAP			90 DAP			110 DAP		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
T_0	3.8	3.3	3.6	4.9	4.1	4.5	6.9	6.4	6.7	9.6	9.1	9.3
T_1	3.8	3.8	3.8	4.9	4.8	4.9	6.9	6.8	6.8	9.9	9.7	9.8
T_2	3.7	3.4	3.6	4.8	4.7	4.7	6.9	6.4	6.6	10.5	9.9	10.2
T_3	3.6	3.7	3.7	4.8	5.1	4.9	6.8	6.8	6.8	10.4	10.1	10.3
T_4	3.5	3.3	3.4	5.0	4.9	5.0	7.1	6.5	6.8	11.7	9.9	10.8
T_5	4.1	3.9	4.0	5.0	4.6	4.8	7.1	6.8	6.9	12.0	9.9	10.9
T_6	4.0	4.1	4.1	4.9	4.7	4.8	7.0	6.5	6.7	11.1	9.8	10.5
T_7	4.3	4.3	4.3	5.0	4.9	5.0	6.9	6.9	6.9	10.2	9.7	10.0
T_8	3.8	3.6	3.7	4.5	4.6	4.6	6.9	6.8	6.8	10.7	9.9	10.3
T_9	4.3	4.3	4.3	4.3	4.6	4.5	6.5	6.4	6.5	12.0	10.1	11.0
T_{10}	4.3	4.2	4.3	4.9	4.9	4.9	7.1	6.7	6.9	10.8	9.9	10.4
T_{11}	4.2	4.3	4.2	5.1	4.9	5.0	6.9	6.9	6.9	12.1	10.3	11.2
T_{12}	4.1	4.4	4.3	4.7	4.9	4.8	7.0	6.7	6.9	10.5	9.9	10.2
T_{13}	4.2	4.5	4.4	4.7	4.8	4.8	6.8	6.7	6.8	10.6	9.5	10.0
T_{14}	3.8	4.2	4.0	4.8	4.7	4.7	7.2	6.9	7.0	11.6	10.1	10.9
T_{15}	4.1	4.0	4.1	5.0	5.0	5.0	7.2	7.0	7.1	12.3	10.4	11.4
C.D.	0.353	0.455	0.404	0.378	0.401	0.390	0.316	0.362	0.339	0.952	0.336	0.644
SE(m)	0.122	0.157	0.140	0.130	0.138	0.134	0.109	0.125	0.117	0.328	0.116	0.222
SE(d)	0.172	0.221	0.197	0.184	0.195	0.190	0.154	0.177	0.166	0.464	0.164	0.314
C.V.	4.289	3.871	4.080	4.660	5.019	4.840	2.713	3.228	2.971	5.171	2.029	3.600

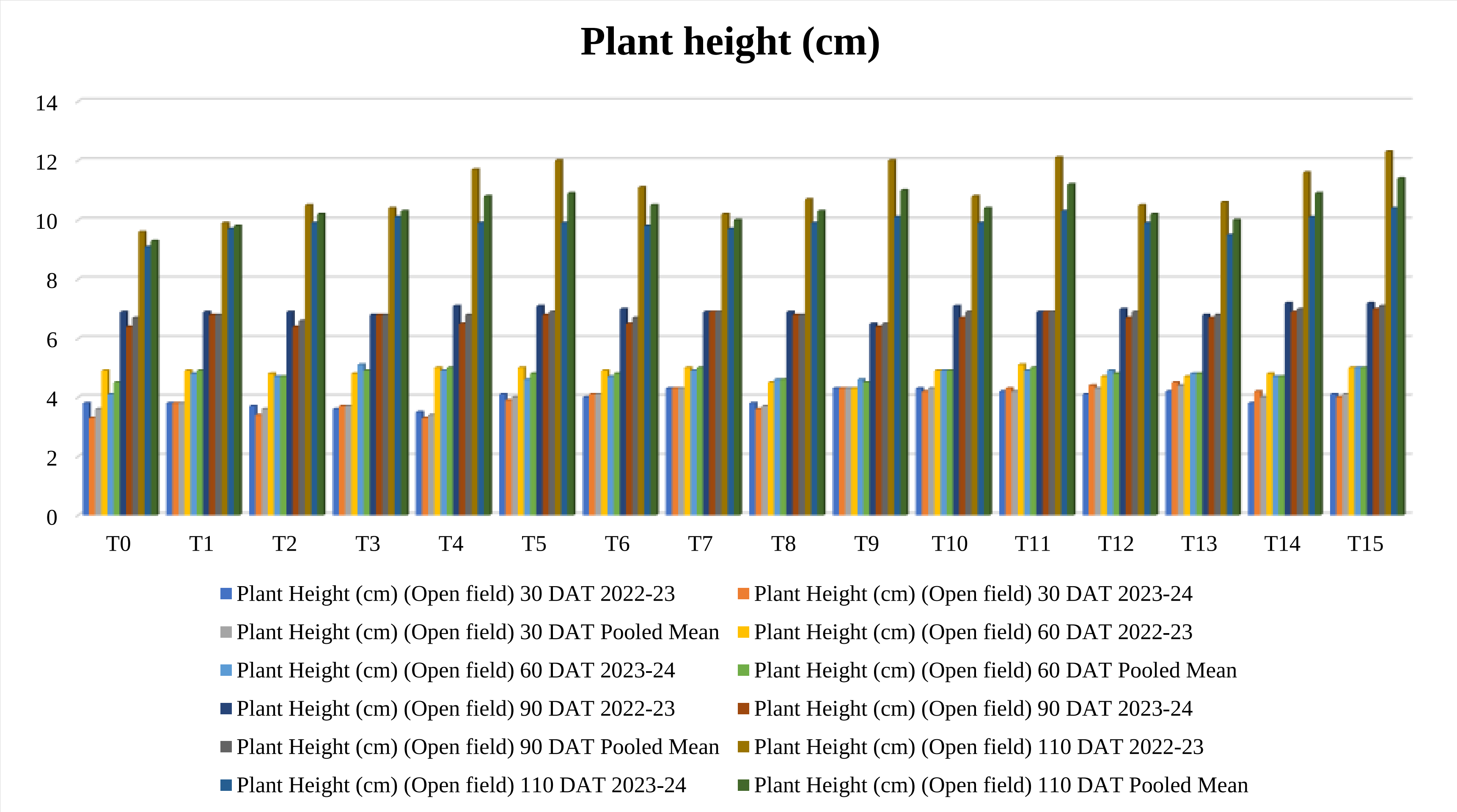

Figure 4.1b: Effect of Nano- ZnO and FeO on plant height (cm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions.

4.1.2 Stem girth (mm):

It is evident from the Table 4.2 that different levels of Nano-ZnO and FeO has a significant influence on stem girth of strawberry plants under protected and open growing conditions. During (2022-23) recorded the maximum (26.62 mm) stem girth under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 24.29 mm under T_{11} (100 ppm ZnO + 100 ppm FeO) against the control treatment (T_0) with the minimum (14.39 mm) stem girth for the first trial. During (2023-24) for the second trial recorded the maximum (24.60 mm) stem girth under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 22.96 mm under T_{10} (100 ppm ZnO + 50 ppm FeO) and minimum (14.98 mm) was observed in control treatment (T_0). Pooling the Data for both the years (2022-23 and 2023-24) recorded the maximum (25.61 mm) stem girth under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 23.35 mm under T_{11} (100 ppm ZnO + 100 ppm FeO) while minimum (14.68 mm) stem girth was observed in control treatment (T_0).

The Data revealed to stem girth presents in Table 4.2, significant variations exist on stem girth under open condition, during (2022-23) recorded the maximum (24.69 mm) stem girth under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 23.67 mm under T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (13.41 mm) stem girth was recorded in control treatment (T_0) for the first year trial. During (2023-24) the maximum (21.35 mm) stem girth was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 20.40 mm under T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (13.34 mm) stem girth was observed in control treatment (T_0). Pooling the Data for both the years (2022-23 and 2023-24) the maximum (23.02 mm) stem girth was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 22.04 mm under T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (13.38 mm) was observed in the control treatment (T_0).

The enhancement in the stem girth of plants through the application of Zn and Fe might be due to the fact that zinc is a crucial cofactor for many enzymes involved in protein synthesis and growth hormone production and iron is essential for the production of chlorophyll, which is crucial for photosynthesis, leading to an overall improvement in girth of plants. These findings underscore the significance of nutrient availability and their role in supporting photosynthetic processes and overall plant growth. Similar studies have been investigated by Khan *et al.,* (2015); Babu *et al.,* (2005); Jat *et al.,* (2014); Khan *et al.,* (2015) and Kumar *et al.,* (2017).

Table 4.2: Effect of Nano- ZnO and FeO on stem girth (mm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions

Stem Girth (mm)						
Treatments	Protected Field Conditions			Open Field Conditions		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
T_0	14.39	14.98	14.68	13.41	13.34	13.38
T_1	17.62	15.67	16.65	15.88	14.51	15.20
T_2	17.99	16.19	17.09	17.47	15.81	16.64
T_3	20.07	18.94	19.51	18.74	17.56	18.15
T_4	20.68	19.45	20.07	20.64	17.70	19.17
T_5	21.96	21.48	21.72	21.19	17.65	19.42
T_6	17.85	19.72	18.79	18.39	17.30	17.85
T_7	22.53	21.10	21.82	21.06	18.82	19.94
T_8	20.00	19.82	19.91	20.74	17.55	19.15
T_9	22.30	21.25	21.78	17.87	18.26	18.07
T_{10}	22.70	22.96	22.83	22.44	18.47	20.46
T_{11}	24.29	22.40	23.35	23.67	20.40	22.04
T_{12}	22.45	22.05	22.25	22.55	19.49	21.02
T_{13}	22.71	21.44	22.08	22.63	19.78	21.21
T_{14}	22.47	20.89	21.68	22.58	19.53	21.06
T_{15}	26.62	24.60	25.61	24.69	21.35	23.02
C.D.	0.263	1.444	0.8515	1.589	1.761	2.175
SE(m)	1.124	1.187	1.156	0.892	0.607	0.750
SE(d)	1.590	1.678	1.634	1.262	0.858	1.060
C.V.	4.285	3.182	3.437	4.633	3.849	3.741

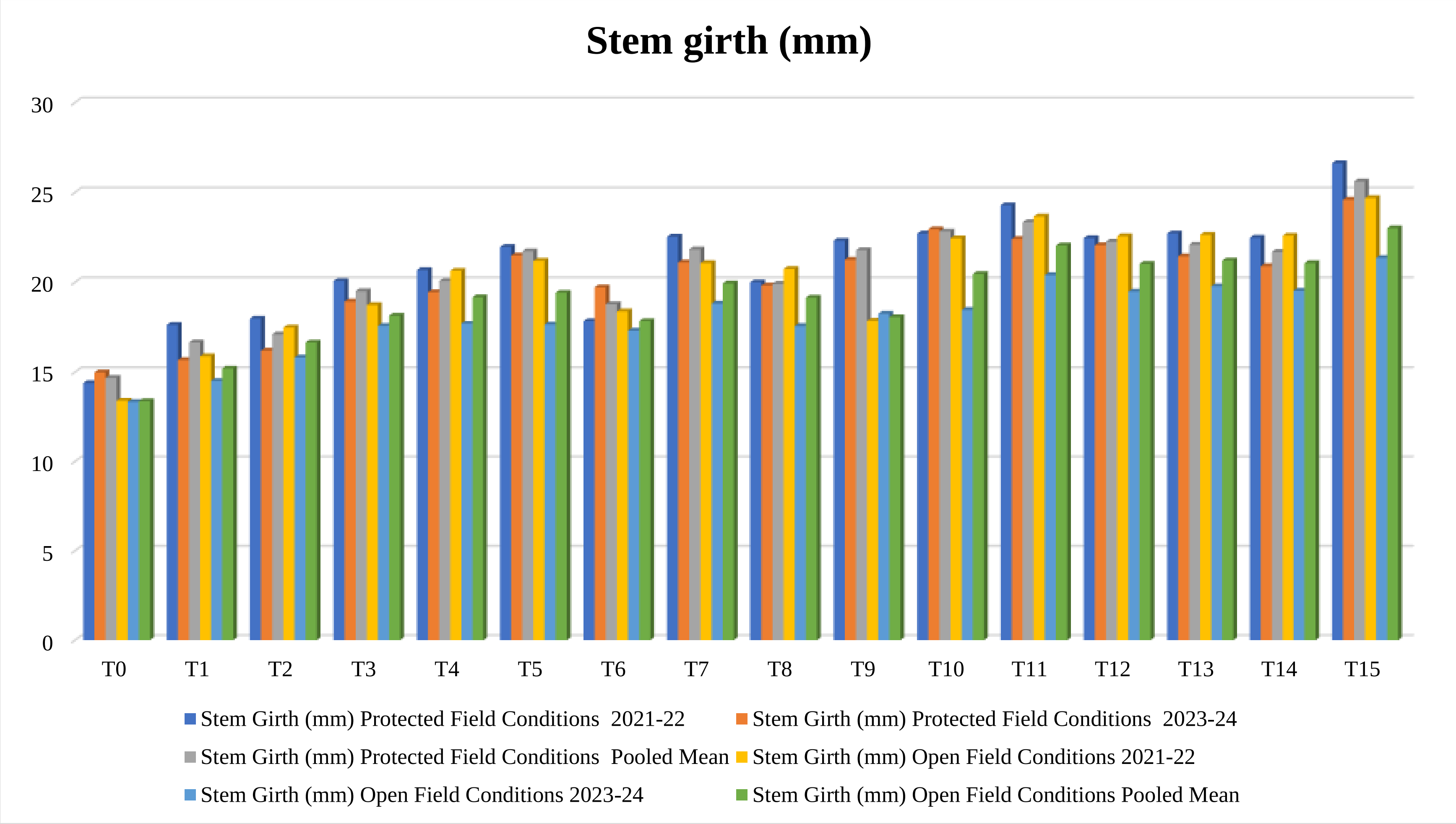

Figure 4.2: Effect of Nano- ZnO and FeO on stem girth (mm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions.

4.1.3 Number of leaves

The Data collected for number of flowers presented in Table 4.3a indicated that, significant variations exist on number of leaves under protected condition and natural growing conditions among all the treatments by the application of different levels of ZnO and FeO. During (2022-23) maximum (15.00) number of leaves were recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) at 110th DAP for first year trial followed by 14.00 under the treatment T_{12} (100 ppm ZnO + 150 ppm FeO) and minimum (9.33) was recorded in T_0 (control). In the second-year trial (2023-24) the maximum (15.00) number of leaves was observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) at 110th DAP, followed by 14.00 under T_{12} (100 ppm ZnO + 150 ppm FeO) and minimum (9.67) number of leaves was recorded in control. Pooling the Data for both the years (2022-23 and 2023-24) revealed maximum (15.00) number of leaves under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) at 110th DAP, followed by 13.83 number of leaves under T_{12} (100 ppm ZnO + 150 ppm FeO) wereas minimum (9.67) number of leaves was noted in T_0 (control).

The study of Table 4.3b revealed that, significant variations exist on number of leaves under open condition among all the treatments by the application of different levels of ZnO and FeO, during (2022-23) maximum (13.00) number of leaves were recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) at 110th DAP, followed by 12.33 number of leaves in T_{13} (100 ppm ZnO + 150 ppm FeO) wereas minimum (10.33) were recorded in control. In the second-year trial (2023-24) maximum number of leaves (13.00) were observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) at 110th DAP, followed by 12.33 number of leaves in T_{10} (100 ppm ZnO + 50 ppm FeO) wereas minimum (9.00) were recorded in T_0 (control). Pooling the Data for both the years (2022-23 and 2023-24) the maximum (13.00) number of leaves were found under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) at 115th DAP, followed by 12.67 number of leaves in T_{13} (150 ppm ZnO + 50 ppm FeO) wereas minimum (9.50) was recorded in T_0 (control).

The combined application of Zn and Fe has a positive impact on the number of leaves which might be due to the involvement of zinc in the synthesis of auxins, particularly indole-3-acetic acid (IAA), a hormone that regulates cell elongation and division. Higher auxin levels promote leaf initiation and expansion, resulting to an increase in leaf numbers and iron is involved in the electron transport chain within chloroplasts, where it facilitates the transfer of electrons during the light-dependent reactions of photosynthesis. Efficient electron transport enhances ATP and NADPH production, providing the energy required for various growth processes, including leaf development resulting in a greater number of leaves per plant. This is obvious when considering that previous research has also shown that Zn and Fe promotes plant growth, supporting the current findings and aligning with the observations of Razzaq *et al.,* (2013); Ullah *et al.,* (2012); Jat *et al.,* (2014); Mishra *et al.,* (2016); Nitin *et al.,* (2012); Raliya *et al.,* (2013) and Pathak *et al.,* (2011).

Table 4.3a: Effect of Nano- ZnO and FeO on number of leaves of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions

Treatments	Number of Leaves (Protected)											
	30 DAP			60 DAP			90 DAP			110 DAP		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_0	2.67	2.33	2.50	5.00	4.67	4.83	6.00	6.00	6.00	9.33	9.67	9.50
T_1	4.00	2.33	3.17	5.67	5.00	5.34	6.33	6.33	6.33	11.33	11.67	11.50
T_2	3.00	2.33	2.67	5.33	5.33	5.33	6.33	6.67	6.50	11.67	11.00	11.34
T_3	3.67	3.00	3.34	5.33	5.67	5.50	6.67	6.33	6.50	12.00	12.00	12.00
T_4	4.33	3.67	4.00	6.33	6.00	6.17	8.00	8.00	8.00	13.00	12.00	12.50
T_5	5.00	2.67	3.84	6.33	6.67	6.50	8.00	8.00	8.00	12.67	13.00	12.84
T_6	4.33	4.67	4.50	5.67	6.33	6.00	6.67	8.67	7.67	12.00	11.67	11.83
T_7	5.67	4.00	4.84	6.33	5.67	6.00	7.00	7.00	7.00	10.33	10.67	10.50
T_8	5.33	3.33	4.33	6.67	6.33	6.50	8.00	8.00	8.00	11.00	10.67	10.83
T_9	5.00	3.00	4.00	7.33	6.67	7.00	8.67	6.67	7.67	13.67	12.67	13.17
T_{10}	3.33	4.00	3.67	5.33	7.00	6.17	7.00	7.67	7.33	11.67	13.33	12.50
T_{11}	5.00	4.00	4.50	6.67	6.00	6.34	7.67	7.67	7.67	13.33	14.00	13.67
T_{12}	4.33	3.67	4.00	5.33	6.67	6.00	7.33	7.33	7.33	14.00	13.67	13.83
T_{13}	5.33	3.67	4.50	6.00	7.00	6.50	7.33	7.33	7.33	13.67	12.00	12.84
T_{14}	4.67	4.00	4.34	5.00	6.67	5.83	8.00	8.00	8.00	12.67	11.33	12.00
T_{15}	4.67	3.67	4.17	7.67	7.33	7.50	9.33	9.00	9.17	15.00	15.00	15.00
C.D.	1.370	1.385	1.378	1.308	1.505	1.407	1.358	1.358	1.358	1.851	1.674	1.763
SE(m)	0.472	0.477	0.475	0.451	0.519	0.485	0.468	0.468	0.468	0.638	0.577	0.608
SE(d)	0.667	0.675	0.671	0.638	0.733	0.686	0.662	0.662	0.662	0.902	0.816	0.859
C.V.	4.590	3.243	3.827	3.014	4.518	3.766	2.959	3.928	3.443	4.959	5.228	5.094

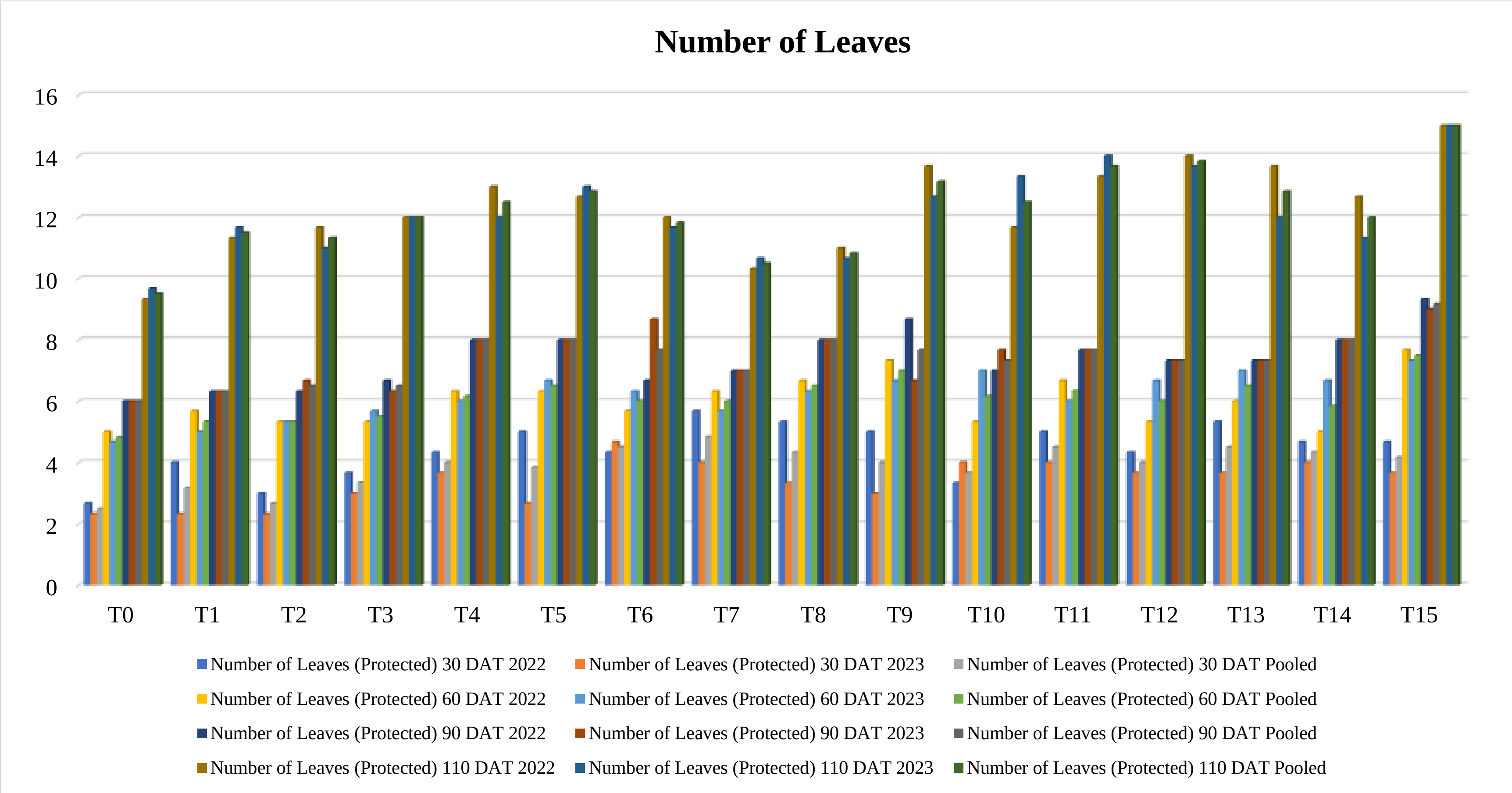

Figure 4.3a: Effect of Nano- ZnO and FeO on the number of leaves of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions.

Table 4.3b: Effect of Nano- ZnO and FeO on Number of leaves of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions

Treatments	Number of Leaves (Open)											
	30 DAP			60 DAP			90 DAP			110 DAP		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_0	4.33	3.67	4.00	6.67	4.67	5.67	8.00	7.33	7.67	10.00	9.00	9.50
T_1	5.67	3.33	4.50	6.67	5.33	6.00	8.67	8.67	8.67	11.33	11.00	11.17
T_2	5.00	3.67	4.34	7.33	6.33	6.83	9.00	7.67	8.34	11.67	11.00	11.34
T_3	5.33	5.33	5.33	7.00	6.33	6.67	9.00	8.67	8.84	12.00	12.00	12.00
T_4	6.00	5.00	5.50	7.00	6.33	6.67	9.33	8.67	9.00	12.00	12.00	12.00
T_5	6.33	3.67	5.00	7.67	6.67	7.17	9.00	8.67	8.84	12.00	12.00	12.00
T_6	6.00	5.67	5.84	7.00	6.33	6.67	9.33	8.33	8.83	11.67	12.00	11.84
T_7	7.00	5.00	6.00	8.67	6.67	7.67	10.67	8.33	9.50	13.00	12.00	12.50
T_8	6.00	5.00	5.50	6.67	6.33	6.50	9.00	8.33	8.67	11.33	11.00	11.17
T_9	6.67	4.00	5.34	7.67	6.33	7.00	9.67	8.67	9.17	13.00	12.00	12.50
T_{10}	4.00	5.33	4.67	6.67	6.33	6.50	9.67	9.00	9.34	11.67	12.33	12.00
T_{11}	5.67	5.67	5.67	7.67	7.67	7.67	9.33	8.67	9.00	12.00	12.00	12.00
T_{12}	6.67	5.67	6.17	6.67	6.33	6.50	8.00	8.33	8.17	10.00	12.00	11.00
T_{13}	6.67	5.00	5.84	6.33	6.33	6.33	8.33	8.67	8.50	12.33	13.00	12.67
T_{14}	5.33	5.00	5.17	7.33	6.67	7.00	8.00	8.67	8.34	11.33	12.00	11.67
T_{15}	5.00	5.00	5.00	8.00	7.33	7.67	9.67	9.67	9.67	13.00	13.00	13.00
C.D.	1.203	1.347	1.275	1.266	0.993	1.130	1.274	0.959	1.117	1.381	1.575	1.478
SE(m)	0.414	0.464	0.439	0.436	0.342	0.389	0.439	0.331	0.385	0.476	0.543	0.510
SE(d)	0.586	0.656	0.621	0.617	0.484	0.551	0.621	0.467	0.544	0.673	0.767	0.720
C.V.	2.529	3.919	3.224	4.512	3.299	3.906	3.407	4.719	4.063	3.650	3.985	3.817

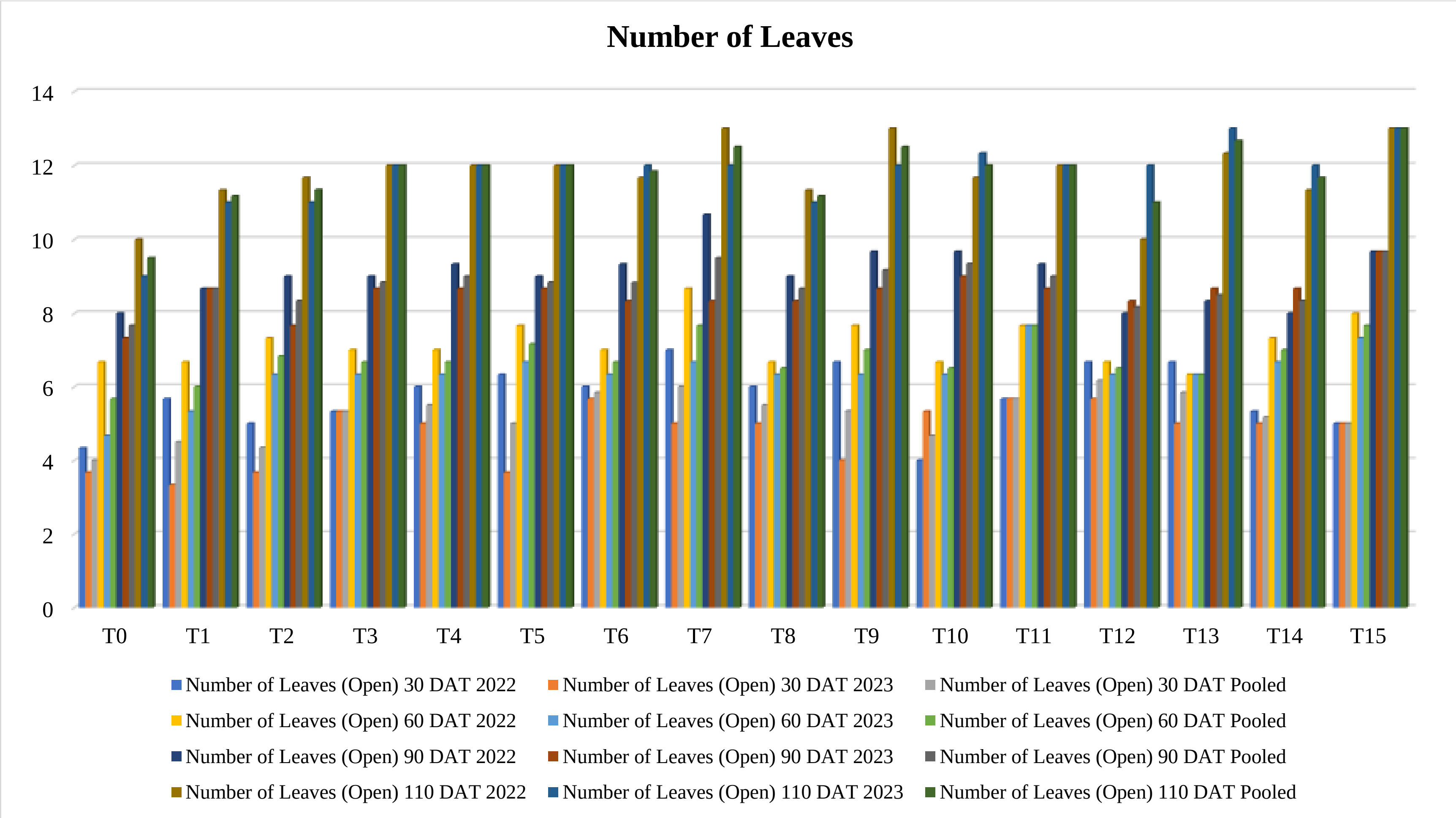

Figure 4.3b: Effect of Nano- ZnO and FeO on Number of leaves of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions

4.1.4 Leaf length (cm)

The Data related to leaf length presented in Table 4.4 indicated significant variations among various treatments with the application of Nano-ZnO and FeO at different concentrations to strawberry plants. During (2022-23) maximum (5.71 cm) leaf length was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 5.42 cm under T_{12} (100 ppm ZnO + 150 ppm FeO) wereas minimum (3.29cm) was recorded under control. In second-year trial (2023-24) maximum (5.37 cm) leaf length was observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 5.23 cm under treatment T_{12} (100 ppm ZnO + 150 ppm FeO) and minimum (3.13 cm) was recorded in control. Pooling the Data for both the years recorded maximum (5.53 cm) leaf length under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 5.3 cm under T_{12} (100 ppm ZnO + 150 ppm FeO) and minimum (3.2 cm) leaf length was found under the treatment T_0 (control).

The Data on leaf length presented in Table 4.4 under natural growing conditions and represented graphically under Figure 4.4 revealed that for first-year trial (2022-23) maximum (5.73 cm) leaf length was recorded under treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 5.27 cm under T_{14} (150 ppm ZnO + 100 ppm FeO) wereas minimum (3.13 cm) leaf length in control. In the second-year trial (22023-24) maximum (5.07 cm) leaf length was noted under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed 4.87 cm in T_{14} (150 ppm ZnO + 100 ppm FeO) wereas minimum (3.43 cm) leaf length was observed under control. Pooling the Data for both the years (2022-23 and 2023-24) revealed maximum (5.40 cm) leaf length was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 5.07 cm in T_{14} (150 ppm ZnO + 100 ppm FeO) wereas minimum (3.28 cm) leaf length recorded in control.

The zinc involved to stabilize the structure of ribosomes and cellular membranes, ensuring proper protein synthesis and membrane function and plays a key role in maintaining cell division and elongation, which likely explains the observed increase in leaf length while iron acts as a cofactor for enzymes involved in nitrogen fixation and assimilation, enhancing nitrogen metabolism and protein synthesis, both crucial for cell growth and division, which may also contribute to the increase in leaf length. The application of Zn and Fe improves the physical, chemical, and biological conditions of the soil, leading to better plant growth. This is obvious when considering that these findings are supported by the work of Ram *et al.,* (2008); Rathore *et al.,* (2003); Tariq *et al.,* (2007); Saini *et al.,* (2021) and Verma *et al.,* (2013) aligning with their research on the effects of these elements on plant growth.

Table 4.4: Effect of Nano- ZnO and FeO on Leaf length (cm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open field conditions

Leaf length (cm)						
Treatments	**Protected Field Conditions**			**Open Field Conditions**		
	2022-23	**2023-24**	**Pooled Mean**	**2022-23**	**2023-24**	**Pooled Mean**
T_{0}	3.30	3.13	3.22	3.13	3.43	3.28
T_{1}	3.57	3.43	3.50	3.47	3.70	3.59
T_{2}	3.90	3.77	3.83	3.90	4.00	3.95
T_{3}	4.20	4.00	4.10	4.13	4.03	4.08
T_{4}	3.83	4.00	3.92	4.23	4.13	4.18
T_{5}	4.53	4.40	4.47	4.07	3.90	3.99
T_{6}	4.60	4.23	4.42	4.43	3.63	4.03
T_{7}	4.47	4.33	4.40	4.93	4.57	4.75
T_{8}	4.57	4.27	4.42	4.53	4.30	4.42
T_{9}	5.17	4.90	5.04	5.03	4.70	4.87
T_{10}	5.40	4.67	5.03	5.00	4.67	4.84
T_{11}	4.83	5.20	5.02	5.10	4.90	5.00
T_{12}	5.43	5.23	5.33	4.80	4.53	4.67
T_{13}	4.37	4.53	4.45	4.57	4.53	4.55
T_{14}	4.77	4.67	4.72	5.27	4.87	5.07
T_{15}	5.70	5.37	5.53	5.73	5.07	5.40
C.D.	0.747	0.771	0.759	0.681	0.561	0.621
SE(m)	0.257	0.266	0.262	0.235	0.193	0.214
SE(d)	0.364	0.376	0.370	0.332	0.273	0.303
C.V.	7.823	7.494	7.658	8.984	7.765	8.375

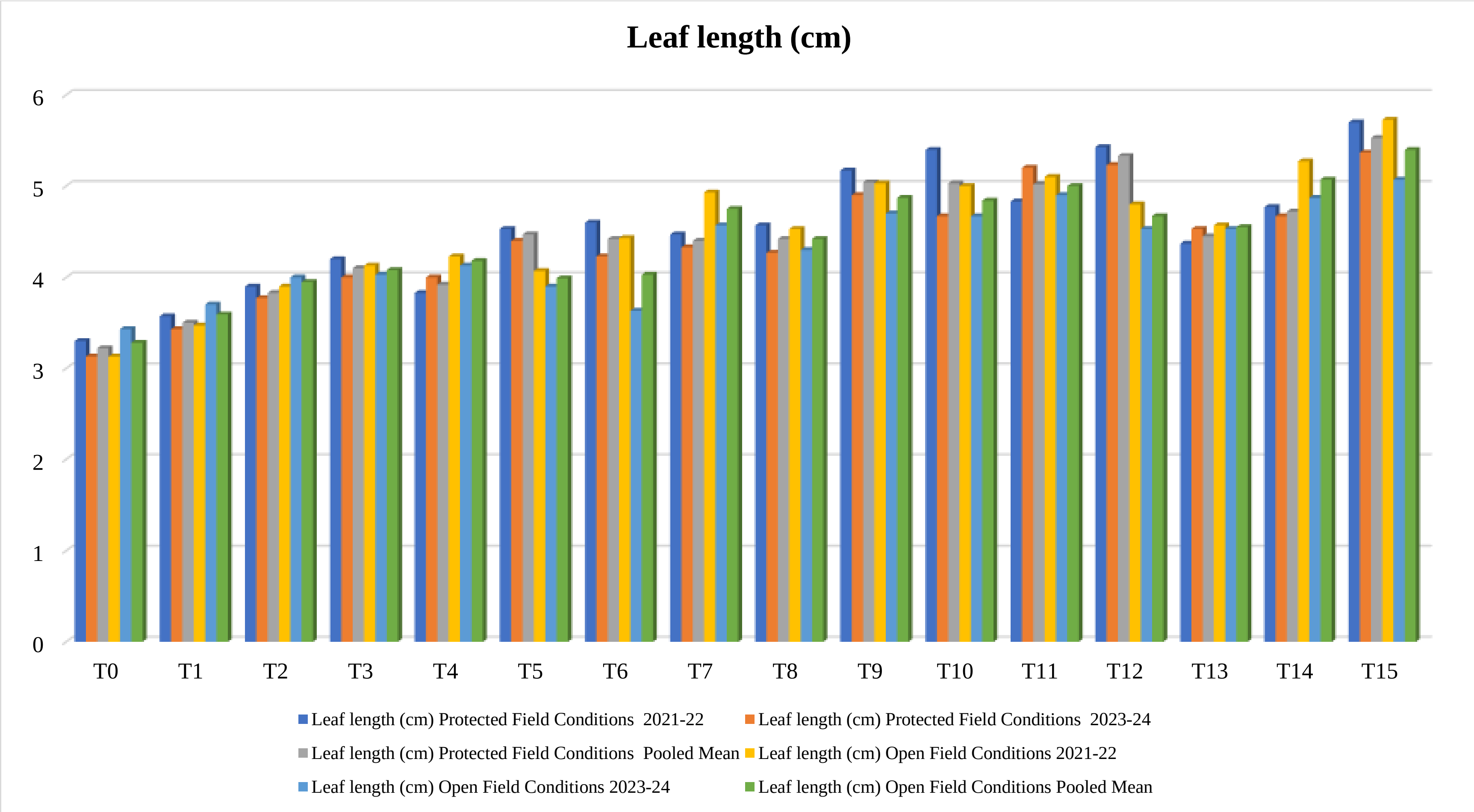

Figure 4.4: Effect of Nano- ZnO and FeO on Leaf length (cm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open field conditions

4.1.5 Petiole length (mm)

The results pertaining to the effect of ZnO and FeO on petiole length elaborated in the Table 4.5 revealed significant variations among the treatments under protected and natural field conditions, during (2022-23) the maximum (9.60 cm) petiole length was recorded under the treatment T_{10} (100 ppm ZnO + 50 ppm FeO) followed by 9.41 cm in T_{15} (150 ppm ZnO + 150 ppm FeO) wereas the minimum (7.28 cm) petiole length was observed in T_0 (control) for the first year trial. During the second-year trial (2023-24) it was observed that maximum (9.30 cm) petiole length was observed in treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by T_{11} (100 ppm ZnO + 100 ppm FeO) wereas minimum (6.93 cm) was observed under the treatment T_0 (control). Pooling the Data for both the years (2022-23 and 2023-24) revealed the maximum (9.36 cm) petiole length in T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 9.27 cm in T_{10} (100 ppm ZnO + 50 ppm FeO) wereas minimum (7.11 cm) petiole length under T_0 (control).

The Data on petiole length (cm) under natural field conditions by application of different levels of ZnO and FeO showed significant variation tabulated in Table 4.5 and represented graphically in Figure 4.5. For first-year trial (2022-23) maximum (9.3 cm) petiole length under T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 9.2 cm in T_{11} (100 ppm ZnO + 100 ppm FeO). The control treatment T_0 recorded the minimum petiole length of 7.1 cm. In the second-year trial (2023-24) recorded the maximum (9.0 cm) petiole length under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 8.9 cm in T_{11} (100 ppm ZnO + 100 ppm FeO) wereas minimum (6.8cm) petiole lemgth in T_0. Pooling the Data for both the years (2022-23 and 2023-24) revealed the maximum petiole length (9.17 cm) under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed 9.05 cm in T_{11} (100 ppm ZnO + 100 ppm FeO). The minimum (6.92 cm) length of petiole was observed under the treatment T_0 (control).

The synthesis of enzymes such as carbonic anhydrase, superoxide dismutase, and dehydrogenase alcohol, which require zinc for activation and contribute to various metabolic processes that influence plant growth, including photosynthesis, respiration, and stress response ultimately leading to prolong length of petiole along with that adequate zinc levels ensure optimal auxin synthesis, promoting cell elongation and expansion. Iron is a crucial component of various respiratory enzymes, including cytochrome oxidase, which plays a role in cellular respiration. Efficient respiration ensures sufficient energy production in the form of ATP, supporting active growth processes like cell division resulting in elongation in the petiole. These results are in accordance with the findings of Taha *et al.,* (2017); Maurya *et al.,* (2016); Naderi *et al.,* (2013); Obaid *et al.,* (2013); Raliya *et al.,* (2013); Saini *et al.,* (2021) and Shen *et al.,* (2013).

Table 4.5: Effect of Nano- ZnO and FeO on Petiole length (cm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open field conditions

Petiole length (cm)						
Treatments	Protected Field Conditions			Open Field Conditions		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
T_0	7.27	6.93	7.10	7.03	6.77	6.90
T_1	6.33	6.67	6.50	7.03	7.27	7.15
T_2	7.47	7.40	7.44	7.43	7.43	7.43
T_3	7.20	7.33	7.27	7.37	7.10	7.24
T_4	7.63	7.07	7.35	7.43	7.23	7.33
T_5	7.50	7.10	7.30	8.37	7.50	7.94
T_6	7.50	7.33	7.42	7.43	7.67	7.55
T_7	8.23	8.20	8.22	7.60	7.43	7.52
T_8	8.33	7.53	7.93	8.07	7.47	7.77
T_9	8.43	8.00	8.22	8.77	8.60	8.69
T_{10}	9.57	8.93	9.25	8.07	8.00	8.04
T_{11}	9.27	9.20	9.24	9.23	8.87	9.05
T_{12}	8.27	8.37	8.32	8.37	8.13	8.25
T_{13}	8.87	8.63	8.75	8.67	8.37	8.52
T_{14}	9.10	8.60	8.85	8.47	8.67	8.57
T_{15}	9.43	9.30	9.37	9.33	9.00	9.17
C.D.	1.140	1.065	1.103	0.899	0.523	0.711
SE(m)	0.393	0.367	0.380	0.310	0.180	0.245
SE(d)	0.555	0.519	0.537	0.438	0.255	0.347
C.V.	4.346	4.033	4.190	4.671	3.976	4.294

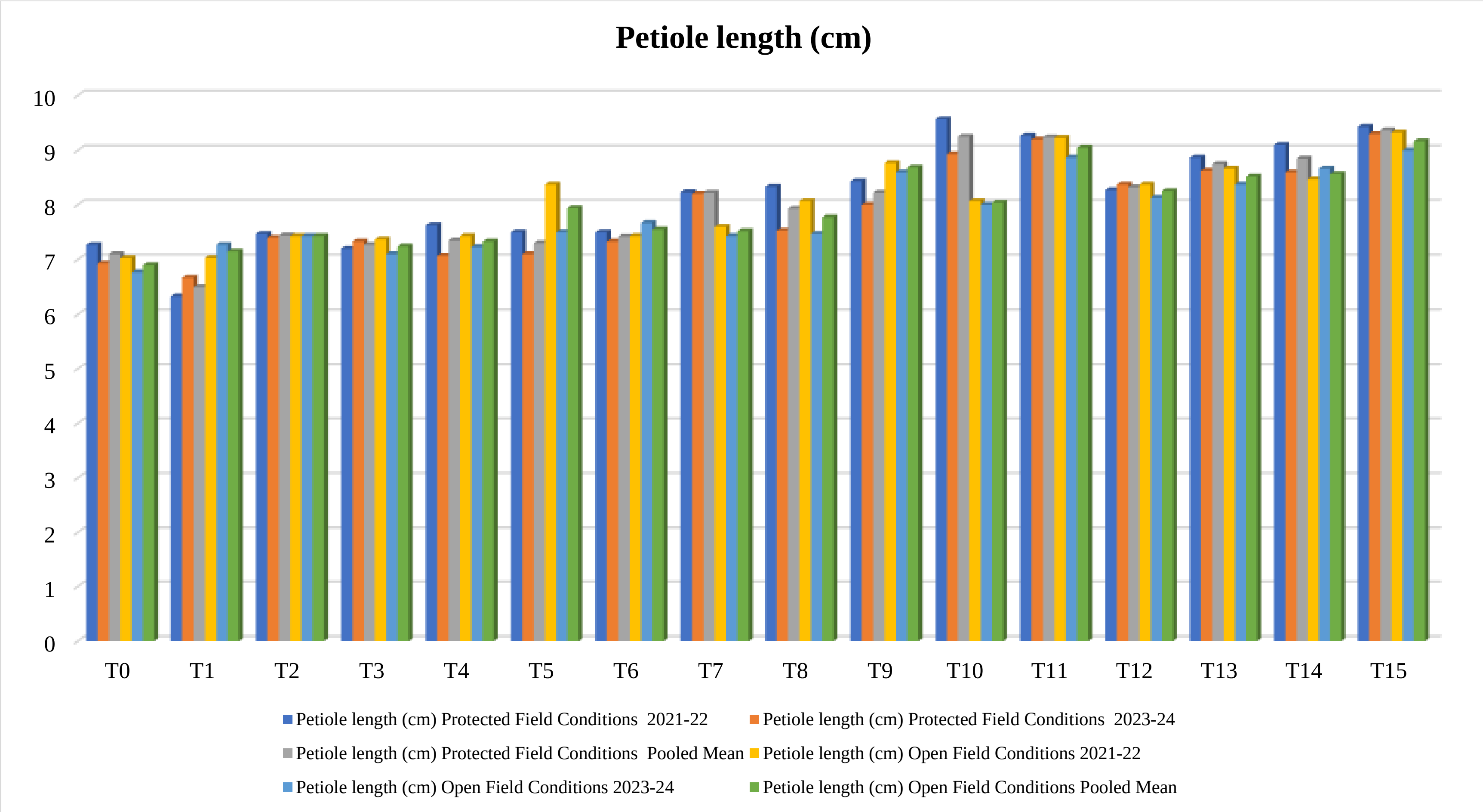

Figure 4.5: Effect of Nano- ZnO and FeO on Petiole length (cm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open field conditions

4.1.6 Leaf area (cm^2)

The study of the Table 4.6 indicated that, Data on leaf area of the plants had significant variation among the treatments with the application of ZnO and FeO, during (2022-23) maximum (73.11 cm^2) leaf area was recorded under in T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 72.12 cm^2 in T_{10} (100 ppm ZnO + 50 ppm FeO). The minimum value (68.62 cm^2) was noticed under the treatment T_0 (control) for the first year trial. In the second year (2023-24) maximum (71.60 cm^2) leaf area was observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 71.26 cm^2 in T_{11} (100 ppm ZnO + 100 ppm FeO). The minimum (65.34 cm^2) leaf area was observed in T_0 (control). Pooling Data of both the years (2022-23 and 2023-24) revealed maximum leaf area (72.36 cm^2) under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 71.23 cm^2 in T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (66.98 cm^2) leaf area was found under treatment T_0 (control).

Significant variations were found among the treatments regarding leaf area (cm^2) (Table 4.6) of plants under open field conditions with the foliar application of ZnO and FeO at different concentrations. For first year trial maximum (74.87 cm^2) leaf area was observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 71.19 cm^2 in T_{11} (100 ppm ZnO + 100 ppm FeO) wereas minimum (72.12 cm^2) leaf area was recorded in T_0 (control). For the second-year trial (2023-24) maximum (74.23 cm^2) leaf area was recorded in treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 73.48 cm^2 in T_{11} (100 ppm ZnO + 100 ppm FeO) wereas minimum (71.26 cm^2) leaf area was recorded in T_0 (control). Pooling the Data for both the years (2022-23 and 2023-24) revealed maximum (74.55 cm^2) leaf area was recorded under T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 74.25 cm^2 in T_3 (150ppm ZnO) and minimum (71.69 cm^2) leaf area was recorded under T_0 (control).

It is obvious that zinc plays a key role in the synthesis of tryptophan, which is known as a precursor of the hormone auxin, which promotes cell elongation and division which might be helpful for inehancing the leaf area while iron is essential for chlorophyll synthesis and electron transport in photosynthesis. Adequate levels of these micronutrients improve chlorophyll content and overall photosynthetic efficiency, leading to increased leaf area and higher LAI. Similar findings were reported by Sharma *et al.,* (2009); Abdollah *et al.,* (2010); Bagali *et al.,* (1993); Raliya *et al.,* (2013) and Malik *et al.,* (2000).

Table 4.6: Effect of Nano- ZnO and FeO on Leaf area (cm²) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open field conditions.

Leaf Area (cm²)						
	Protected Field Conditions			Open Field Conditions		
Treatments	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
T_0	68.62	65.34	66.98	72.12	71.26	71.69
T_1	69.75	69.08	69.42	72.90	72.51	72.71
T_2	69.90	67.82	68.86	73.54	72.35	72.95
T_3	70.41	67.26	68.84	74.60	73.89	74.25
T_4	71.37	67.89	69.63	71.78	72.51	72.15
T_5	71.92	68.74	70.33	74.59	72.38	73.49
T_6	70.00	68.02	69.01	73.89	71.59	72.74
T_7	69.51	67.86	68.69	73.70	72.36	73.03
T_8	69.94	68.16	69.05	73.64	71.41	72.53
T_9	70.30	69.63	69.97	74.09	72.40	73.25
T_{10}	72.12	70.11	71.12	70.65	71.49	71.07
T_{11}	71.19	71.26	71.23	74.19	73.48	73.84
T_{12}	70.02	69.96	69.99	71.42	72.23	71.83
T_{13}	69.93	69.59	69.76	72.66	72.42	72.54
T_{14}	71.55	69.61	70.58	73.54	72.12	72.83
T_{15}	73.11	71.60	72.36	74.87	74.23	74.55
C.D.	1.160	2.553	1.857	1.456	1.574	1.515
SE(m)	0.400	0.880	0.640	0.502	0.542	0.522
SE(d)	0.565	1.244	0.905	0.710	0.767	0.739
C.V.	0.980	2.212	1.596	1.186	1.298	1.242

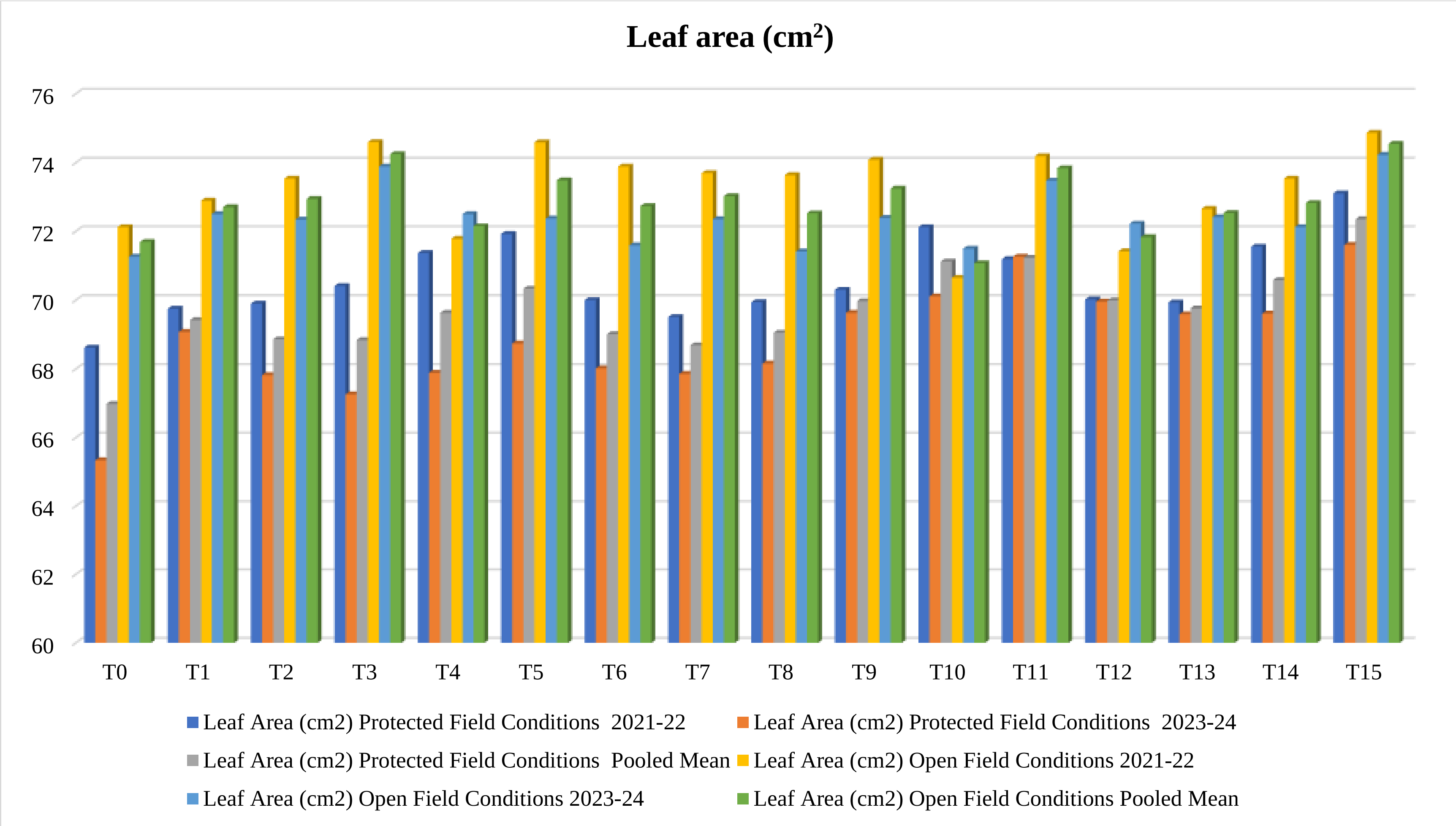

Figure 4.6: Effect of Nano- ZnO and FeO on Leaf area (cm^2) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open field conditions

4.1.7 Plant spread

The Data pertaining to effects of different levels of ZnO and FeO on plant spread presented in Table 4.7a and represented graphically in Figure 4.7a indicated that significant variations were observed among all the treatments. During (2022-23), the maximum (22.99 cm) plant spread at 120th DAP was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 22.55 cm in T_9 (50 ppm ZnO + 150 ppm FeO) wereas minimum (20.77 cm) plant spread was found in T_0 (control) for the first year trial. In the second-year trial (2023-24), the maximum (22.85 cm) plant spread at 120th DAP was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 22.60 cm in T_{11} (100 ppm ZnO + 100 ppm FeO).

Pooling the Data for both the years (2022-23 and 2023-24) at 120th DAP observations revealed the maximum spread of plant (22.92 cm) in the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 22.45 cm in T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (20.49 cm) plant spread was recorded under T_0 (control).

The Data presented to plant spread in Table 4.7b indicated that significant varitions were found among the treatments, during (2022-23) at 120th DAP, the maximum (23.10 cm) plant spread was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 22.83 cm in T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (21.20 cm) plant spread was obtained under T_0 (control). In the second-year trial (2023-24) at 120th DAP, the maximum (23.20 cm) plant spread was observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 22.83 cm in T_3 (150 ZnO).

Pooling the Data for both the years (2022-23 and 2023-24) observations revealed maximum (23.15 cm) plant spread at 120th DAP was noted under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 22.69 cm in T_{11} (100 ppm ZnO + 100 ppm FeO) wereas the minimum (20.65 cm) was observed in the treatment control (T_0).

The zinc enhances the plant spread in strawberries through several key physiological mechanisms by the synthesis of auxins, which are essential for cell division and elongation, potentially leading to increased plant spread. It also appears to enhance chlorophyll synthesis, thereby improving photosynthetic efficiency while, iron being vital for chlorophyll production, acts as a cofactor in various enzymatic reactions within the photosynthetic pathway. Together, these micronutrients seem to boost the plant's metabolic activities, resulting in increased vegetative growth and a more extensive plant spread. These findings align with previous studies emphasizing the importance of Zn and Fe to optimizing plant growth and development, consistent with the observations of Marschner *et al.,* (2012); Adhikari *et al.,* (2015); Bhoyar *et al.,* (2016); Kazemi *et al.,* (2014); Nitin *et al.,* (2012) and Pathak *et al.,* (2011).

Table 4.7a. Effect of Nano- ZnO and FeO on Plant Spread (cm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions

Plant Spread (cm) (Protected)												
Treatments	**30 DAP**			**60 DAP**			**90 DAP**			**110 DAP**		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**2022-23**
T_0	7.50	7.47	7.49	10.07	10.01	10.04	15.88	15.50	15.69	20.77	20.21	20.49
T_1	7.60	7.30	7.45	10.26	10.34	10.30	16.21	16.14	16.18	21.40	20.82	21.11
T_2	7.66	7.36	7.51	10.30	10.42	10.36	16.48	16.45	16.47	21.48	21.23	21.36
T_3	7.80	7.47	7.64	10.36	10.29	10.33	16.55	16.32	16.44	21.77	21.36	21.57
T_4	7.72	7.41	7.57	10.42	10.43	10.43	16.84	16.74	16.79	22.10	21.77	21.94
T_5	7.79	7.72	7.76	10.43	10.54	10.49	16.87	16.65	16.76	22.19	21.66	21.93
T_6	7.57	7.74	7.66	10.27	10.26	10.27	16.42	16.39	16.41	21.44	21.76	21.60
T_7	7.24	7.25	7.25	10.52	10.73	10.63	16.37	16.06	16.22	21.64	21.48	21.56
T_8	7.58	7.42	7.50	10.15	10.54	10.35	16.10	16.74	16.42	21.00	22.07	21.54
T_9	6.34	7.22	6.78	10.53	10.77	10.65	16.35	16.47	16.41	22.55	21.84	22.20
T_{10}	7.83	7.76	7.80	10.62	10.76	10.69	17.24	17.33	17.29	22.23	21.90	22.07
T_{11}	7.80	7.56	7.68	10.92	10.80	10.86	17.35	17.93	17.64	22.29	22.60	22.45
T_{12}	7.94	7.80	7.87	10.67	10.57	10.62	16.86	17.45	17.16	22.26	22.42	22.34
T_{13}	7.96	7.61	7.79	10.52	10.59	10.56	16.74	16.94	16.84	21.98	21.86	21.92
T_{14}	7.43	7.51	7.47	10.45	10.55	10.50	17.58	17.91	17.75	22.33	22.12	22.23
T_{15}	7.96	7.57	7.77	11.02	10.85	10.94	17.96	17.98	17.97	22.99	22.85	22.92
C.D.	0.176	0.237	0.207	0.447	0.240	0.344	0.790	0.416	0.603	0.950	0.178	0.564
SE(m)	0.061	0.082	0.072	0.154	0.083	0.119	0.272	0.143	0.208	0.327	0.061	0.194
SE(d)	0.086	0.116	0.101	0.218	0.117	0.168	0.385	0.203	0.294	0.463	0.087	0.275
C.V.	1.381	1.885	1.633	2.548	1.359	1.954	2.816	1.477	2.147	2.590	0.488	1.539

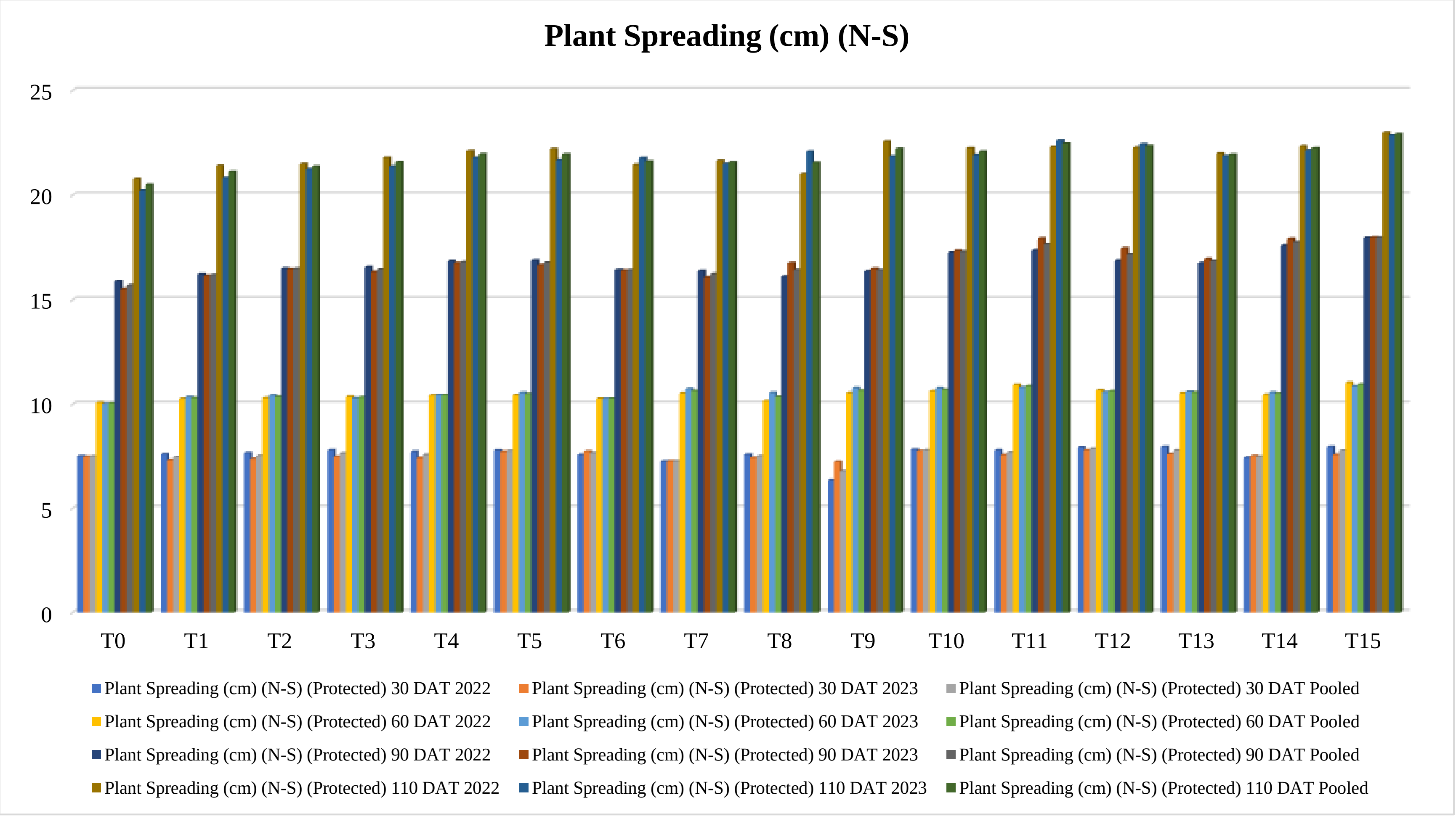

Figure 4.7a: Effect of Nano- ZnO and FeO on Plant Spread (cm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions

Table 4.7b: Effect of Nano- ZnO and FeO on plant spread (cm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions

Plant Spread (cm) (Open)												
Treatments	**30 DAP**			**60 DAP**			**90 DAP**			**110 DAP**		
	2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_0	7.27	6.90	7.08	9.57	7.53	8.55	15.03	13.90	14.47	21.20	20.10	20.65
T_1	7.63	6.87	7.25	10.03	8.00	9.02	16.23	15.54	15.89	21.43	22.00	21.72
T_2	7.37	7.03	7.20	10.27	8.70	9.48	16.30	15.76	16.03	21.90	22.20	22.05
T_3	7.27	7.20	7.23	10.57	8.73	9.65	16.57	15.58	16.08	22.23	22.83	22.53
T_4	7.37	6.83	7.10	10.67	9.63	10.15	16.97	16.62	16.79	22.40	22.10	22.25
T_5	7.77	6.93	7.35	10.54	9.70	10.12	16.87	16.37	16.62	22.60	21.83	22.22
T_6	7.40	6.97	7.19	10.60	8.90	9.75	16.70	16.47	16.59	22.73	21.97	22.35
T_7	7.50	7.17	7.34	10.78	8.70	9.74	16.87	16.41	16.64	22.77	22.07	22.42
T_8	7.73	7.07	7.40	10.43	9.00	9.72	16.93	16.64	16.79	21.90	22.07	21.99
T_9	7.50	6.90	7.20	10.44	9.72	10.08	16.76	16.65	16.70	22.27	22.07	22.17
T_{10}	7.60	7.00	7.30	10.68	10.05	10.36	16.67	16.23	16.45	22.53	22.27	22.40
T_{11}	7.50	6.87	7.19	10.70	10.15	10.43	16.97	16.89	16.93	22.83	22.57	22.70
T_{12}	7.37	6.90	7.13	10.60	9.67	10.14	16.63	16.13	16.38	22.15	22.33	22.24
T_{13}	7.70	7.10	7.40	10.57	9.70	10.13	16.97	16.66	16.81	22.39	22.27	22.33
T_{14}	7.33	7.00	7.17	10.97	9.95	10.46	16.90	16.58	16.74	22.07	22.00	22.03
T_{15}	7.60	6.90	7.25	11.24	10.23	10.73	17.60	17.34	17.47	23.10	23.20	23.15
C.D.	0.157	0.220	0.188	0.713	0.353	0.533	0.692	0.873	0.783	0.970	0.365	0.668
SE(m)	0.179	0.076	0.128	0.246	0.121	0.184	0.239	0.301	0.270	0.334	0.126	0.230
SE(d)	0.253	0.107	0.180	0.347	0.172	0.260	0.337	0.425	0.381	0.473	0.178	0.326
C.V.	4.135	1.884	3.010	4.037	2.269	3.153	2.477	3.209	2.843	2.599	0.984	1.792

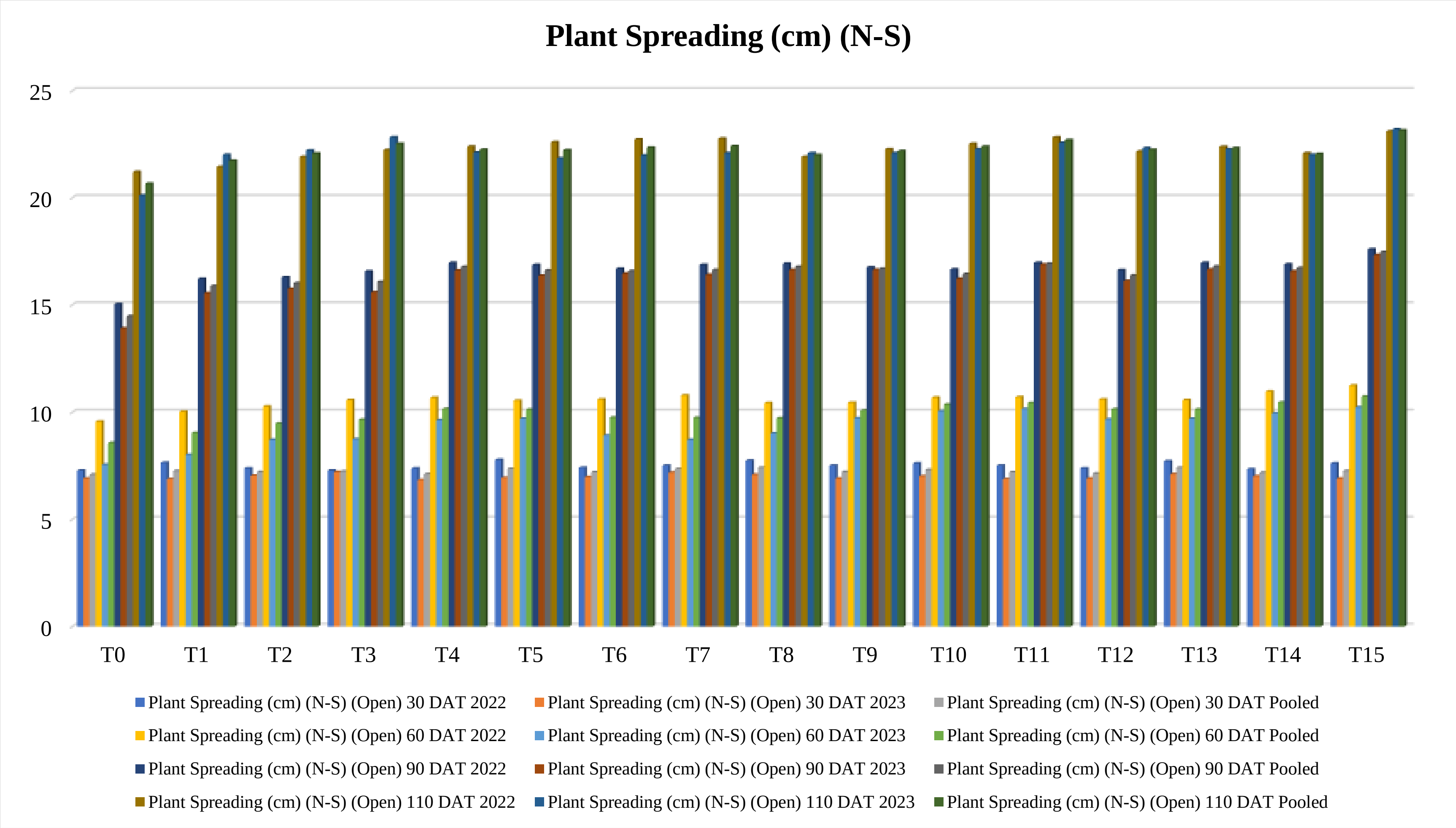

Figure 4.7b: Effect of Nano- ZnO and FeO on plant spreading (cm) (N-S) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions.

4.1.8 Plant spread

The study of the Table 4.8a revealed that significant variations were found among all the treatments with the application of Nano-ZnO and FeO at various concentrations in strawberry plants. During (2022-23) maximum (23.18 cm) plant spread at 120th DAP was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 23.50 cm in T_{10} (100 ppm ZnO + 50 ppm FeO) wereas minimum (21.98 cm) plant spread was recorded under the treatment T_0 (control). In the second-year trial (2023-24), the maximum (23.10 cm) plant spread EW at 120th DAP was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 22.94 cm in T_{11} (100 ppm ZnO + 100 ppm FeO).

Combining the pooled Data for both the years (2022-23 and 2023-24) the maximum (23.14 cm) plant spread at 120th DAP was noticed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 22.97 cm in T_{14} (150 ppm ZnO + 100 ppm FeO) wereas minimum (21.86 cm) was obtained under the treatment control (T_0).

The Data on plant spread under open conditions presented in Table 4.8b and represented graphically in Figure 4.8b revealed that for first year trial (2022-23) maximum (23.13 cm) plant spread at 120th DAP, the was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 22.85 cm under T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (21.42 cm) was recorded in the treatment T_0 (control). The second-year trial (2023-24) at 120th DAP, the maximum (23.40 cm) plant spread was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 22.30 cm under T_{11} (100 ppm ZnO + 100 ppm FeO).

Pooling the Data for both the years (2022-23 and 2023-24) at 120th DAP observations revealed the maximum plant spread EW (23.13 cm) under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by T_{14} (150 ppm ZnO + 100 ppm FeO) having a value of 22.91 cm while the minimum (21.50 cm) was recorded under the treatment control (T_0).

It is obvious that zinc might enhance plant spread in strawberries by promoting cell division and elongation, as well as improving chlorophyll synthesis and photosynthetic efficiency and crucial for the synthesis of auxins, that regulate growth and development, while iron is essential for the formation of chlorophyll and electron transport in photosynthesis. These mechanisms could result in increased vegetative growth and a wider plant spread. The present results align with the findings of Marschner *et al.,* (2012); Bhatia *et al.,* (2001); de la Rosa *et al.,* (2013); Hafeez *et al.,* (2013) and Yoon *et al.,* (2017) supporting the role of these micronutrients in plant development.

Table 4.8a: Effect of Nano- ZnO and FeO on plant spreading (cm) (E-W) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions

Plant Spreading (cm) (E-W) (Protected)												
	30 DAP			60 DAP			90 DAP			110 DAP		
Treatments	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**2022-23**
T_0	7.73	7.66	7.70	9.71	9.88	9.80	15.55	15.00	15.28	21.98	21.74	21.86
T_1	7.86	7.81	7.84	10.38	10.23	10.31	16.40	16.72	16.56	22.09	21.55	21.82
T_2	7.42	7.53	7.48	10.53	10.41	10.47	16.63	16.78	16.71	22.20	22.43	22.32
T_3	7.70	7.76	7.73	10.44	10.76	10.60	16.71	16.43	16.57	22.19	22.25	22.22
T_4	7.45	7.65	7.55	10.57	10.46	10.52	17.03	16.27	16.65	22.45	22.45	22.45
T_5	7.56	7.75	7.66	10.62	10.54	10.58	16.99	16.88	16.94	22.00	22.59	22.30
T_6	7.54	7.65	7.60	10.47	10.66	10.56	16.63	16.45	16.54	23.03	22.57	22.80
T_7	7.91	7.85	7.88	10.58	10.66	10.62	16.59	16.76	16.68	22.57	22.54	22.56
T_8	7.97	7.82	7.90	10.35	10.25	10.30	16.93	16.93	16.93	22.94	22.84	22.89
T_9	7.87	7.74	7.81	10.42	10.80	10.61	16.84	17.07	16.96	22.54	22.29	22.42
T_{10}	7.91	8.15	8.03	10.85	10.77	10.81	17.26	17.29	17.28	23.50	22.58	23.04
T_{11}	7.92	7.81	7.87	10.43	10.85	10.64	17.00	17.79	17.40	22.34	22.94	22.64
T_{12}	7.47	7.55	7.51	10.84	10.79	10.81	17.01	16.60	16.81	22.16	22.60	22.38
T_{13}	7.98	8.03	8.01	10.93	10.83	10.88	16.74	16.69	16.72	22.91	22.64	22.78
T_{14}	8.04	8.13	8.09	10.77	10.79	10.78	17.31	17.34	17.33	23.09	22.86	22.98
T_{15}	8.02	7.93	7.98	11.23	10.93	11.08	17.71	17.89	17.80	23.18	23.10	23.14
C.D.	0.221	0.180	0.201	0.466	0.298	0.382	0.679	0.336	0.508	0.438	0.345	0.392
SE(m)	0.076	0.062	0.069	0.161	0.103	0.132	0.234	0.116	0.175	0.151	0.119	0.135
SE(d)	0.108	0.088	0.098	0.227	0.145	0.186	0.331	0.164	0.248	0.213	0.168	0.191
C.V.	1.699	1.375	1.537	2.634	1.678	2.156	2.407	1.194	1.801	1.158	0.915	1.037

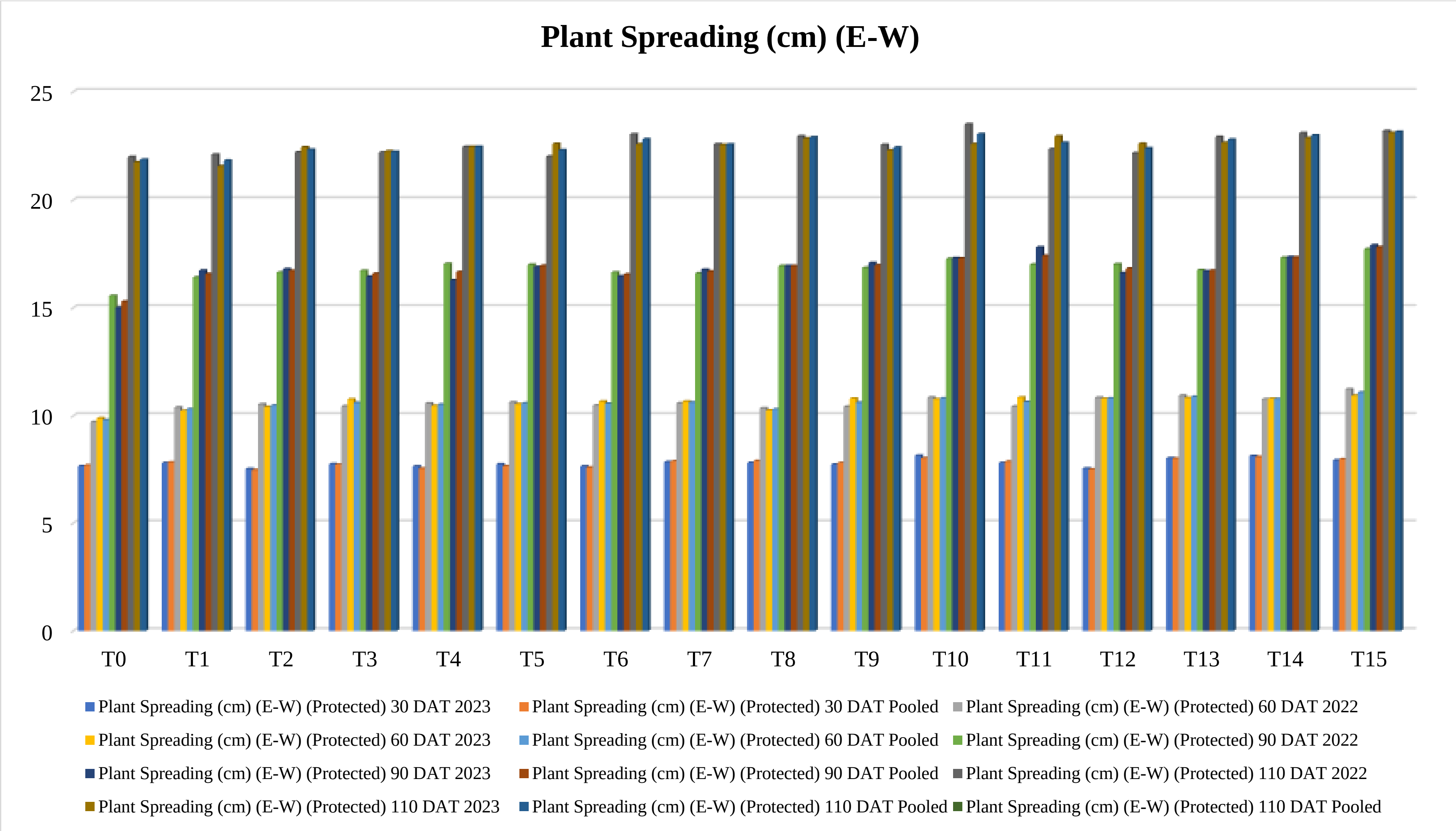

Figure 4.8a: Effect of Nano- ZnO and FeO on plant spreading (cm) (E-W) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions

Table 4.8b: Effect of Nano- ZnO and FeO on plant spreading (cm) (E-W) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions

Plant Spreading (cm) (E-W) (Open)												
Treatments	**30 DAP**			**60 DAP**			**90 DAP**			**110 DAP**		
	2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
T_0	7.20	6.90	7.05	9.10	8.70	8.90	14.90	14.17	14.54	21.43	20.15	20.79
T_1	7.13	7.00	7.07	9.33	8.97	9.15	15.80	14.53	15.17	22.27	21.57	21.92
T_2	7.17	7.10	7.14	9.97	9.67	9.82	16.17	15.30	15.74	22.13	21.41	21.77
T_3	7.23	7.00	7.12	9.83	9.50	9.67	15.97	14.60	15.29	21.87	22.18	22.03
T_4	7.30	7.10	7.20	9.97	9.67	9.82	15.90	15.33	15.62	21.73	21.63	21.68
T_5	7.70	7.00	7.35	10.07	10.00	10.04	16.47	15.10	15.79	22.77	22.25	22.51
T_6	7.43	7.20	7.32	10.17	9.70	9.94	16.23	14.37	15.30	22.80	21.71	22.26
T_7	7.23	7.17	7.20	10.63	10.07	10.35	16.63	15.40	16.02	22.80	21.33	22.07
T_8	7.50	7.20	7.35	10.37	9.97	10.17	16.43	15.37	15.90	22.43	21.48	21.96
T_9	7.37	6.97	7.17	10.13	9.83	9.98	16.27	15.37	15.82	22.87	21.72	22.30
T_{10}	7.43	7.17	7.30	10.60	9.97	10.29	16.77	15.33	16.05	22.07	21.53	21.80
T_{11}	7.73	7.20	7.47	10.77	10.40	10.59	17.10	16.23	16.67	22.87	22.33	22.60
T_{12}	7.87	7.00	7.44	10.67	10.27	10.47	16.53	15.63	16.08	22.80	21.43	22.12
T_{13}	7.40	6.97	7.19	10.73	9.97	10.35	15.87	15.53	15.70	22.50	22.26	22.38
T_{14}	7.87	6.60	7.24	10.47	10.27	10.37	16.03	15.73	15.88	22.37	21.67	22.02
T_{15}	7.50	6.90	7.20	11.13	10.83	10.98	17.50	16.60	17.05	23.13	23.44	23.29
C.D.	0.365	0.295	0.330	0.762	0.444	0.603	0.554	1.298	0.926	0.887	1.389	1.138
SE(m)	0.126	0.102	0.114	0.263	0.153	0.208	0.191	0.447	0.319	0.306	0.479	0.393
SE(d)	0.178	0.144	0.161	0.371	0.216	0.294	0.270	0.632	0.451	0.432	0.677	0.555
C.V.	2.928	2.506	2.717	4.439	2.689	3.564	2.029	5.066	3.548	2.360	3.810	3.085

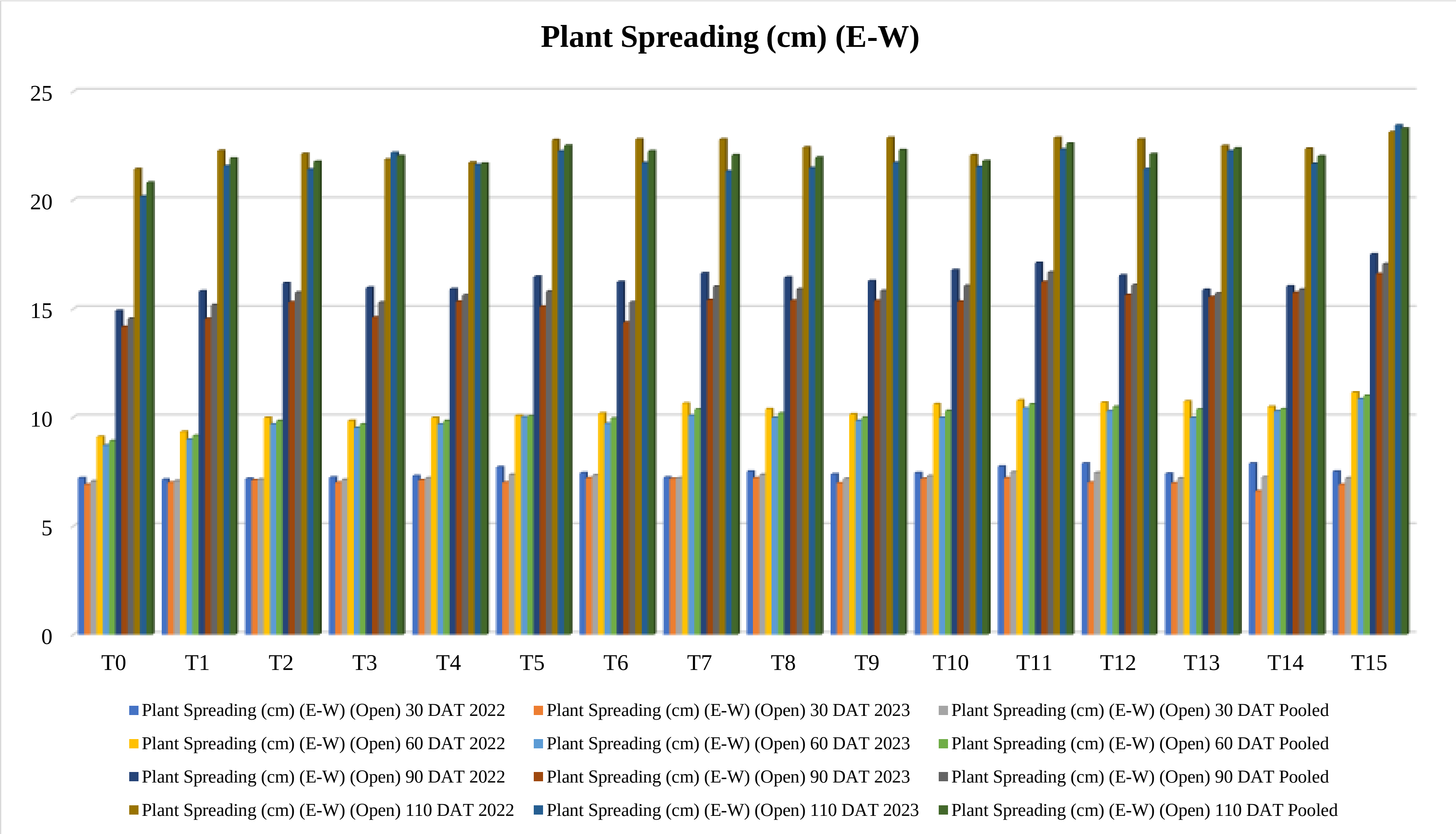

Figure 4.8b: Effect of Nano- ZnO and FeO on plant spreading (cm) (E-W) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions

4.1.9 Chlorophyll content

The chlorophyll content presented in Table 4.9 indicated significant variations were found among all the treatments with the application of Nano-ZnO and FeO at different concentrations. During (2022-23), the maximum (55.47) chlorophyll content was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 54.20 under T_{10} (100 ppm ZnO + 50 ppm FeO) while the minimum (46.03) chlorophyll content was recorded under the treatment T_0 (control) for the first year research trial. During (2023-24), the maximum (54.24) chlorophyll content was observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 53.97 under T_4 (50ppm FeO) and minimum chlorophyll content was recorded under the treatment T_0 (control). Pooling the Data revealed the maximum (54.85) chlorophyll content was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 53.93 under T_4 (50ppm FeO) while the minimum (46.37) remained under the treatment T_0 (control).

The chlorophyll content for open field conditions presented in Table 4.9 revealed significant variations among the treatments. During (2022-23) for the first-year research trial the maximum (53.40) chlorophyll content was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum chlorophyll content (45.08) was observed under the treatment T_0 (control). In the second-year research trial (2023-24), the maximum (52.80) chlorophyll content was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 52.74 under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (43.30) chlorophyll content was recorded under the treatment T_0 (control). Pooling the Data revealed the maximum (53.10) chlorophyll content under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 52.90 under T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (44.19) remained under the treatment T_0 (control).

The increase in plant spread observed in strawberry plants following the application of nano zinc and iron can be attributed to their roles in enhancing chlorophyll content and photosynthetic efficiency. Zinc promotes the activity of enzymes like chlorophyll synthase, which is crucial for the formation of chlorophyll molecules and providing more energy for more synthesis of cholorophyll content in leaves, including the expansion of plant canopies. Meanwhile iron supports the health of chloroplasts and improves the electron transport chain's efficiency in photosynthesis, ensuring a balanced and sustained chlorophyll content in leaves. Together, these effects contribute to the overall vigor and spreading of the plants by promoting more robust growth and expansion of the vegetative parts. These observations align with the findings of Khan *et al.,* (2018); Abdollahi *et al.,* (2010); Bhoyer *et al.,* (2006); Kazemi *et al.,* (2014); Nandita *et al.,* (2020).

Table 4.9: Effect of Nano- ZnO and FeO on Chlorophyll content (mg/ µmol) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Treatments	Chlorophyll content (mg/µmol)					
	Protected Field Conditions			Open Field Conditions		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
T_0	46.03	46.71	46.37	45.08	43.30	44.19
T_1	48.57	47.34	47.96	46.88	44.82	45.85
T_2	51.27	48.52	49.90	49.60	47.61	48.61
T_3	52.97	50.67	51.82	51.31	49.32	50.32
T_4	53.90	53.97	53.94	51.43	50.58	51.01
T_5	54.00	52.82	53.41	51.03	50.65	50.84
T_6	51.13	51.14	51.14	51.26	48.27	49.77
T_7	51.40	52.45	51.93	52.73	50.44	51.59
T_8	51.77	52.78	52.28	51.15	50.73	50.94
T_9	50.48	50.24	50.36	52.61	51.66	52.14
T_{10}	54.20	53.07	53.64	51.64	50.83	51.23
T_{11}	51.44	53.60	52.52	53.06	52.74	52.90
T_{12}	49.71	52.34	51.03	52.27	52.27	52.27
T_{13}	50.71	52.49	51.60	52.48	51.63	52.05
T_{14}	51.14	50.26	50.70	52.25	51.69	51.97
T_{15}	55.47	54.24	54.86	53.40	52.80	53.10
C.D.	2.260	2.926	2.593	1.983	1.653	1.818
SE(m)	0.779	1.008	0.894	0.683	0.569	0.626
SE(d)	1.101	1.426	1.264	0.966	0.805	0.886
C.V.	2.618	3.396	3.007	2.314	1.974	2.144

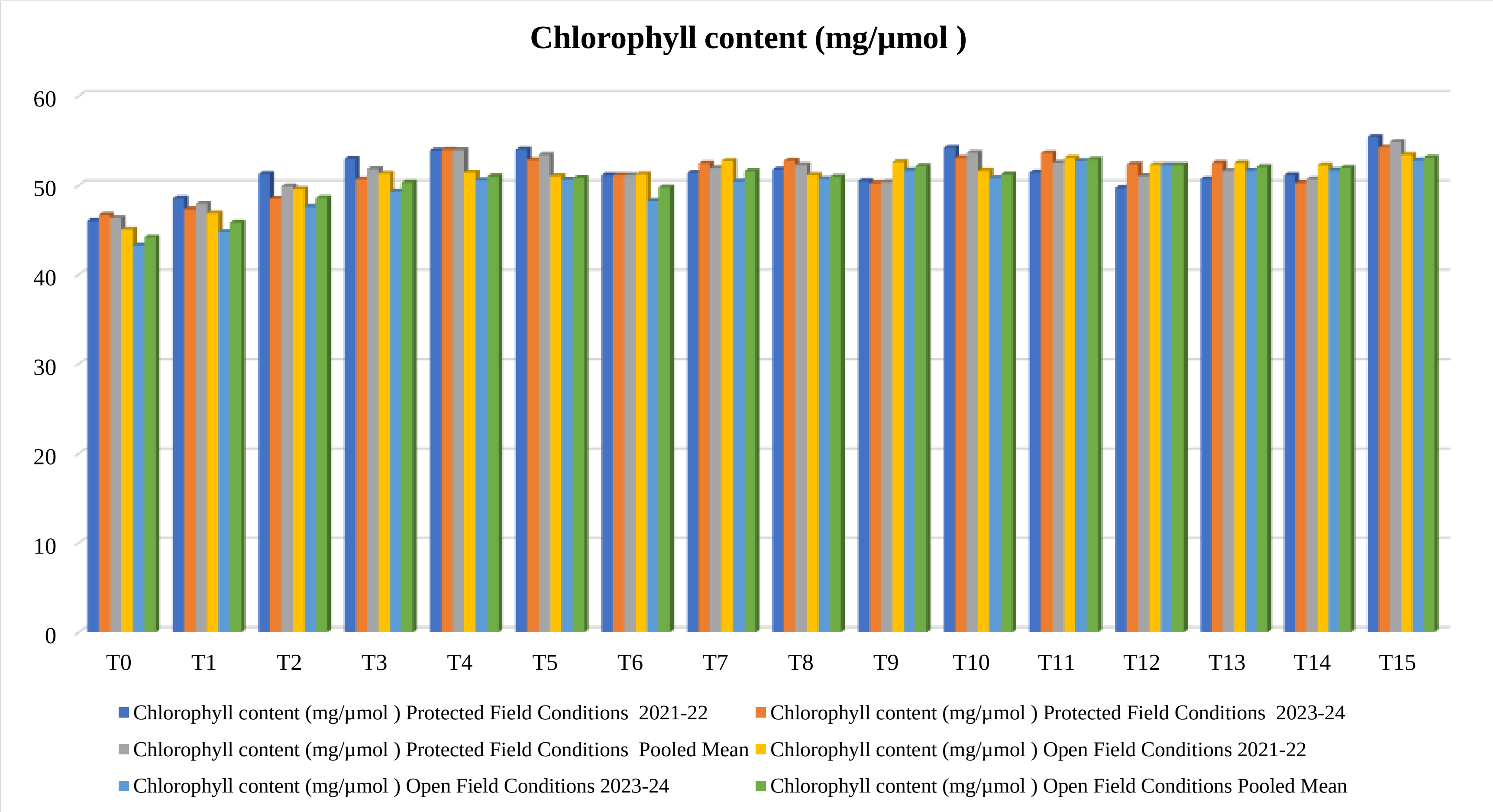

Figure 4.9: Effect of Nano- ZnO and FeO on Chlorophyll content (mg/ µmol) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions.

4.1.10 Days to Flower Initiation

The Data related to flower initiation is presented in Table 4.10 and indicates that there exist a significant variations among all the treatents, for first-year research trial (2022-23), the maximum (51.00) days to flower initiation were recorded under the treatment T_0 (control) followed by 50.00 under T_{15} (150 ppm ZnO + 150 ppm FeO) while the minimum 47.00 days to flower initiation were recorded under the treatment T_{11} (100 ppm ZnO + 100 ppm FeO). During (2023-24) for the second the maximum (50.00) days to flower initiation were observed under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) followed by T_0 (control). Combining the Data for both the years (2022-23 and 2023-24) recorded the maximum (50.333) days to flower initiation under T_0 (control) followed by 49.83 under T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (47.00) was recorded under the treatment T_9 (50 ppm ZnO + 150 ppm FeO).

The Data pertaining to days for flower initiation presented in Table 4.10 for open field conditions, during (2022-23) the maximum (49.67) days to flower initiation were recorded under the treatment T_0 (control) followed by 49.00 under T_{12} (100 ppm ZnO + 150 ppm FeO) and minimum (47.00) days to flower initiation were recorded under the treatment T_{11} (100 ppm ZnO + 100 ppm FeO) for first year research trial. During (2023-24) for second year the maximum (50.00) days to flower initiation were observed under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) followed by T_0 (control). Pooling the Data for both the years (2022-23 and 2023-24) recorded the maximum (50.333) days to flower initiation under T_0 (control) followed by 49.83 under T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (47.00) was recorded under the treatment T_9 (50 ppm ZnO + 150 ppm FeO).

The application of zinc and iron helps to reduce the days to first flowering by enhancing nutrient efficiency and hormonal regulation and helps to improved bioavailability of nano-sized nutrients, which enhances their uptake and leads to optimal levels of zinc and iron in the plant. Zn appears crucial for the synthesis of auxins, which promote flower initiation, while iron supports overall plant metabolism and energy production, potentially accelerating the flowering process. The present findings are supported by the findings of Raliya *et al.*, (2013); Nair *et al.*, (2016); Malik *et al.*, (2000), Laware *et al.*, (2014), Naderi *et al.*, (2013) highlighting the role of these nutrients in plant development.

Table 4.10: Effect of Nano- ZnO and FeO on Days to flower Initiation of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions.

Days to flower Initiation						
Treatments	**Protected Field Conditions**			**Open Field Conditions**		
	2022-23	**2023-24**	**Pooled Mean**	**2022-23**	**2023-24**	**Pooled Mean**
T_0	51.00	49.67	50.33	49.67	49.00	49.33
T_1	48.00	49.33	48.67	46.33	47.33	46.83
T_2	49.00	48.00	48.50	47.00	46.00	46.50
T_3	48.00	48.00	48.00	46.67	48.00	47.33
T_4	48.70	47.33	48.02	47.00	46.33	46.67
T_5	47.70	49.00	48.35	47.00	46.00	46.50
T_6	48.00	49.00	48.50	47.33	46.33	46.83
T_7	48.00	47.33	47.67	46.00	46.00	46.00
T_8	48.00	47.67	47.83	47.33	48.00	47.67
T_9	47.70	46.33	47.02	46.33	47.00	46.67
T_{10}	49.30	48.33	48.82	47.67	46.33	47.00
T_{11}	47.00	47.33	47.17	47.67	46.00	46.83
T_{12}	49.00	49.33	49.17	49.00	47.00	48.00
T_{13}	49.70	50.00	49.85	48.00	47.33	47.67
T_{14}	48.00	47.67	47.83	48.67	47.00	47.83
T_{15}	50.00	46.67	48.33	47.33	46.00	46.67
C.D.	1.536	2.091	1.814	1.365	1.605	1.485
SE(m)	0.529	0.720	0.625	0.789	0.553	0.671
SE(d)	0.748	1.019	0.884	1.116	0.782	0.949
C.V.	2.432	2.589	2.511	2.881	2.045	2.463

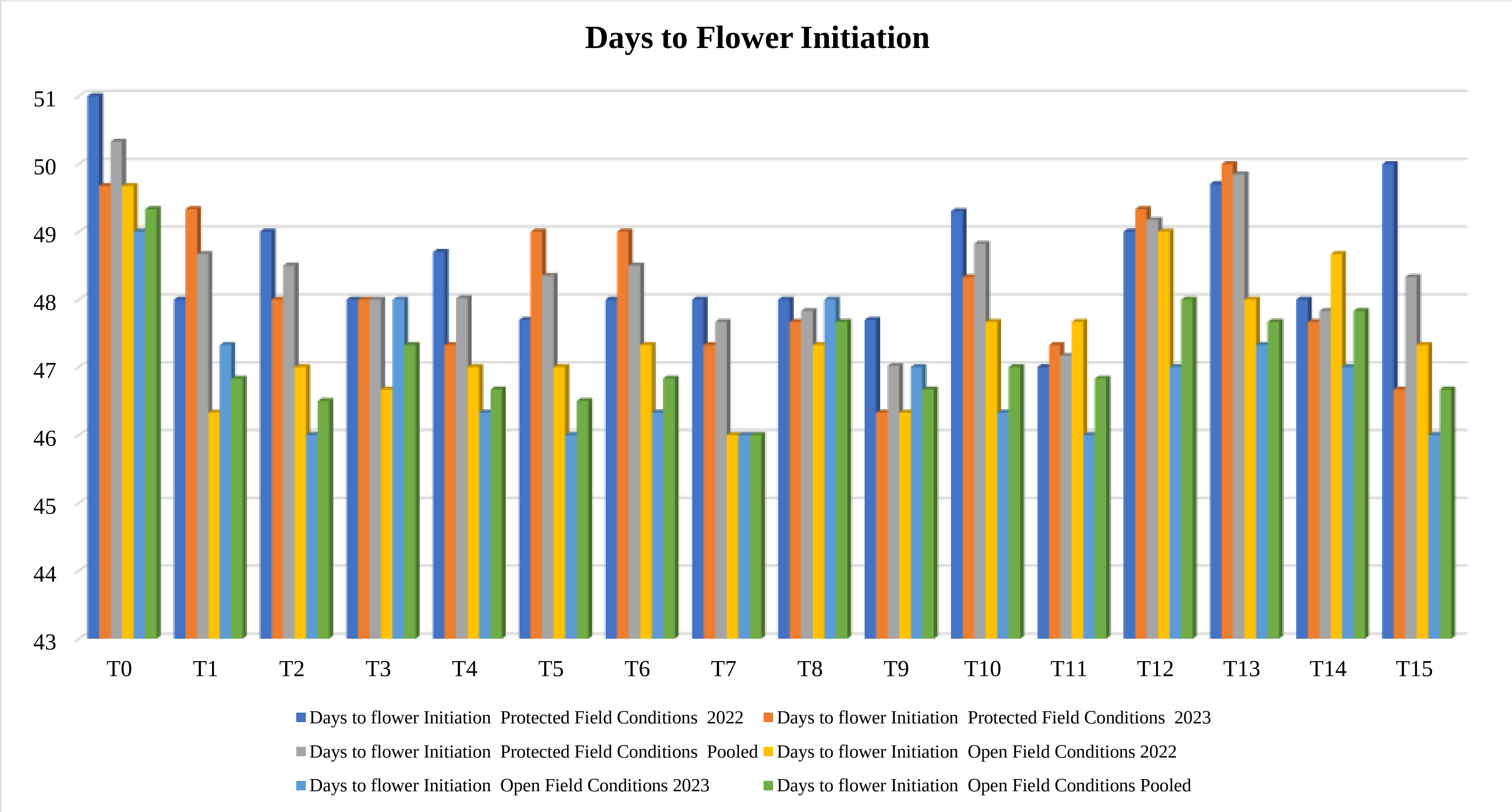

Figure 4.10: Effect of Nano- ZnO and FeO on Days to flower Initiation of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.1.11 Number of flowers per plant

The study of the Table 4.11a revealed that there exists a significant variation related to number of flowers per plant among all the treatments by applying Nano-ZnO and FeO to the strawberry plants. During (2022-23) at 80th DAP, the maximum (11.00) number of flowers plant^{-1} were noticed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 10.00 under T_{13} (150 ppm ZnO + 50 ppm FeO) and minimum (8.33) were recorded under the treatment T_0 (control) for the first year research trial. During (2023-24) for the second year trial at 80th DAP observation recorded the utmost (12.33) number of flowers per plant under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 12.00 under T_7 (50 ppm ZnO + 50 ppm FeO) while the minimum (9.67) were recorded under the treatment T_0 (control). Pooled analysis for both the years (2022-23 and 2023-24) at 80th DAP, reflected the maximum (11.7) number of flowers plant^{-1} under treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 10.8 under T_{13} (150 ppm ZnO + 50 ppm FeO) and minimum (9.0) were recorded under the treatment T_0 (control). The Data on the number of flowers plant per plant under natural growing conditions presented in Table 4.11b revealed that, during (2022-23), at the 80th DAP the maximum (12.67) number of flowers plant^{-1} were recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 12.33 under T_{11} (150 ppm ZnO + 100 ppm FeO) while the minimum (9.67) were recorded under the treatment T_0 (control). During (2023-24) in the second year trial at 80th DAP observation recorded the utmost (10.33) number of flowers plant^{-1} under treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 10.00 under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (7.67) were recorded under the treatment T_0 (control). Pooled analysis for both the years (2022-23 and 2023-24) Data recorded at 80th DAP showed maximum (11.50) number of flowers plant^{-1} under treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 11.17 under T_{11} (100 ppm ZnO + 100 ppm FeO) and the minimum (8.67) were recorded under the treatment T_0 (control).

It is obvious that Zn plays a significant role in increasing the number of flowers in plants, possibly due to the enhancement of nutrient availability and hormonal balance might be due to zinc's vital function in enzyme activation and hormone regulation, which promotes cell division and growth, ultimately leading to increased flowering.

While, iron is crucial for chlorophyll synthesis and energy production, which improves photosynthesis and overall plant vigor, thereby supporting more abundant flowering. The present results are aligned with the findings of Raliya *et al.,* (2015); Barooh *et al.,* (2020); de la Rosa *et al.,* (2013); Reddy *et al.,* (2021); Saini *et al.,* (2021) and Chen *et al.,* (2018).

Table 4.11a: Effect of Nano- ZnO and FeO on Number of flowers per plant of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions

Treatments	Number of flowers per plant (Protected)											
	60 DAP			80 DAP			100 DAP			115 DAP		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_0	3.33	4.33	3.83	8.33	9.67	9.00	6.33	6.33	6.33	2.67	3.67	3.17
T_1	3.67	4.67	4.17	8.67	10.33	9.50	6.67	7.00	6.84	3.67	4.67	4.17
T_2	4.33	6.67	5.50	9.00	10.00	9.50	7.00	7.00	7.00	3.33	5.00	4.17
T_3	4.33	5.33	4.83	9.33	10.33	9.83	7.00	6.67	6.84	3.67	4.00	3.84
T_4	4.67	6.33	5.50	9.33	9.67	9.50	7.33	7.33	7.33	3.33	4.33	3.83
T_5	4.67	6.00	5.34	8.00	10.67	9.34	7.67	7.00	7.34	3.67	5.33	4.50
T_6	3.67	6.00	4.84	9.00	10.00	9.50	6.33	6.33	6.33	3.33	4.33	3.83
T_7	4.33	7.67	6.00	8.67	12.00	10.34	7.00	7.67	7.34	4.33	5.67	5.00
T_8	4.33	6.33	5.33	9.00	11.00	10.00	6.67	6.67	6.67	4.67	4.67	4.67
T_9	4.67	6.00	5.34	9.67	10.00	9.84	7.33	7.67	7.50	4.00	5.33	4.67
T_{10}	3.67	6.67	5.17	10.00	11.00	10.50	7.67	7.33	7.50	5.33	4.33	4.83
T_{11}	4.33	8.00	6.17	9.00	10.67	9.84	7.67	8.00	7.84	3.67	5.00	4.34
T_{12}	3.67	7.33	5.50	8.33	12.33	10.33	7.00	7.00	7.00	5.00	4.00	4.50
T_{13}	3.67	8.00	5.84	10.00	11.67	10.84	6.67	6.33	6.50	3.67	5.33	4.50
T_{14}	3.67	8.33	6.00	9.00	10.00	9.50	5.67	6.67	6.17	5.00	4.00	4.50
T_{15}	5.33	8.00	6.67	11.00	12.33	11.67	8.33	8.67	8.50	5.33	6.67	6.00
C.D.	0.997	1.364	1.181	1.499	1.409	1.454	1.269	1.308	1.289	1.076	1.177	1.127
SE(m)	0.344	0.470	0.407	0.516	0.485	0.501	0.437	0.451	0.444	0.371	0.405	0.388
SE(d)	0.486	0.665	0.576	0.730	0.687	0.709	0.618	0.638	0.628	0.524	0.573	0.549
C.V.	7.355	6.325	6.840	9.780	7.837	8.809	7.787	6.991	7.389	6.391	6.718	6.305

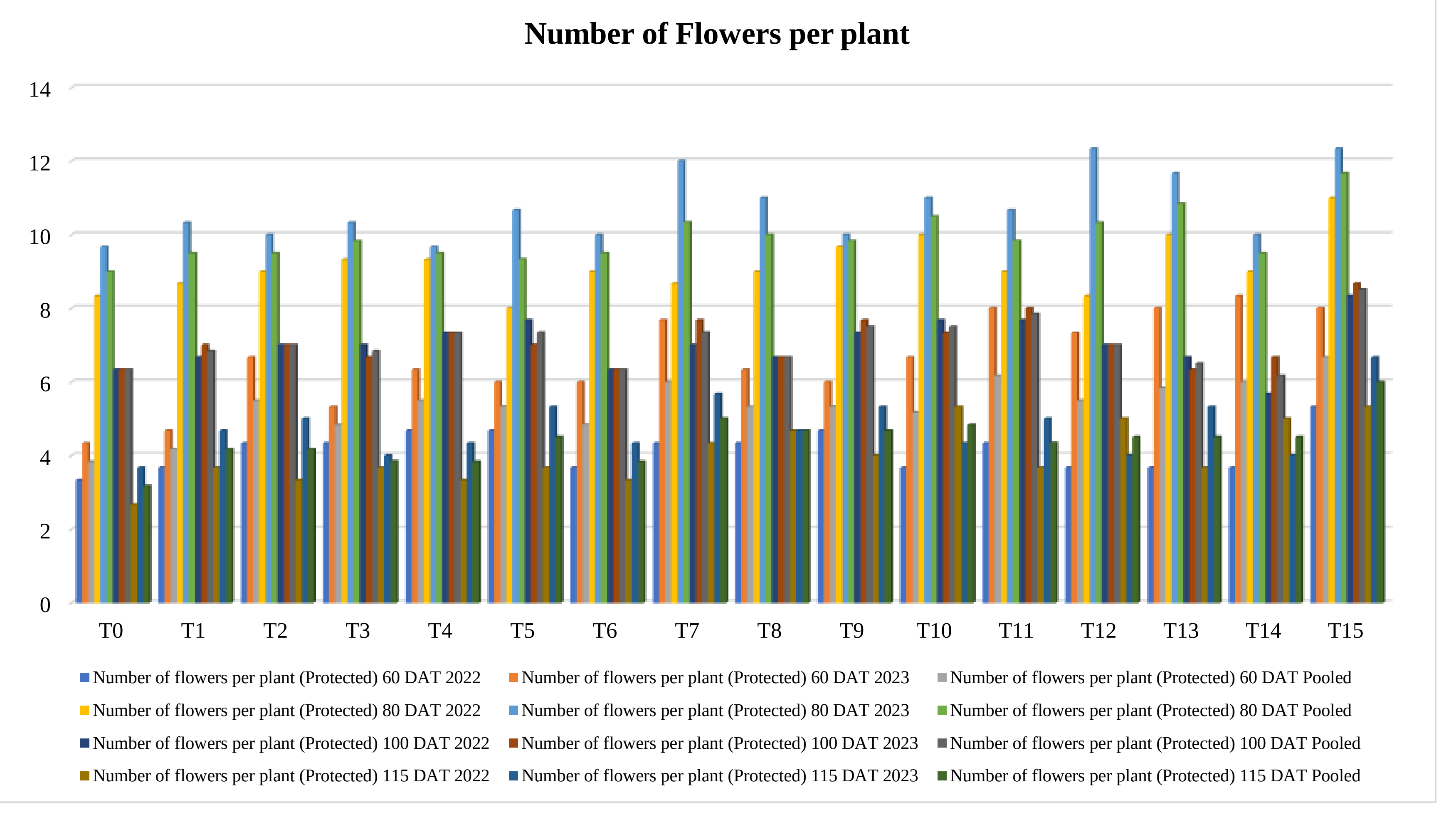

Figure 4.11a: Effect of Nano- ZnO and FeO on Number of flowers per plant of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions

Table 4.11b: Effect of Nano- ZnO and FeO on Number of flowers per plant of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions

Treatments	Number of flowers per plant (Open)											
	60 DAP			80 DAP			100 DAP			115 DAP		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_0	4.33	4.00	4.17	9.67	7.70	8.68	6.00	5.00	5.50	3.67	3.00	3.33
T_1	4.67	3.70	4.18	9.67	8.30	8.98	7.33	7.00	7.17	4.00	4.00	4.00
T_2	5.33	4.30	4.82	10.00	9.30	9.65	7.67	6.00	6.83	4.33	3.00	3.67
T_3	6.00	6.00	6.00	10.33	7.70	9.02	7.67	5.00	6.33	4.67	4.70	4.68
T_4	6.33	6.00	6.17	10.33	8.30	9.32	7.67	7.00	7.33	5.00	4.30	4.65
T_5	6.67	4.70	5.68	10.67	8.70	9.68	7.00	6.00	6.50	5.33	5.00	5.17
T_6	6.00	5.00	5.50	10.00	8.00	9.00	7.67	7.00	7.33	4.67	3.70	4.18
T_7	7.67	5.00	6.33	12.00	8.00	10.00	8.33	6.00	7.17	5.67	4.30	4.98
T_8	6.00	6.00	6.00	10.00	8.70	9.35	7.67	7.00	7.33	4.33	4.00	4.17
T_9	6.33	5.00	5.67	11.00	9.00	10.00	8.67	6.00	7.33	5.33	4.30	4.82
T_{10}	6.67	6.00	6.33	11.00	8.30	9.65	6.67	5.30	5.98	4.00	3.70	3.85
T_{11}	8.00	5.00	6.50	12.33	10.00	11.17	8.00	8.00	8.00	5.00	4.70	4.85
T_{12}	7.33	7.00	7.17	11.67	9.30	10.48	6.33	6.00	6.17	4.33	3.30	3.82
T_{13}	8.00	5.00	6.50	10.00	9.00	9.50	6.00	5.00	5.50	4.00	3.70	3.85
T_{14}	8.00	6.00	7.00	11.67	9.30	10.48	6.00	6.00	6.00	5.33	5.00	5.17
T_{15}	8.67	6.70	7.68	12.67	10.30	11.48	8.33	7.00	7.67	6.00	5.30	5.65
C.D.	1.352	1.665	1.509	1.526	1.112	1.319	1.332	1.717	1.525	1.200	1.216	1.208
SE(m)	0.466	0.574	0.520	0.526	0.383	0.455	0.459	0.592	0.526	0.413	0.419	0.416
SE(d)	0.659	0.811	0.735	0.743	0.542	0.643	0.649	0.837	0.743	0.585	0.592	0.589
C.V.	6.182	5.632	5.857	8.422	7.583	8.003	6.871	7.505	7.188	6.138	7.589	6.814

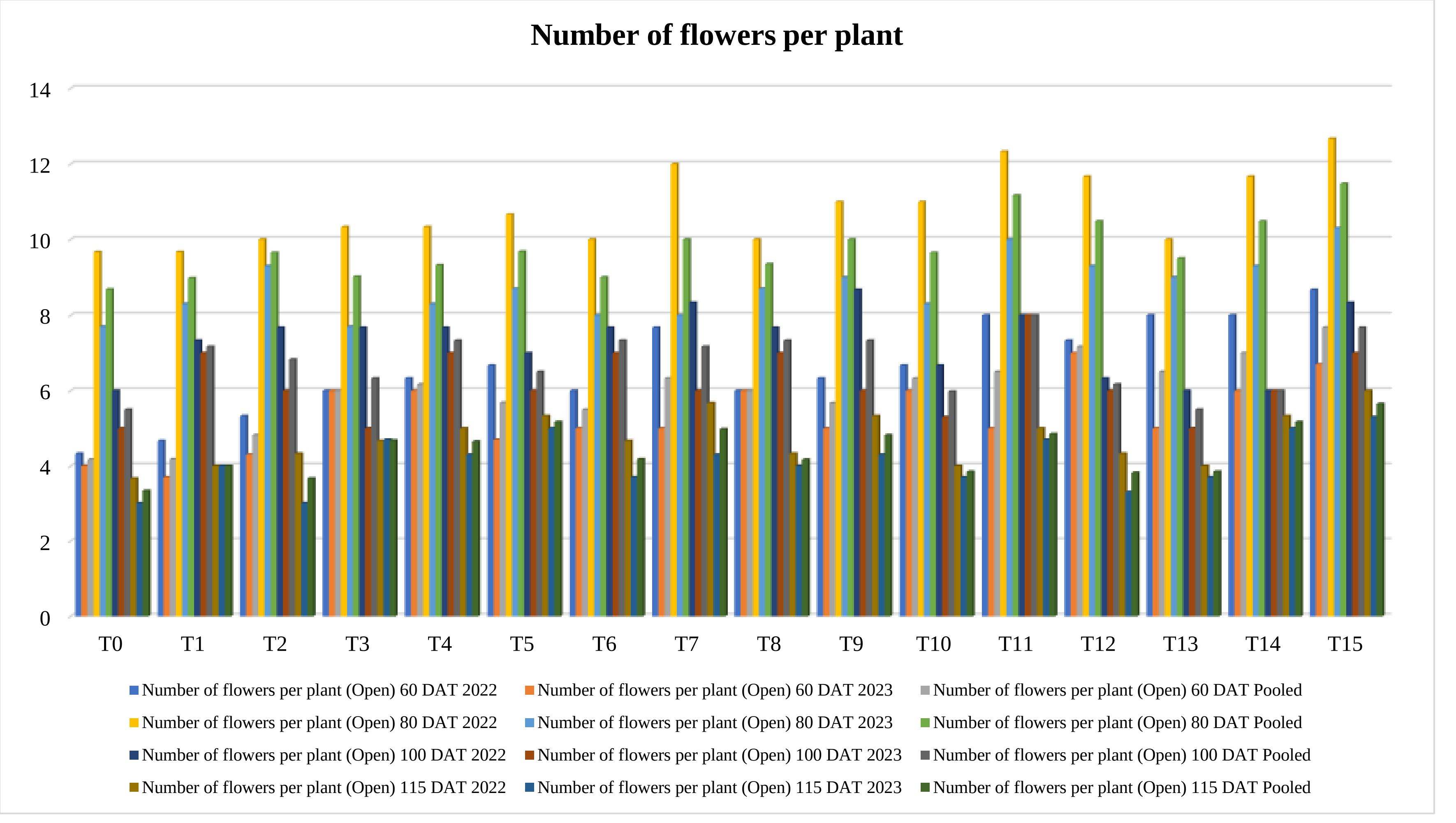

Figure 4.11b: Effect of Nano- ZnO and FeO on Number of flowers per plant of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions

4.1.12 Duration of flowering

The duration of flowering under protected conditions is elaborated in Table 4.12 defines that each of the treatment has significant variation with the application of Nano-znO and FeO, during (2022-23) first-year research trial, maximum (55.00) duration of flowering is noticed in the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 54.67 under T_2 (100ppm ZnO) and the minimum (52.33) duration of flowering was recorded under the treatment T_0 (control). In the second year (2023-24) research trial the maximum (54.33) duration of flowering was observed under the treatment T_{11} (100 ppm ZnO + 100 ppm FeO) followed by 54.00 under T_{15} (150 ppm ZnO + 150 ppm FeO) while the minimum (51.00) duration of flowering was recorded under the treatment T_0 (control). Pooled analysis of both the years (2022-23 and 2023-24) revealed the maximum (54.50) duration of flowering under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 53.83 under T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (51.67) was remained under the treatment T_0 (control).

The Data on duration of flowering under protected conditions is presented in Table 4.12 and represented graphically in Figure 4.12 revealed that, during (2022-23) the maximum (55.00) duration of flowering is noticed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 53.33 under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (51.33) duration of flowering was recorded under the treatment T_0 (control) for first year trial. In the second-year trial (2023-24) the maximum (54.00) duration of flowering was observed under treatment T_7 (50 ppm ZnO + 50 ppm FeO) followed by 53.00 under T_{15} (150 ppm ZnO + 150 ppm FeO) while the minimum (50.33) duration of flowering was recorded under the treatment T_0 (control). The pooled analysis of both the years (2022-23 and 2023-24) revealed the maximum (54.00) duration of flowering under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 53.50 under T_7 (50 ppm ZnO + 50 ppm FeO) while the minimum (50.83) remained under the treatment T_0 (control).

The extension in the duration of flowering, possibly due to enhancememt in the nutrient uptake and hormonal regulation within the plants because zinc plays significant role in auxin production appears to support prolonged flowering, while iron's importance in chlorophyll synthesis and energy production likely sustains flower development over an extended period. These results are consistent with the findings of Siddiqui *et al.,* (2015); Barooh *et al.,* (2020); Kazemi *et al.,* (2014); Li *et al.,* (2022) and Nitin *et al.,* (2012).

Table 4.12: Effect of Nano- ZnO and FeO on Duration of Flowering of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Duration of Flowering						
	Protected Field Conditions			**Open Field Conditions**		
Treatments	**2022-23**	**2023-24**	**Pooled Mean**	**2022-23**	**2023-24**	**Pooled Mean**
T_0	52.33	51.00	51.67	51.33	50.33	50.83
T_1	53.00	53.00	53.00	51.67	52.00	51.83
T_2	54.67	53.00	53.84	52.67	52.00	52.33
T_3	53.00	53.33	53.17	52.33	53.00	52.67
T_4	53.00	51.00	52.00	52.00	52.00	52.00
T_5	52.67	52.67	52.67	52.33	52.00	52.17
T_6	53.00	52.33	52.67	51.67	52.00	51.83
T_7	52.67	53.00	52.84	53.00	54.00	53.50
T_8	52.67	53.67	53.17	52.33	53.00	52.67
T_9	53.67	54.00	53.84	52.67	51.00	51.83
T_{10}	53.67	53.33	53.50	51.67	52.00	51.83
T_{11}	53.33	54.33	53.83	53.33	53.00	53.17
T_{12}	53.00	53.00	53.00	52.67	52.00	52.33
T_{13}	53.00	52.00	52.50	51.67	52.00	51.83
T_{14}	53.33	52.33	52.83	52.67	52.00	52.33
T_{15}	55.00	54.00	54.50	55.00	53.00	54.00
C.D.	1.431	1.890	1.661	1.542	1.676	1.609
SE(m)	0.493	0.651	0.572	0.708	0.577	0.643
SE(d)	0.697	0.921	0.809	1.002	0.816	0.909
C.V.	1.604	2.133	1.869	2.340	1.915	2.128

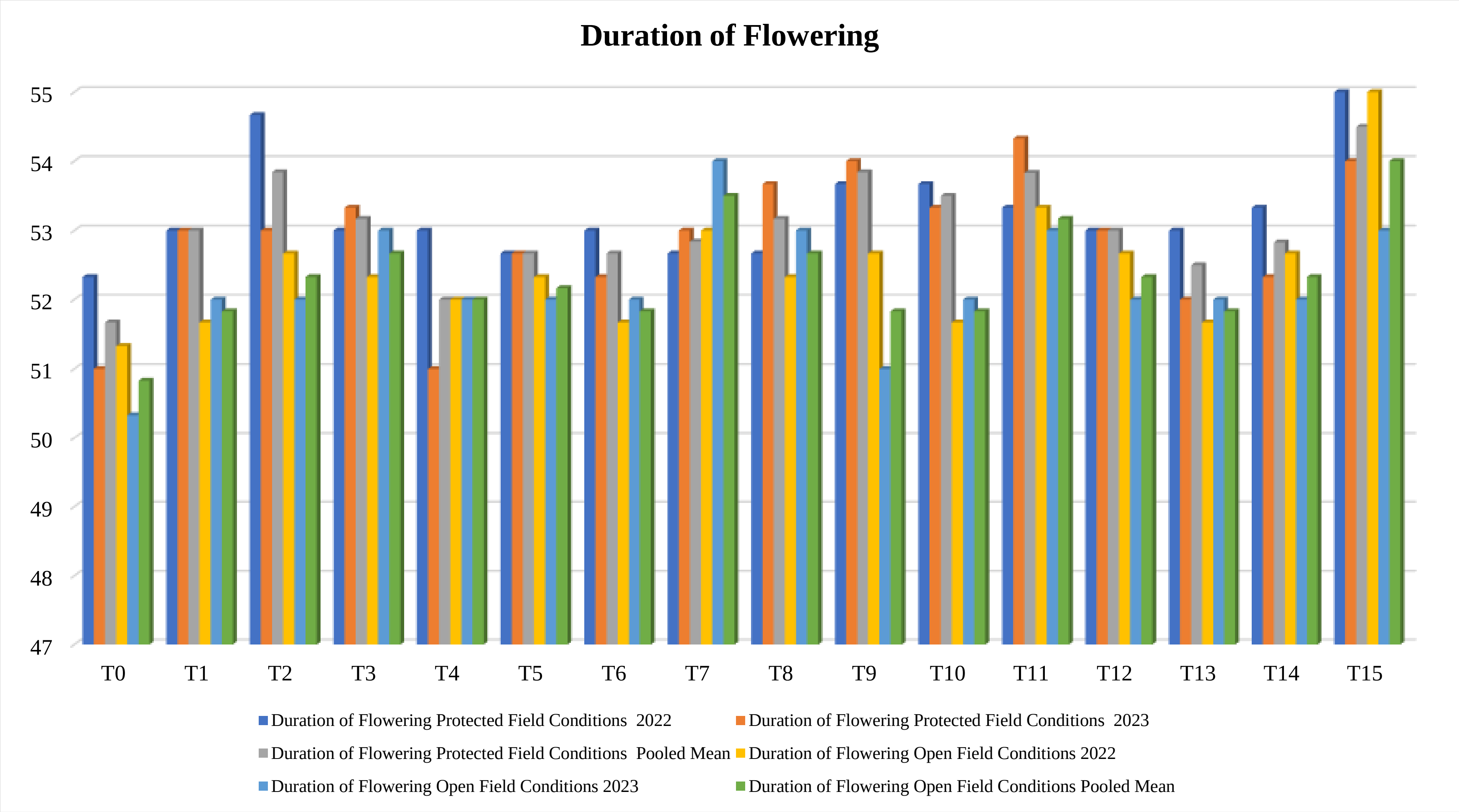

Figure 4.12: Effect of Nano- ZnO and FeO on Duration of Flowering of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.1.13 Number of fruits per plant

Various treatments registered significant variations pertaining to number of fruits per plant by application of different levels of Nano-ZnO and FeO under protected cultivation as presented in Table 4.13a and Figure 4.13a. It is evident from the study of the table 4.13a that maximum (9.67) number of fruits during first-year trail (2022-23) at 95th DAP, were obsrved under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 8.67 under T_5 (100ppm FeO) while the minimum (6.67) were recorded under the treatment T_0 (control). In second-year trail (2023-24) at 95th DAP, the maximum (7.67) number of fruits were recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 7.33 under T_{11} (100 ppm ZnO + 100ppm FeO) while the lowest number of fruits were recorded under the treatment T_0 (control). The study of pooled Data (Table 4.13a) for both the years (2022-23 and 2023-24) revealed after 95 days of planting maximum (8.67) number of fruits were recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 7.83 under T_{10} (100 ppm ZnO + 50 ppm FeO while the minimum (6.17) number of fruits were recorded under the treatment T_0 (control).

The study of the Table 4.13b revealed significant variations relevant to number of fruits per plant under open field conditions among all the treatments by the application of different levels of Nano-ZnO and Nano-FeO. During (2022-23), maximum (8.00) number of fruits at 95th DAP, were recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 8.67 under T_5 (100ppm FeO) while the minimum (7.33) under the treatment T_0 (control) for the first year research trial. In the second-year trail (2023-24) at 95th DAP maximum (7.67) number of fruits were noticed under treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 7.33 under T_{12} (100 ppm ZnO + 150 ppm FeO) while the minimum (6.67) were recorded under the treatment T_0 (control). Combining the Data for both the years, maximum (8.00) number of fruits were observed under the treatment T_{11} (100 ppm ZnO + 100 ppm FeO) followed by 7.83 under T_{15} (150 ppm ZnO + 150 ppm FeO) while the minimum (6.50) number of fruits were recorded under the treatment T_1 (50ppm ZnO).

It is obvious that Zn and Fe plays a significant role in enhancing fruit productivity, possibly due to its influence on key physiological processes in plants with the combined application of Nano-ZnO and FeO, seems to promote a balanced uptake of essential nutrients, ensuring optimal metabolic function. Zinc's critical role in the synthesis of auxins likely supports better fruit set and development by regulating cell division and elongation, leading to an increase in the number of fruits per plant. These results are supported by the findings of Raliya *et al.,* (2013). Additionally, iron's vital contribution to chlorophyll synthesis and photosynthesis may improve energy capture and conversion, providing the necessary energy for fruit growth and development. Together, these micronutrients appear to optimize physiological processes such as nutrient assimilation, energy metabolism, and hormonal regulation, ultimately boosting fruit yield and quality. The present findings are align with the studies of Ahmad *et al.,* (2017); Kazemi *et al.,* (2014); Kumar *et al.,* (2017); Mishra *et al.,* (2016) and Subbaiah *et al.* (2016).

Table 4.13a: Effect of Nano- ZnO and FeO on Number of fruits per plant of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions

Number of fruits per plant (Protected)												
Treatments	**80 DAP**			**95 DAP**			**110 DAP**			**125 DAP**		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**
T_0	4.67	5.00	4.84	6.67	5.67	6.17	4.33	3.33	3.83	1.67	1.65	1.66
T_1	5.33	4.33	4.83	7.33	5.67	6.50	5.67	4.00	4.84	2.00	1.78	1.89
T_2	5.67	4.67	5.17	7.67	5.33	6.50	5.67	3.33	4.50	2.00	2.11	2.06
T_3	5.67	4.33	5.00	8.00	5.67	6.84	6.00	3.67	4.84	2.33	2.67	2.50
T_4	6.00	5.33	5.67	8.00	5.33	6.67	6.33	4.00	5.17	2.33	2.00	2.17
T_5	5.67	4.67	5.17	8.67	6.00	7.34	6.67	4.67	5.67	2.67	2.33	2.50
T_6	5.00	4.33	4.67	7.33	6.00	6.67	5.67	4.33	5.00	2.00	1.95	1.98
T_7	7.00	4.67	5.84	6.67	6.00	6.34	5.67	4.33	5.00	3.33	3.12	3.23
T_8	5.33	6.00	5.67	7.00	5.67	6.34	6.00	5.33	5.67	1.67	2.00	1.84
T_9	6.33	6.00	6.17	6.67	7.00	6.84	6.67	6.33	6.50	2.33	2.67	2.50
T_{10}	6.33	6.00	6.17	8.33	7.33	7.83	7.00	5.00	6.00	3.00	2.67	2.84
T_{11}	6.00	6.33	6.17	7.33	7.33	7.33	5.67	6.33	6.00	3.33	3.00	3.17
T_{12}	6.00	6.00	6.00	7.33	7.33	7.33	7.00	5.67	6.34	2.00	1.77	1.89
T_{13}	6.67	6.00	6.34	6.33	6.00	6.17	6.67	4.67	5.67	3.00	2.67	2.84
T_{14}	6.33	6.00	6.17	7.33	6.67	7.00	6.67	4.67	5.67	3.00	2.78	2.89
T_{15}	7.33	7.00	7.17	9.67	7.67	8.67	7.67	6.67	7.17	4.00	3.67	3.84
C.D.	0.999	1.370	1.185	1.020	1.186	1.103	1.013	1.381	1.197	0.981	1.009	0.995
SE(m)	0.344	0.472	0.408	0.352	0.409	0.381	0.349	0.476	0.413	0.338	0.348	0.343
SE(d)	0.487	0.667	0.577	0.497	0.578	0.538	0.493	0.673	0.583	0.478	0.492	0.485
C.V.	6.008	7.089	6.549	7.054	6.254	6.676	7.735	6.274	6.905	6.044	7.496	6.457

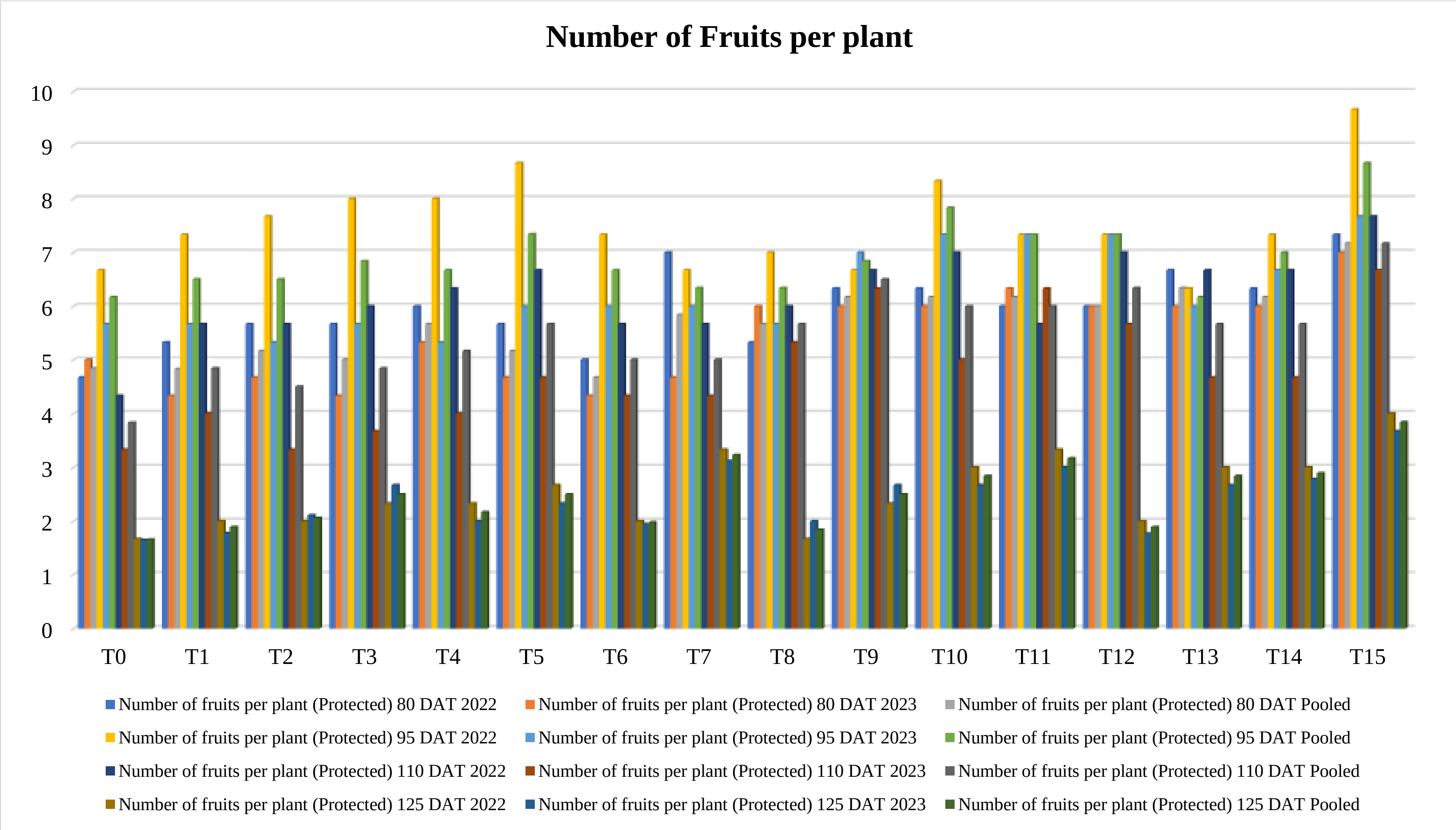

Figure 4.13a: Effect of Nano- ZnO and FeO on Number of fruits per plant of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions

Table 4.13b: Effect of Nano- ZnO and FeO on Number of fruits per plant of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions

Treatments	Number of fruits per plant (Open)											
	80 DAP			95 DAP			110 DAP			125 DAP		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_0	5.67	3.00	4.33	7.33	6.67	7.00	4.67	4.67	4.67	2.00	1.67	1.84
T_1	6.33	4.00	5.17	7.33	5.67	6.50	5.33	5.67	5.50	2.33	2.33	2.33
T_2	6.67	3.33	5.00	7.33	6.67	7.00	5.67	4.33	5.00	2.00	2.67	2.34
T_3	6.67	4.00	5.33	8.00	7.33	7.67	5.33	5.33	5.33	2.67	1.67	2.17
T_4	7.00	4.33	5.67	8.33	6.67	7.50	6.00	5.67	5.84	2.67	2.33	2.50
T_5	6.33	4.00	5.17	8.67	6.00	7.33	6.33	5.33	5.83	2.67	2.33	2.50
T_6	6.00	4.33	5.17	8.00	6.33	7.17	5.67	5.67	5.67	2.00	2.67	2.34
T_7	8.00	4.00	6.00	9.67	5.67	7.67	7.00	6.00	6.50	3.33	3.00	3.17
T_8	6.67	4.33	5.50	7.67	7.33	7.50	5.67	5.33	5.50	2.33	2.33	2.33
T_9	7.00	3.33	5.17	8.67	6.33	7.50	6.67	5.67	6.17	2.67	2.67	2.67
T_{10}	6.67	4.00	5.33	7.67	7.33	7.50	5.67	6.00	5.83	2.00	3.00	2.50
T_{11}	7.67	5.00	6.33	8.33	7.67	8.00	6.67	6.67	6.67	3.67	3.67	3.67
T_{12}	6.67	4.33	5.50	7.67	7.33	7.50	6.00	5.67	5.84	3.33	3.00	3.17
T_{13}	6.00	5.00	5.50	8.33	6.33	7.33	5.33	5.67	5.50	3.33	2.67	3.00
T_{14}	6.33	4.00	5.17	7.67	7.00	7.33	6.33	6.33	6.33	3.33	3.33	3.33
T_{15}	8.33	6.00	7.17	8.00	7.67	7.84	6.67	7.00	6.83	4.33	4.33	4.33
C.D.	1.163	1.471	1.317	1.180	1.183	1.182	1.206	1.136	1.171	1.133	1.129	1.131
SE(m)	0.401	0.507	0.454	0.407	0.408	0.408	0.416	0.391	0.404	0.390	0.389	0.390
SE(d)	0.567	0.717	0.642	0.575	0.577	0.576	0.588	0.554	0.571	0.552	0.550	0.551
C.V.	4.285	5.966	5.056	5.756	5.461	5.509	4.122	5.921	5.022	4.214	4.693	4.454

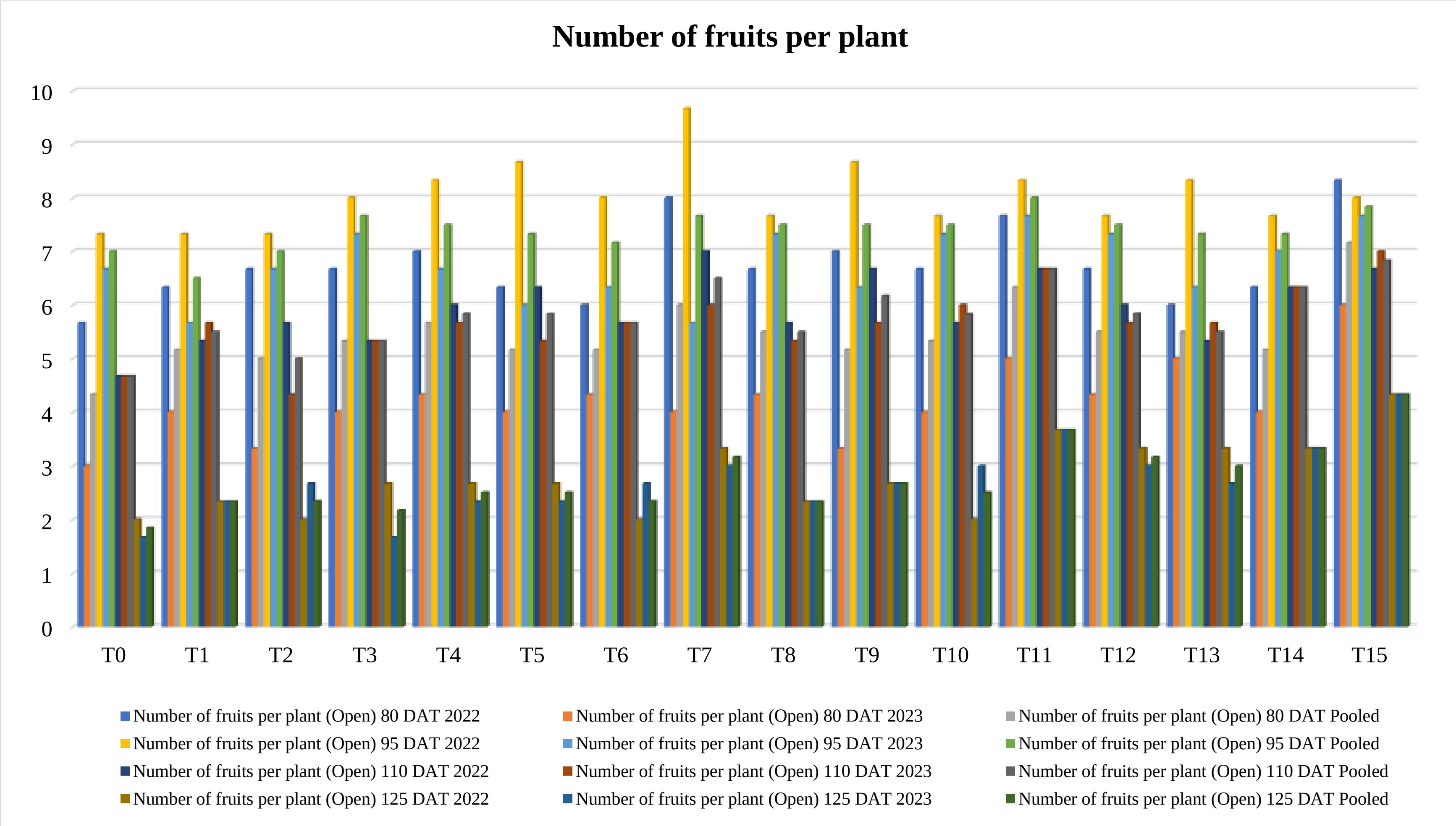

Figure 4.13b: Effect of Nano- ZnO and FeO on Number of fruits per plant of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions

4.1.14 Days taken for fruit maturity

The Data on days taken for fruit maturity under protected conditions presented in Table 4.14 revealed significant variation among the treatments, during (2022-23) recorded the minimum (25.33) days for fruit maturity under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 26.00 under T_9 (50 ppm ZnO + 150 ppm FeO) while the maximum (28.33) days taken for fruit maturity were recorded under the treatment T_0 (control) for the first year trial. In second-year trial (2023-24) minimum (25.33) days for fruit maturity were recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 25.67 under T_{11} (100 ppm ZnO + 100 ppm FeO) while the maximum (30.00) days taken for fruit maturity were recorded under the treatment T_0 (control). Pooling the Data for both the years (2022-23 and 2023-24) minimum (25.33) days taken for maturity followed by 26.17 were observed under treatment T_9 (50 ppm ZnO + 150 ppm FeO) while the maximum (29.17) days taken for fruit maturity were recorded under the treatment T_0 (control).

The Data recorded on days taken for fruit maturity under open field conditions presented in Table 4.14 and represented graphically in Figure 4.14 showed significant variation among the treatments with the application of different levels of Zno and FeO. During (2022-23), minimum (25.33) days for fruit maturity were recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 26.00 under T_9 (50 ppm ZnO + 150 ppm FeO) while the maximum (28.33) days taken for fruit maturity were recorded under the treatment T_0 (control). In second-year trial (2023-24) minimum (25.33) days for fruit maturity were observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 25.67 under T_{11} (100 ppm ZnO + 100 ppm FeO) while the maximum (30.00) days taken for fruit maturity were recorded under the treatment T_0 (control). Pooling the Data for both the years (2022-23 and 2023-24) recorded the minimum (25.33) days taken for maturity followed by 26.17 under T_9 (50 ppm ZnO + 150 ppm FeO) while the maximum (29.17) days taken for fruit maturity were recorded under the treatment T_0 (control).

It is obvious that zinc reduces the days taken for fruit maturity by improving nutrient uptake and metabolic efficiency and helps to increase bioavailability of nano-sized nutrients ensures that plants receive optimal levels of nutrition to the plant, which are critical for enzymatic activities and hormone synthesis while, iron plays critical role in chlorophyll synthesis and energy production appears to accelerate the maturation process. These observations are aligned with the findings of Subbaiah *et al.*, (2016); Ali *et al.*, (2019); Bhoyar *et al.*, (2016); Jat *et al.*, (2014) and Nitin *et al.*, (2012), supporting the impact of Zn and Fe on fruit development and maturation.

Table 4.14: Effect of Nano- ZnO and FeO on Days taken for fruit maturity of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Days taken for fruit maturity						
Treatments	**Protected Field Conditions**			**Open Field Conditions**		
	2022-23	**2023-24**	**Pooled Mean**	**2022-23**	**2023-24**	**Pooled Mean**
T_0	29.00	28.00	28.50	28.33	30.00	29.17
T_1	28.00	28.00	28.00	28.67	27.00	27.83
T_2	28.00	27.67	27.84	28.33	26.67	27.50
T_3	28.33	27.00	27.67	28.00	27.00	27.50
T_4	26.33	27.00	26.67	27.00	27.67	27.34
T_5	27.67	26.33	27.00	27.33	27.33	27.33
T_6	27.00	27.33	27.17	27.67	25.67	26.67
T_7	26.33	26.33	26.33	28.00	27.00	27.50
T_8	25.67	26.00	25.84	27.00	29.00	28.00
T_9	27.00	26.33	26.67	26.00	26.33	26.17
T_{10}	25.33	26.33	25.83	26.33	27.33	26.83
T_{11}	27.33	26.00	26.67	27.00	25.67	26.34
T_{12}	28.00	27.00	27.50	27.00	26.33	26.67
T_{13}	27.33	27.33	27.33	27.67	27.00	27.33
T_{14}	28.00	26.67	27.34	27.00	26.33	26.67
T_{15}	25.00	25.67	25.34	25.33	25.33	25.33
C.D.	1.374	1.284	1.329	1.652	1.389	1.521
SE(m)	0.473	0.443	0.458	0.569	0.479	0.524
SE(d)	0.669	0.626	0.648	0.805	0.677	0.741
C.V.	3.020	2.859	2.940	3.613	3.073	3.343

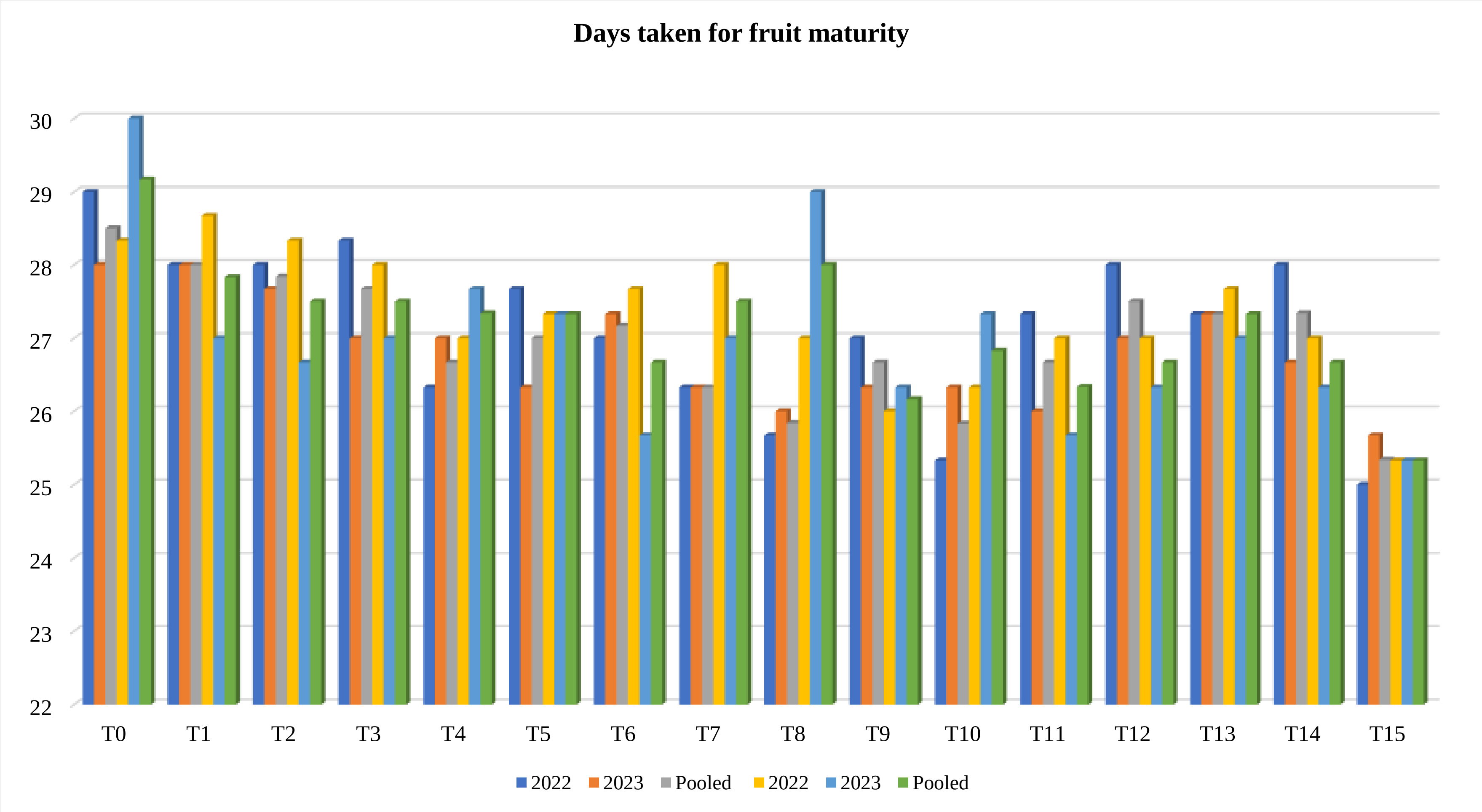

Figure 4.14: Effect of Nano- ZnO and FeO on Days taken for fruit maturity of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.1.15 Yield per plant (gm)

The study of the Table 4.15a revealed that with the application of different levels of ZnO and FeO had significant variations among the treatments regarding yield under protected and open field conditions. During (2022-23), maximum (299.00 gm) yield per plant was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 270.00 gm under T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (174.70 gm) yield plant^{-1} was observed under the treatment T_0 (control) for the first year research trial. In the second-year trial (2023-24) maximum (272.30 gm) yield plant^{-1} was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 267.30 gm yield plant^{-1} under T_{14} (150 ppm ZnO + 100 ppm FeO) and the lowest (166.70 gm) yield per plant was noticed under the treatment T_0 (control). The study of the pooled Data presented in the Table (4.15) indicated maximum (285.67 gm) yield per plant was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 170.67 gm under T_{14} (150 ppm ZnO + 100 ppm FeO) and minimum yield plant^{-1} was observed under the treatment T_0 (control).

The Data presented in the Table 4.15b indicated significant variations amomg the treatments with the application of Zno and FeO at different levels for the yield under open field conditions. Maximum (297.00 gm) yield per plant was observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 232.30 gm under the treatment T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (171.70 gm) yield per plant under the treatment T_0 (control) during (2022-23). In the second-year trial (2023-24) maximum (228.00 gm) yield per plant under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 223.70 gm under T_{13} (150 ppm ZnO + 50 ppm FeO) and minimum (162.00 gm) yield per plant under the treatment T_0 (control). The study of the pooled Data presented in table (4.14b) revealed maximum (262.50 gm) yield per plant was observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 223.67 gm under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (166.83 gm) yield per plant was observed under the treatment T_0 (control).

It is obvious that Zn and Fe plays a significant role in boosting yield and inenhancing vital plant function. The zinc seems to be helpful in the improvement of the plant's ability in absorbing and utilizing nutrients more efficiently resulting in better root development and overall plant growth. This ultimately has led to more robust root formation and maturation. Besides this the enzymatic activities seems to have activated by the application of Zn. Contributing to various metabolic processes that influence photosynthesis, respiration, and stress response. These findings are supported by the findings of Raliya *et al.,* (2015).

The presence of sufficient zinc has been helpful in enhancing the transport of auxins from the shoot apex to other parts of the plant, further stimulating petiole growth. zinc helps maintain the integrity of cellular membranes by stabilizing their structure and regulating ion transport within the plant to ensures essential nutrients and water are efficiently and promoting overall productivity meanwhile iron is crucial for maintaining healthy chlorophyll levels and energy production, which are essential for photosynthesis. The present findings are in conformity to the findings of Zafar *et al.,* (2018). Together, these micronutrients seem to have played synergetic effect in the physiological processes involved in nutrient assimilation, energy metabolism and hormonal regulation, ultimately boosting fruit yield and quality. The present findings are align with the findings of Sharma *et al.,* 2017; Raliya *et al.,* 2015 and Zafar *et al.,* (2019); Mishra *et al.,* (2016); Ahmad *et al.,* (2012) and Laware *et al.,* (2014).

Table 4.15: Effect of Nano- ZnO and FeO on Yield per plant (g) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Treatments	Yield per plant (g)					
	Protected Field Conditions			Open Field Conditions		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
T_0	132.43	110.45	121.44	154.58	120.16	137.37
T_1	155.35	112.80	134.08	167.68	132.68	150.18
T_2	160.44	110.45	135.45	170.30	127.67	148.99
T_3	168.08	115.15	141.62	178.16	137.68	157.92
T_4	173.17	119.85	146.51	191.26	147.70	169.48
T_5	180.81	124.55	152.68	188.64	132.68	160.66
T_6	152.80	119.85	136.33	170.30	142.69	156.50
T_7	173.17	126.90	150.04	220.08	140.19	180.14
T_8	152.80	133.95	143.38	175.54	145.19	160.37
T_9	168.08	155.10	161.59	196.50	135.18	165.84
T_{10}	188.45	148.05	168.25	172.92	152.70	162.81
T_{11}	170.63	164.50	167.57	206.98	172.73	189.86
T_{12}	170.63	152.75	161.69	186.02	152.70	169.36
T_{13}	173.17	138.65	155.91	180.78	147.70	164.24
T_{14}	178.27	138.65	158.46	186.02	155.21	170.62
T_{15}	219.01	176.25	197.63	214.84	187.75	201.30
C.D.	3.056	6.653	4.855	7.355	4.407	5.881
SE(m)	8.390	5.738	8.564	7.871	4.964	8.918
SE(d)	9.108	8.115	6.112	6.203	7.020	6.612
C.V.	4.971	4.837	3.904	4.690	4.490	4.590

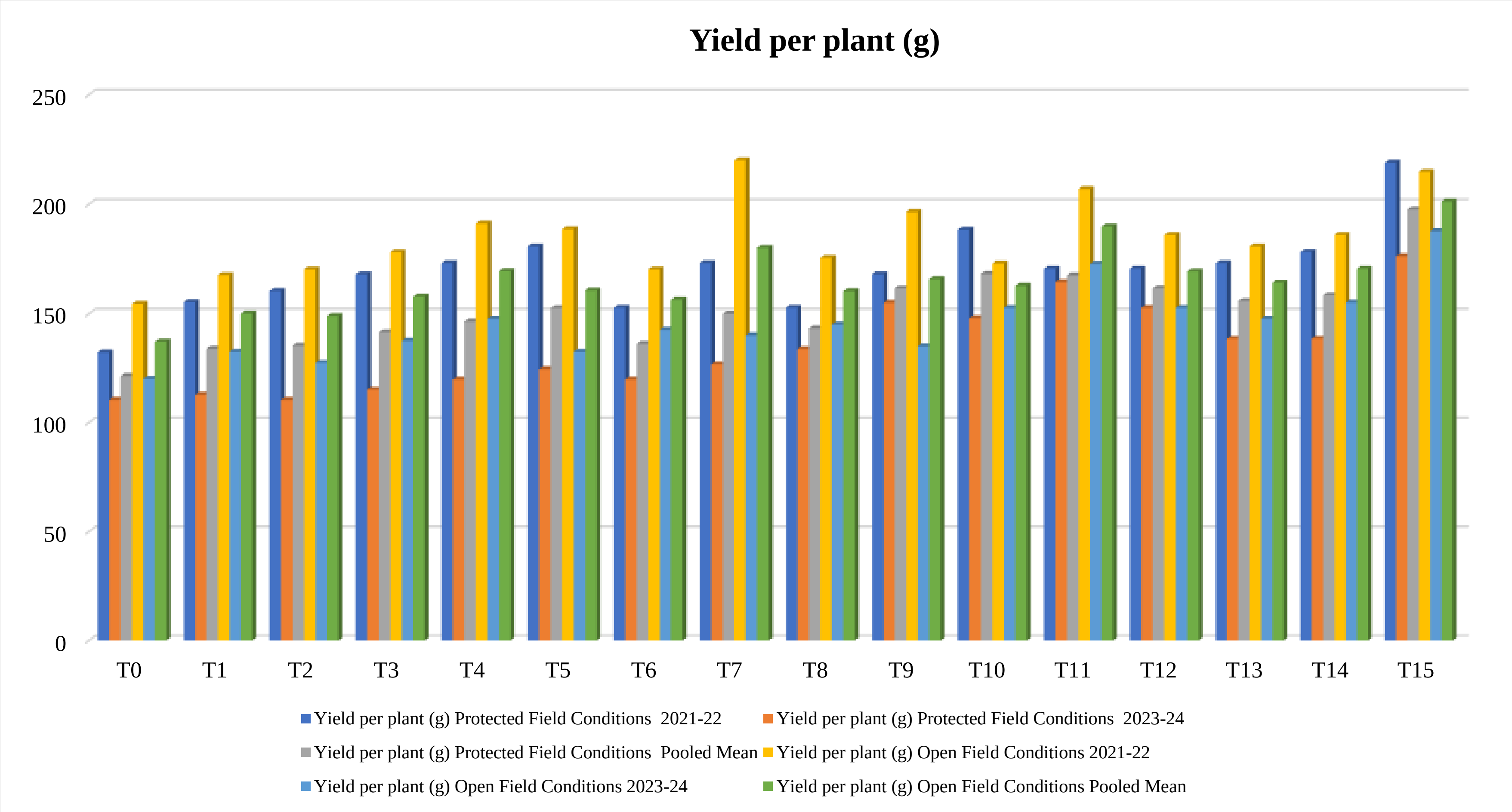

Figure 4.15: Effect of Nano- ZnO and FeO on Yield per plant (g) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.1.16 Fruit length (mm)

The Data for fruit length under protected conditions presented in Table 4.16 and indicated that each of treatment has significant variation, during (2022-23) recorded the maximum (44.87 mm) fruit length under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 44.73 mm under T_5 (100 FeO) while the minimum (41.19 mm) fruit length was recorded under the treatment T_0 (control). In second-year trial (2023-24), maximum (45.52) fruit length was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 45.48 mm under T_7 (50 ppm ZnO + 50 ppm FeO) while the minimum (40.38) was noticed under the treatment T_0 (control). Pooling the Data for both the years (2022-23 and 2023-24) recorded the maximum (45.20 mm) fruit length under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 45.42 mm in T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (40.79 mm) fruit length was noticed under the treatment T_0 (control).

The study of Table 4.16 and Figure 4.16 revealed that, significant variations exist among all the treatments under protected condition for fruit length. During (2022-23), maximum (45.85 mm) fruit length was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 45.14 mm under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (42.97 mm) fruit length was recorded under the treatment T_0 (control). In second-year trial (2023-24) recorded the maximum (44.51 mm) fruit length under the treatment T_7 (50 ppm ZnO + 50 ppm FeO) followed by 44.41 mm under T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (41.70) fruit length was recorded under the treatment T_0 (control). Pooling the Data for both the years (2022-23 and 2023-24) recorded the maximum (45.12 mm) fruit length under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 44.76 mm under T_7 (50 ppm ZnO + 50 ppm FeO) and least (42.34 mm) fruit length was noted under the treatment T_0 (control).

The zinc plays a significant role in increasing fruit length, likely due to its impact on enhancing nutrient absorption and plant growth mechanisms which ultimately improved bioavailability of other micronutrients facilitates efficient uptake, supporting better cellular processes and hormonal regulation besides this zinc is involved in auxin production, promoting cell elongation and fruit development, while iron supports chlorophyll synthesis and energy metabolism, both contributing to longer fruit length. These results are consistent with the studies of Dimkpa *et al.,* (2016); Naderi *et al.,* (2013); Pathak *et al.,* (2011) and Yoon *et al.,* (2017).

Table 4.16: Effect of Nano- ZnO and FeO on Fruit length (cm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Fruit length (mm)						
Treatments	**Protected Field Conditions**			**Open Field Conditions**		
	2022-23	**2023-24**	**Pooled Mean**	**2022-23**	**2023-24**	**Pooled Mean**
T_0	41.19	40.38	40.79	42.97	41.70	42.34
T_1	43.44	42.08	42.76	43.35	42.81	43.08
T_2	44.47	40.37	42.42	43.92	43.22	43.57
T_3	45.49	43.68	44.59	44.29	42.50	43.40
T_4	44.36	42.85	43.61	44.37	42.48	43.42
T_5	44.73	44.21	44.47	44.22	41.61	42.92
T_6	44.45	44.38	44.42	44.04	41.54	42.79
T_7	44.70	45.48	45.09	45.01	44.51	44.76
T_8	46.48	43.51	45.00	43.97	42.56	43.27
T_9	47.52	43.31	45.42	44.44	42.47	43.46
T_{10}	43.49	43.58	43.54	44.48	42.49	43.49
T_{11}	44.26	43.78	44.02	45.14	43.68	44.41
T_{12}	44.21	45.01	44.61	43.93	42.29	43.11
T_{13}	44.50	44.65	44.58	44.41	44.41	44.41
T_{14}	44.69	42.00	43.35	43.55	43.66	43.61
T_{15}	44.87	45.52	45.20	45.85	44.39	45.12
C.D.	1.961	1.984	1.973	1.168	1.939	1.554
SE(m)	0.676	0.684	0.680	0.402	0.668	0.535
SE(d)	0.956	0.967	0.962	0.569	0.945	0.757
C.V.	2.627	2.727	2.677	1.575	2.698	2.137

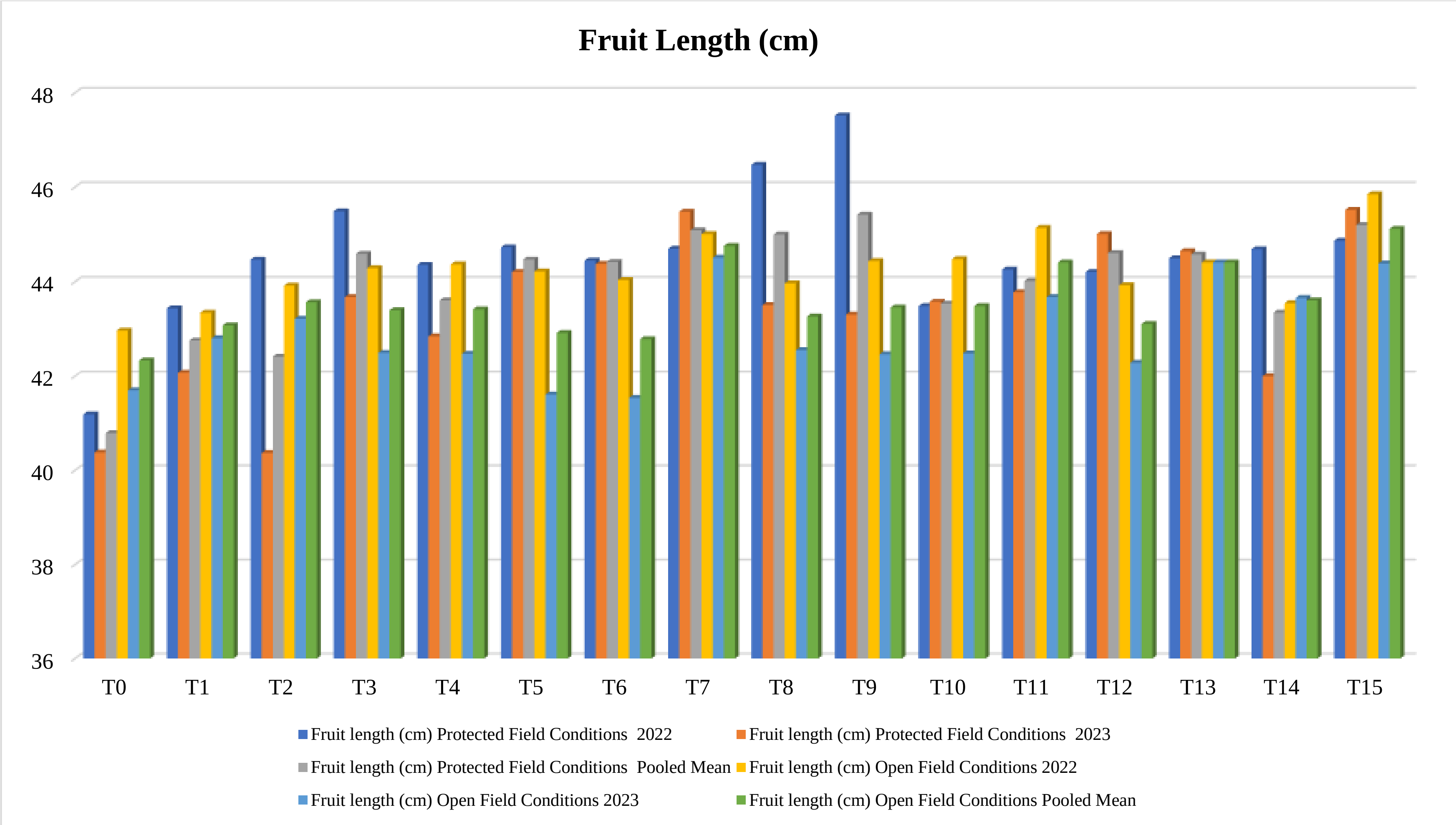

Figure 4.16: Effect of Nano- ZnO and FeO on Fruit length (cm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.1.17 Fruit breadth (mm)

The Data on fruit breadth (mm) under protected conditions tabulated in Table 4.17 in which each of the treatments has significant variation with breadth of fruits. During (2022-23), maximum (28.35 mm) fruit breadth was noticed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 27.60 mm under T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (21.15 mm) of fruit breadth was noted in treatment T_0 (control) for first year research trial. In second year, trial (2023-24) maximum (26.65 mm) fruit breadth was recorded under the treatment T_9 (50 ppm ZnO + 150 ppm FeO) followed by 26.40 mm under T_{15} (150 ppm ZnO + 150 ppm FeO). Combining the Data of both the years (2022-23 and 2023-24) showed the maximum (27.38 mm) fruit breath under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 27.12 mm under T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (20.24mm) fruit breadth remained under the treatment T_0 (control).

The Data on fruit breadth under open field conditions presented in Table 4.1 revealed that, during (2022-23) maximum fruit breadth (27.83 mm) was observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 25.96 mm under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (21.18 mm) fruit breadth was noted in the treatment T_0 (control). In second-year trial (2023-24) recorded the maximum (24.76 mm) fruit breadth was noted under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 24.64 mm under T_9 (50 ppm ZnO + 150 ppm FeO). Combining the Data of both the years (2022-23 and 2023-24) showed the maximum (26.30 mm) fruit breath was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 25.20 mm under T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (21.20) fruit breadth remained under the treatment T_0 (control).

There are various enzymes involved in the synthesis of of proteins, carbohydrates, and auxins and zinc plays a crucial role as a cofactor for these enzymes. Auxins, as plant hormones, are essential for regulating cell elongation, division, and expansion, thereby supporting fruit enlargement. This highlights zinc's pivotal involvement in these growth processes. Similarly, iron facilitates chlorophyll production and metabolic activities, aiding the development of larger fruits. Efficient respiration, ensuring adequate energy production in the form of ATP, is vital for supporting active growth processes such as cell division and fruit elongation. These findings are aligned with the findings made by Zafar *et al.*, (2019); Arvind *et al.*, (2012); Jat *et al.*, (2014); Kazemi *et al.*, (2014); Maurya *et al.*, (2016); Naderi *et al.*, (2013) and Reddy *et al.,* (2021).

Table 4.17: Effect of Nano- ZnO and FeO on fruit breadth (mm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions

Treatments	Fruit bredth (mm)					
	Protected Field Conditions			Open Field Conditions		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_0	21.15	19.32	20.24	21.18	21.21	21.20
T_1	21.09	22.56	21.82	21.48	20.59	21.04
T_2	21.14	23.23	22.18	22.12	22.72	22.42
T_3	22.28	23.33	22.81	21.66	22.42	22.04
T_4	21.37	21.42	21.40	20.78	21.57	21.18
T_5	24.59	23.36	23.98	23.90	22.28	23.09
T_6	25.87	25.44	25.65	24.61	22.46	23.53
T_7	23.25	24.33	23.79	24.86	23.08	23.97
T_8	21.78	22.51	22.15	21.73	21.63	21.68
T_9	27.60	26.65	27.12	25.75	24.64	25.19
T_{10}	25.30	23.44	24.37	23.49	23.83	23.66
T_{11}	24.75	24.68	24.72	25.96	24.11	25.04
T_{12}	26.53	23.55	25.04	25.48	22.78	24.13
T_{13}	25.13	24.56	24.84	24.81	23.58	24.20
T_{14}	24.79	23.55	24.17	24.18	23.59	23.89
T_{15}	28.35	26.40	27.37	27.83	24.76	26.29
C.D.	3.466	1.723	2.595	2.958	1.932	2.445
SE(m)	1.194	0.594	0.894	1.019	0.666	0.843
SE(d)	1.689	0.840	1.265	1.441	0.941	1.191
C.V.	8.597	4.349	6.473	7.437	5.050	6.244

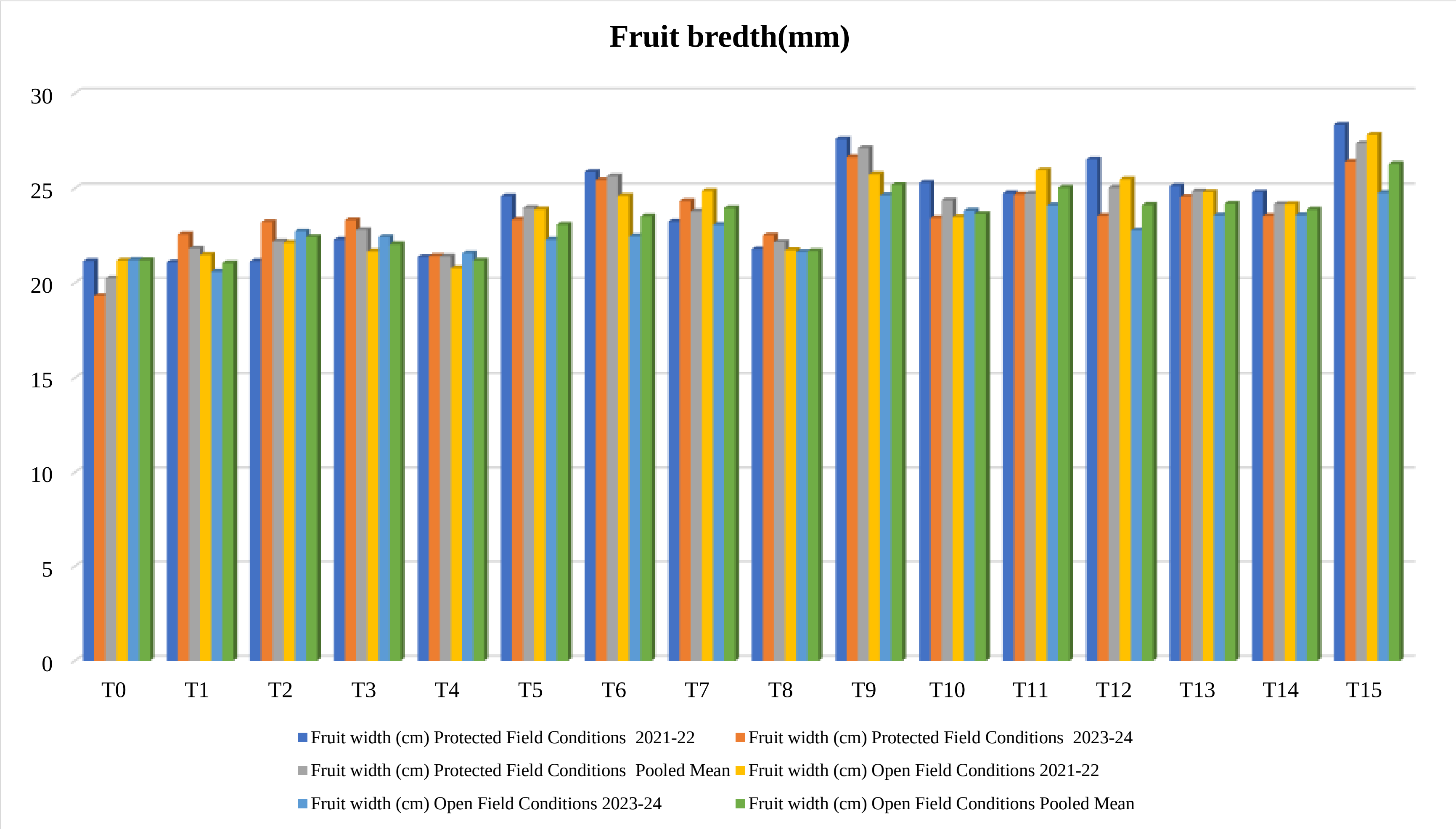

Figure 4.17: Effect of Nano- ZnO and FeO on Fruit width (mm) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.1.18 Fruit weight (gm)

The Data on fruit weight, as shown in Table 4.18 and illustrated in Figure 4.18, indicated significant differences across treatments with various levels of Nano-ZnO and FeO. In the 2022-23 trial, the highest fruit weight of 11.91 grams was recorded with treatment T_{15} (150 ppm ZnO + 150 ppm FeO), followed closely by 11.89 grams with T_9 (50 ppm ZnO + 150 ppm FeO). The lowest fruit weight of 7.64 grams was observed in the control group (T_0). In the following year, 2023-24, the highest fruit weight of 10.93 grams was again seen with T_{15} (150 ppm ZnO + 150 ppm FeO), followed by T_{11} (100 ppm ZnO + 100 ppm FeO). The control group (T0) recorded the lowest fruit weight of 7.05 grams. Combining the Data of both the years (2022-23 and 2023-24) showed the maximum (11.42 gm) fruit weight was noted under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (7.35 gm) fruit weight remained under the treatment T_0 (control).

The Data on fruit weight under open field conditions presented in Table 4.18 and revealed that for first-year trial (2022-23) maximum (11.74 gm) fruit breadth was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 11.38 gm under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (7.86 gm) fruit weight was recorded under the treatment T_0 (control). In second-year trial (2023-24) recorded the maximum (10.55 gm) fruit weight under the treatment T_9 (50 ppm ZnO + 150 ppm FeO) followed by 10.52 gm under T_{15} (150 ppm ZnO + 150 ppm FeO) while the minimum (7.51 gm) was recorded under T_0 (control). Combining the Data of both the years (2022-23 and 2023-24) showed the maximum (11.13 gm) fruit weight under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 10.96 gm under T_{11} (100 ppm ZnO + 100 ppm FeO) with the value of while the minimum (7.69 gm) fruit breadth remained under the treatment T_0 (control).

It is obvious that Zn and Fe enhance the weight of fruit of strawberries by optimizing nutrient uptake and boosting plant metabolic functionsa and helps to improves their absorption and utilization, which in turn supports higher levels of growth hormones and chlorophyll production ultimately has led to more fruit weight. Zinc facilitates the production of hormones that encourage fruit weight, meanwhile iron improves energy metabolism and overall plant health, leading to larger and heavier fruits. The results are corroborated with the observations of Raliya *et al.,* (2013); Rawat *et al.,* (2010); Parveen *et al.,* (2002); Sajid *et al.,* (2012) and Yadav *et al.,* (2011).

Table 4.18: Effect of Nano- ZnO and FeO on Fruit weight (g) of Strawberry (Fragaria × ananassa Duch.) cv. Winter Dawn under protected and open conditions

Fruit weight (g)						
Treatments	Protected Field Conditions			Open Field Conditions		
	2022-23	**2023-24**	**Pooled Mean**	**2022-23**	**2023-24**	**Pooled Mean**
T_0	7.64	7.05	7.35	7.86	7.51	7.69
T_1	8.90	7.35	8.13	8.93	7.53	8.23
T_2	9.81	8.19	9.00	9.78	8.36	9.07
T_3	10.55	9.23	9.89	10.37	7.81	9.09
T_4	10.67	9.11	9.89	10.59	9.49	10.04
T_5	11.48	10.79	11.14	10.37	7.66	9.01
T_6	11.37	9.74	10.55	10.00	9.29	9.65
T_7	8.05	8.69	8.37	11.32	9.67	10.49
T_8	9.02	9.41	9.22	9.63	9.38	9.51
T_9	11.89	10.52	11.21	10.67	10.55	10.61
T_{10}	10.09	10.06	10.08	10.62	10.46	10.54
T_{11}	9.92	10.85	10.39	11.38	10.53	10.96
T_{12}	10.38	10.80	10.59	10.87	9.77	10.32
T_{13}	9.79	10.01	9.90	10.59	9.67	10.13
T_{14}	9.82	9.93	9.87	10.71	9.60	10.16
T_{15}	11.91	10.93	11.42	11.74	10.52	11.13
C.D.	1.448	1.140	1.294	1.243	1.408	1.326
SE(m)	0.499	0.393	0.446	0.428	0.485	0.457
SE(d)	0.705	0.556	0.631	0.606	0.686	0.646
C.V.	8.571	7.133	7.852	7.173	9.098	8.136

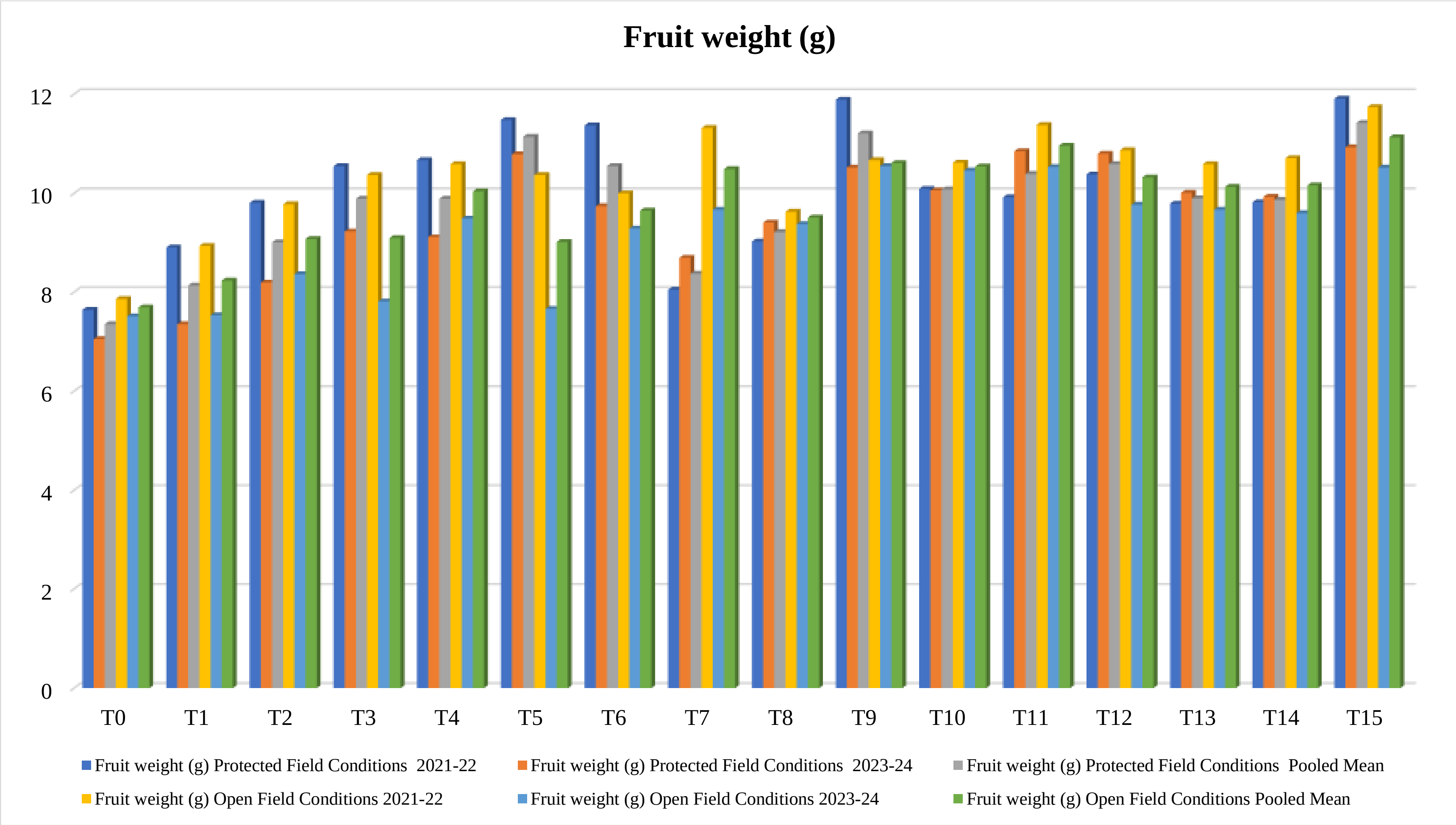

Figure 4.18: Effect of Nano- ZnO and FeO on Fruit weight (g) of Strawberry (Fragaria × ananassa Duch.) cv. Winter Dawn under protected and open conditions

4.1.19 Number of harvestings

The Data on the number of harvests under protected conditions, shown in Table 4.19, revealed significant differences among treatments using Nano-ZnO and FeO. In the first-year trial (2022-23), the highest number of harvests, 6.00, was achieved with treatment T_{15} (150 ppm ZnO + 150 ppm FeO), followed by 5.50 with T_{10} (100 ppm ZnO + 50 ppm FeO). The lowest number of harvests, 3.33, was observed in the control group (T_0). In the second-year trial (2023-24) maximum (4.67) number of harvestings were recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 4.33 under the treatment T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (2.33) was recorded under T_0 (control). The pooled analysis of both the years (2022-23 and 2023-24) recorded the maximum (5.33) number of harvestings under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by T_{10} (100 ppm ZnO + 50 ppm FeO) while the least (2.83) number of harvestings were noted under the treatment (T_0) control.

The Data on the number of harvestings under open conditions presented in Table 4.19b and represented graphically in Figure 4.19b revealed that during first-year trial (2022-23) maximum (5.33) number of harvestings were recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 5.00 under T_{12} (100 ppm ZnO + 150 ppm FeO) while the minimum (3.00) were recorded under the treatment T_0 (control). In second-year trial (2023-24) maximum number of harvestings (4.33) were observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 4.67 under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (3.67) was recorded under the treatment T_0 (control). The pooled analysis of both the years (2022-23 and 2023-24) recorded the maximum (4.83) number of harvestings under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 4.67 under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (3.33) number of harvestings were noted in treatment (T_0) control.

The application of zinc and iron significantly increases the number of harvests in strawberry plants by enhancing key physiological processes within the plant. This might be due to zinc's crucial role in enzyme activation and protein synthesis, which are essential for cell division, growth, and the development of reproductive organs. Zinc also influences auxin metabolism, leading to improved fruit set and retention. Similarly, iron is essential for chlorophyll formation, which enhances photosynthesis and energy production, fueling continuous flowering and fruiting. This is prominent in the way ZnO and FeO collectively improve plant vigor, nutrient uptake, and stress resistance, resulting in extended flowering periods and more frequent harvests. The results from the present studies are align with the findings of Ali *et al.,* (2019); Pippal *et al.,* (2019); Saini *et al.,* (2021) and Li *et al.,* (2022).

Table 4.19: Effect of Nano- ZnO and FeO on Number of Harvesting of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Number of Harvesting						
Treatments	Protected Field Conditions			Open Field Conditions		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
T_0	3.33	2.33	2.83	3.00	3.67	3.34
T_1	4.33	3.00	3.67	4.00	3.33	3.67
T_2	4.00	3.67	3.84	4.00	3.33	3.67
T_3	4.67	3.33	4.00	3.67	4.33	4.00
T_4	3.67	3.00	3.34	4.00	4.33	4.17
T_5	3.67	3.33	3.50	4.33	3.33	3.83
T_6	4.67	3.67	4.17	3.67	3.67	3.67
T_7	3.67	3.33	3.50	4.67	4.67	4.67
T_8	4.67	4.33	4.50	3.67	3.67	3.67
T_9	5.00	3.67	4.34	4.67	3.33	4.00
T_{10}	5.67	3.67	4.67	4.67	3.67	4.17
T_{11}	4.67	4.33	4.50	4.67	4.67	4.67
T_{12}	4.00	3.33	3.67	5.00	3.67	4.34
T_{13}	4.33	2.67	3.50	4.67	3.33	4.00
T_{14}	4.00	3.33	3.67	4.00	4.67	4.34
T_{15}	6.00	4.67	5.34	5.33	4.33	4.83
C.D.	1.073	1.094	1.084	1.321	0.975	1.148
SE(m)	0.370	0.377	0.374	0.503	0.336	0.420
SE(d)	0.523	0.533	0.528	0.712	0.475	0.594
C.V.	4.561	8.768	6.665	4.509	5.023	7.766

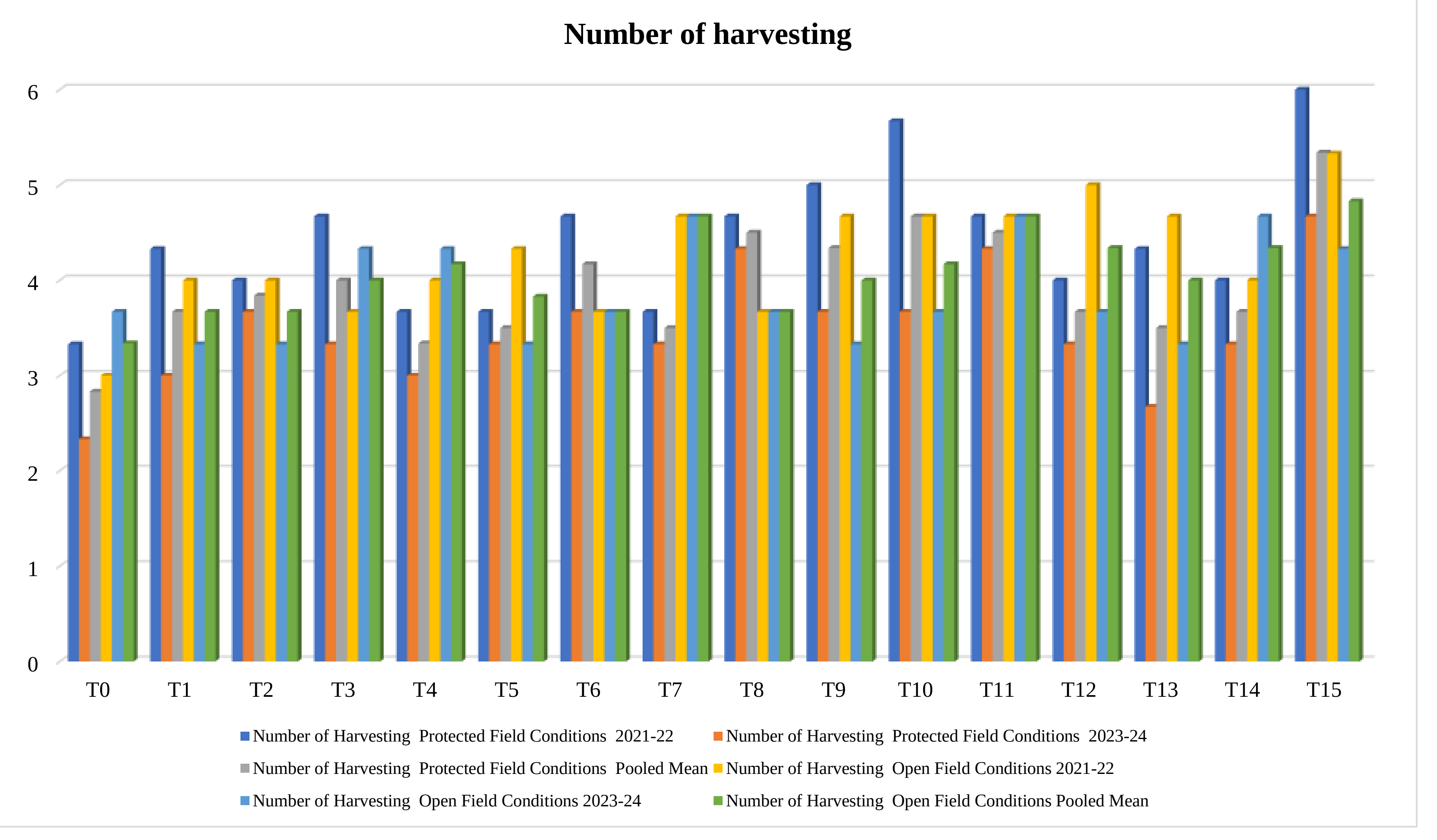

Figure 4.19: Effect of Nano- ZnO and FeO on Number of Harvesting of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.1.20 Duration of harvesting

The Data on harvesting duration under protected conditions, detailed in Table 4.20 and illustrated in Figure 4.20, showed significant differences across treatments with Nano-ZnO and FeO. During the 2022-23 trial, the longest harvesting duration of 57.33 days was observed with treatment T_{15} (150 ppm ZnO + 150 ppm FeO), followed by 55.67 days with T_{13} (150 ppm ZnO + 50 ppm FeO). The shortest duration of 45.00 days was recorded in the control group (T_0). In the second year (2023-24), the longest duration of 57.00 days was again seen with T_{15}, while T_{13} recorded 54.00 days, and the control group had a duration of 46.00 days. Combining Data from both years (2022-23 and 2023-24), the average longest harvesting duration was 57.17 days for T_{15}, followed by 54.83 days for T_{13}, with the control group having an average of 45.50 days.

The Data on harvesting duration under open field conditions, as shown in Table 4.20, indicated significant differences among treatments. In the 2022-23 trial, the longest harvesting duration of 56.00 days was observed with treatment T_{15} (150 ppm ZnO + 150 ppm FeO), followed by 53.33 days with T_{13} (150 ppm ZnO + 50 ppm FeO). The shortest duration of 44.00 days was recorded in the control group (T_0). In the subsequent year (2023-24), the longest harvesting duration of 56.00 days was noted with T_{13}, while T_{15} had 54.67 days, and the control group had 42.67 days. Combining the Data from both years, the average longest harvesting duration was 55.33 days for T_{15}, 54.67 days for T_{13}, and 43.33 days for the control (T_0).

The application of nano zinc and iron significantly extends the duration of harvesting by enhancing key physiological processes like zinc increases chlorophyll content, improving photosynthetic efficiency and delaying plant senescence, thereby supporting prolonged fruiting. Additionally, nano zinc boosts antioxidant defenses, protecting plants from oxiDAPive stress and extending their productive lifespan while, iron on the other hand, plays a crucial role in metabolic processes and nutrient assimilation, ensuring a steady supply of essential nutrients that sustain fruit development over an extended period. These combined effects collectively prolong the harvestable period of strawberries by maintaining plant vigor and resilience. The results from the present findings are align with the studies of Ali *et al.,* (2021): Tahir *et al.,* (2020); Saini *et al.,* (2021); Taha *et al.,* (2017); Malik *et al.,* (2000); Ahmad *et al.,* (2017) and Kumar & Verma (2019).

Table 4.20: Effect of Nano- ZnO and FeO on Duration of Harvesting of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Treatments	Duration of Harvesting					
	Protected Field Conditions			Open Field Conditions		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
T_0	45.00	46.00	45.50	44.00	42.67	43.34
T_1	47.67	48.00	47.84	47.00	45.67	46.34
T_2	46.67	51.00	48.84	47.67	46.00	46.83
T_3	49.00	48.00	48.50	48.33	45.33	46.83
T_4	49.33	48.33	48.83	49.00	47.67	48.34
T_5	49.67	50.00	49.84	49.00	46.67	47.84
T_6	51.33	49.00	50.17	50.67	50.00	50.33
T_7	53.67	52.00	52.84	53.00	51.67	52.34
T_8	55.67	53.00	54.34	52.67	54.67	53.67
T_9	51.00	54.00	52.50	52.33	53.00	52.67
T_{10}	54.00	54.00	54.00	52.33	54.33	53.33
T_{11}	51.00	57.00	54.00	53.00	54.00	53.50
T_{12}	53.33	50.00	51.67	53.00	54.33	53.67
T_{13}	55.67	54.00	54.84	53.33	56.00	54.67
T_{14}	55.33	53.00	54.17	55.00	53.00	54.00
T_{15}	57.33	57.00	57.17	56.00	54.67	55.34
C.D.	2.813	1.586	2.200	3.125	2.710	2.918
SE(m)	0.969	0.546	0.758	1.077	0.934	1.006
SE(d)	1.371	0.773	1.072	1.523	1.321	1.422
C.V.	3.253	1.837	2.545	3.656	3.197	3.427

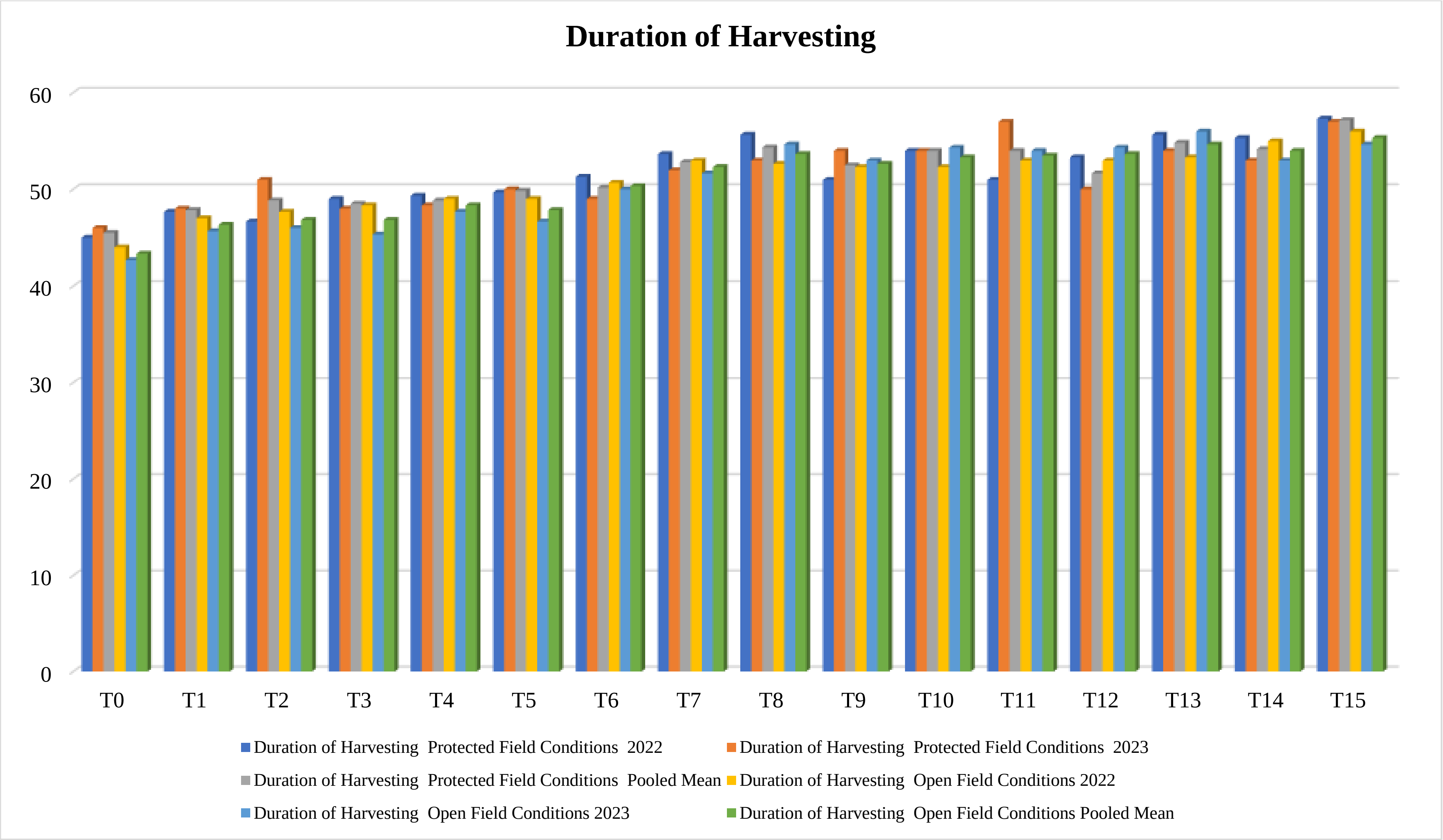

Figure 4.20: Effect of Nano- ZnO and FeO on Duration of Harvesting of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.1.21 Number of crowns

The Data collected for no. of crowns presented in Table 4.21 indicated significant variations among the treatments with the application of Nano-ZnO and FeO at different concentrations under protected and natural growing conditions. During (2022-23), maximum (3.67) no. of crowns were recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 3.00 under treatment T_{12} (100 ppm ZnO + 150 ppm FeO) while the minimum (2.33) were reported under the treatment (T_0) control. In the second-year trial (2023-24), maximum (3.67) no. of crowns were noted under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 3.33 under treatment T_{13} (150 ppm ZnO + 50 ppm FeO) and the minimum (2.33) were reported under the treatment (T_0) control. Pooled analysis of both the years (2022-23 and 2023-24) revealed the maximum (3.67) no. of crowns were observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 3.33 under T_{10} (100 ppm ZnO + 50 ppm FeO) while the minimum (2.33) was reported under the treatment (T_0) control.

The Data pertaining to number of crowns under open field conditions tabulated in Table 4.21 and revealed significant variations among the treatements, during (2022-23) maximum (4.33) number of crowns were noticed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 3.67 under T_{14} (150 ppm ZnO + 100 ppm FeO) while the minimum (2.00) crowns were reported under the treatment (T_0) control for first year research trial. In the second-year trial (2023-24) maximum (3.67) number of crowns were reported under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 3.33 under T_{11} (100 ppm ZnO + 1000 ppm FeO) while the minimum (2.33) crowns were recorded under the treatment (T_0) control. Pooled analysis of both the years (2022-23 and 2023-24) revealed maximum number of crowns (4.00) were observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 3.83 under T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (2.17) were reported under the treatment (T_0) control.

It is obvious that the application of zinc and iron plays a significant role in increasing the number of crowns in strawberry plants by enhancing nutrient uptake efficiency and by improvement of the bioavailability of other, which allows the plants to absorb and utilize these essential micronutrients more effectively. Zinc seems to have contributed towards the development of new growth hormones, resulting in the increased number of crowns, while iron supports enhanced energy production and overall plant health. This is prominent in the way these physiological changes, driven by improved micronutrient absorption, result in robust growth and the development of multiple crowns. Zinc aids in auxin synthesis, stimulating crown formation, while iron supports chlorophyll production and overall plant vigor. These observations from the present studies are align with the findings of Liu *et al.,* (2015); Bakshi *et al.,* (2013); Hafeez *et al.,* (2013); Lee *et al.,* (2018); Meena *et al.,* (2024); Bharti *et al.,* (2020) and Nandita *et al.,* (2020).

Table 4.21: Effect of Nano- ZnO and FeO on Number of Crowns of Strawberry (Fragaria × ananassa Duch.) cv. Winter Dawn under protected and open conditions

Treatments	Number of Crowns					
	Protected Field Conditions			Open Field Conditions		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
T_0	2.33	2.33	2.33	2.00	2.33	2.17
T_1	2.67	3.33	3.00	2.33	2.67	2.50
T_2	2.67	3.33	3.00	2.67	3.33	3.00
T_3	2.67	3.67	3.17	2.33	2.33	2.33
T_4	2.67	2.33	2.50	2.67	3.33	3.00
T_5	2.33	3.33	2.83	2.00	2.67	2.34
T_6	2.33	3.67	3.00	2.67	2.33	2.50
T_7	2.00	3.33	2.67	3.00	2.67	2.84
T_8	2.67	3.67	3.17	2.67	3.33	3.00
T_9	2.67	3.33	3.00	2.67	2.33	2.50
T_{10}	3.00	3.67	3.34	3.33	2.67	3.00
T_{11}	2.33	2.67	2.50	4.33	3.33	3.83
T_{12}	3.00	3.00	3.00	3.33	3.33	3.33
T_{13}	2.00	3.33	2.67	2.67	2.33	2.50
T_{14}	3.00	2.67	2.84	3.67	2.67	3.17
T_{15}	3.67	3.67	3.67	4.33	3.67	4.00
C.D.	1.132	0.935	1.034	1.293	0.961	1.127
SE(m)	0.401	0.322	0.362	0.446	0.331	0.389
SE(d)	0.567	0.455	0.511	0.630	0.468	0.549
C.V.	3.447	2.385	2.856	2.465	3.249	2.835

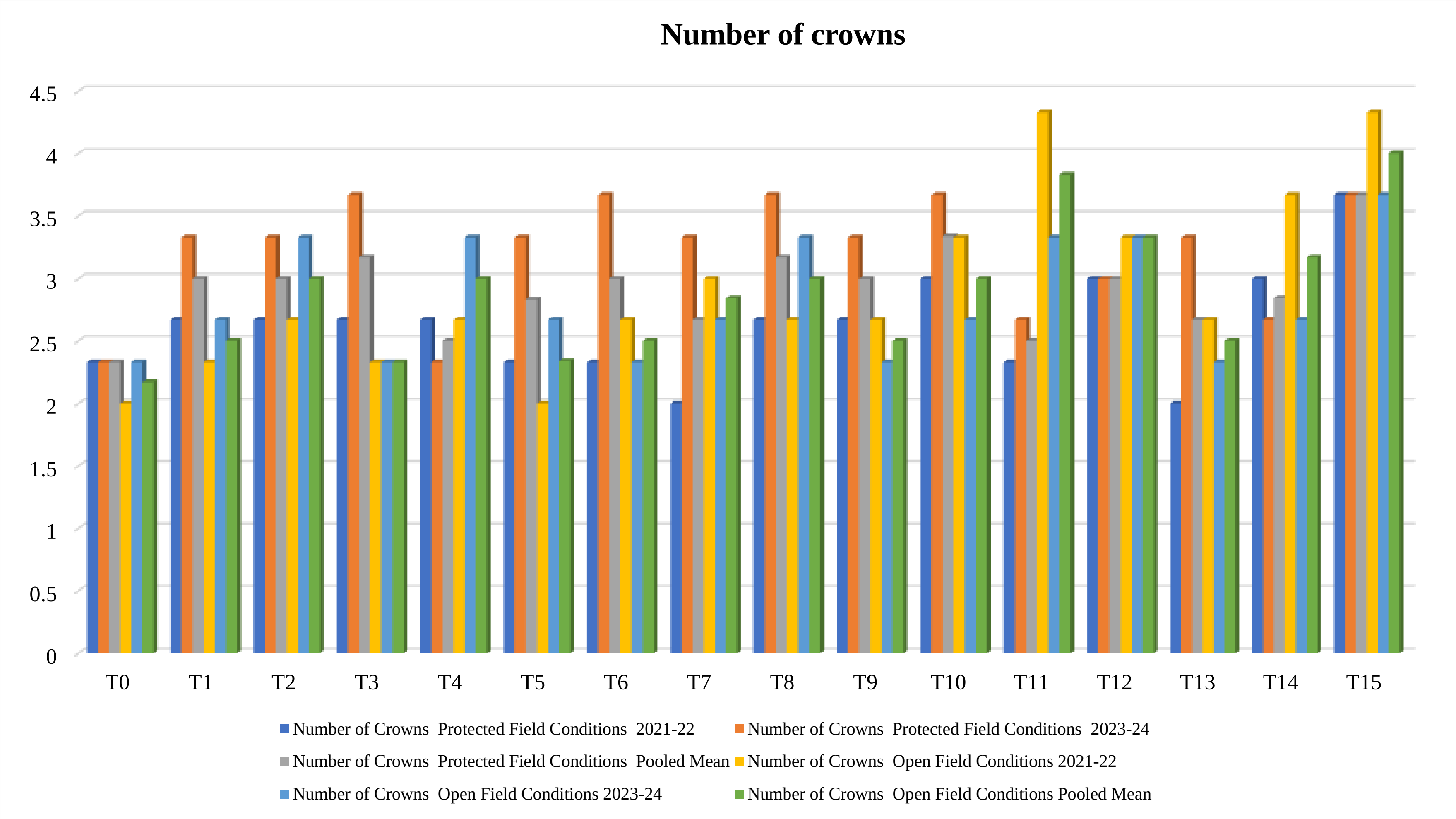

Figure: 4.21: Effect of Nano- ZnO and FeO on Number of Crowns of Strawberry (Fragaria × ananassa Duch.) cv. Winter Dawn under protected and open conditions.

4.1.22 Fruit TSS (°brix)

The study of Table 4.22 and Figure 4.22 revealed that, significant variations exist on Fruit TSS (°brix) across all treatments with the application of different levels of Nano-ZnO and Nano-FeO. For first-year research trial (2022-23) recorded the maximum (6.72 °brix) TSS under T_9 (50 ppm ZnO + 150 ppm FeO) followed by T_6 (150ppm FeO) while the minimum (5.51 °brix) TSS was recorded under T_0 (control). In the second year (2023-24) maximum (6.73 °brix) TSS was noticed under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) followed by 6.68 °brix under T_{14} (150 ppm ZnO + 100 ppm FeO) and minimum (5.44 °brix) TSS was recorded under the treatment T_1 (50ppm ZnO). The pooled analysis of both the years (2022-23 and 2023-24) revealed maximum (6.73 °brix) TSS was recorded under T_{13} (150 ppm ZnO + 50 ppm FeO) followed by 6.63 °brix under T_{14} (150 ppm ZnO + 100 ppm FeO) and the minimum (5.55 °brix) was recorded under T_1 (50ppm ZnO).

The Data pertaining to fruit TSS (°brix) under open field conditions presented in Table 4.22 and revealed significant variations among all the treatments, during (2022-23) maximum TSS (6.85 °brix) was recorded under T_{13} (150 ppm ZnO + 50 ppm FeO) followed by T_8 (50 ppm ZnO + 100 ppm FeO) while the minimum (6.08 °brix) was recorded under T_0 (control). In the second year (2023-24) the maximum (6.70 °brix) TSS was found under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) followed by 6.65 °brix under T_{12} (100 ppm ZnO + 150 ppm FeO) while the minimum (6.19) was recorded under the treatment T_5 (100ppm FeO). The pooled analysis of both the years (2022-23 and 2023-24) revealed the maximum (6.77 °brix) TSS under T_{13} (150 ppm ZnO + 50 ppm FeO) followed by 6.54 °brix TSS under T_6 (150ppm FeO) while the minimum (6.14 °brix) was recorded under T_5 (100ppm FeO).

The zinc and iron play crucial roles in enhancing the total soluble solids (TSS °Brix) in strawberries by improving nutrient uptake and metabolic functions and enhances the plant's ability to produce sugars and other soluble compounds. Zinc is instrumental in key enzymatic reactions involved in sugar metabolism, while iron boosts chlorophyll production and photosynthesis. These effects collectively contribute to higher total sugars in the fruits. The present findings are aligned with the findings of Tarafdar *et al.,* (2014); Tripathi *et al.,* (2018); Dimpka *et al.,* (2016); Singh *et al.,* (2017) and Kumar *et al.,* (2020).

Table 4.22: Effect of Nano- ZnO and FeO on Fruit TSS (º brix) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Fruit TSS (ºbrix)						
	Protected Field Conditions			Open Field Conditions		
Treatments	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
T_0	5.51	5.58	5.55	6.41	6.39	6.40
T_1	5.56	5.44	5.50	6.33	6.34	6.34
T_2	5.70	5.56	5.63	6.10	6.70	6.40
T_3	6.03	5.65	5.84	6.12	6.19	6.16
T_4	6.20	6.00	6.10	6.21	6.44	6.33
T_5	6.04	5.92	5.98	6.08	6.19	6.14
T_6	5.74	5.94	5.84	6.64	6.44	6.54
T_7	6.98	6.11	6.55	6.47	6.34	6.41
T_8	5.58	5.92	5.75	6.57	6.23	6.40
T_9	6.79	5.92	6.36	6.54	6.43	6.49
T_{10}	6.37	6.25	6.31	6.47	6.31	6.39
T_{11}	6.37	6.28	6.33	6.13	6.33	6.23
T_{12}	6.48	6.65	6.57	6.38	6.65	6.52
T_{13}	6.72	6.73	6.73	6.85	6.70	6.78
T_{14}	6.58	6.68	6.63	6.55	6.33	6.44
T_{15}	6.25	6.34	6.30	6.29	6.37	6.33
C.D.	0.367	0.461	0.414	0.341	0.237	0.289
SE(m)	0.127	0.159	0.143	0.221	0.082	0.152
SE(d)	0.179	0.224	0.202	0.313	0.116	0.215
C.V.	3.548	4.536	4.042	6.005	2.214	4.110

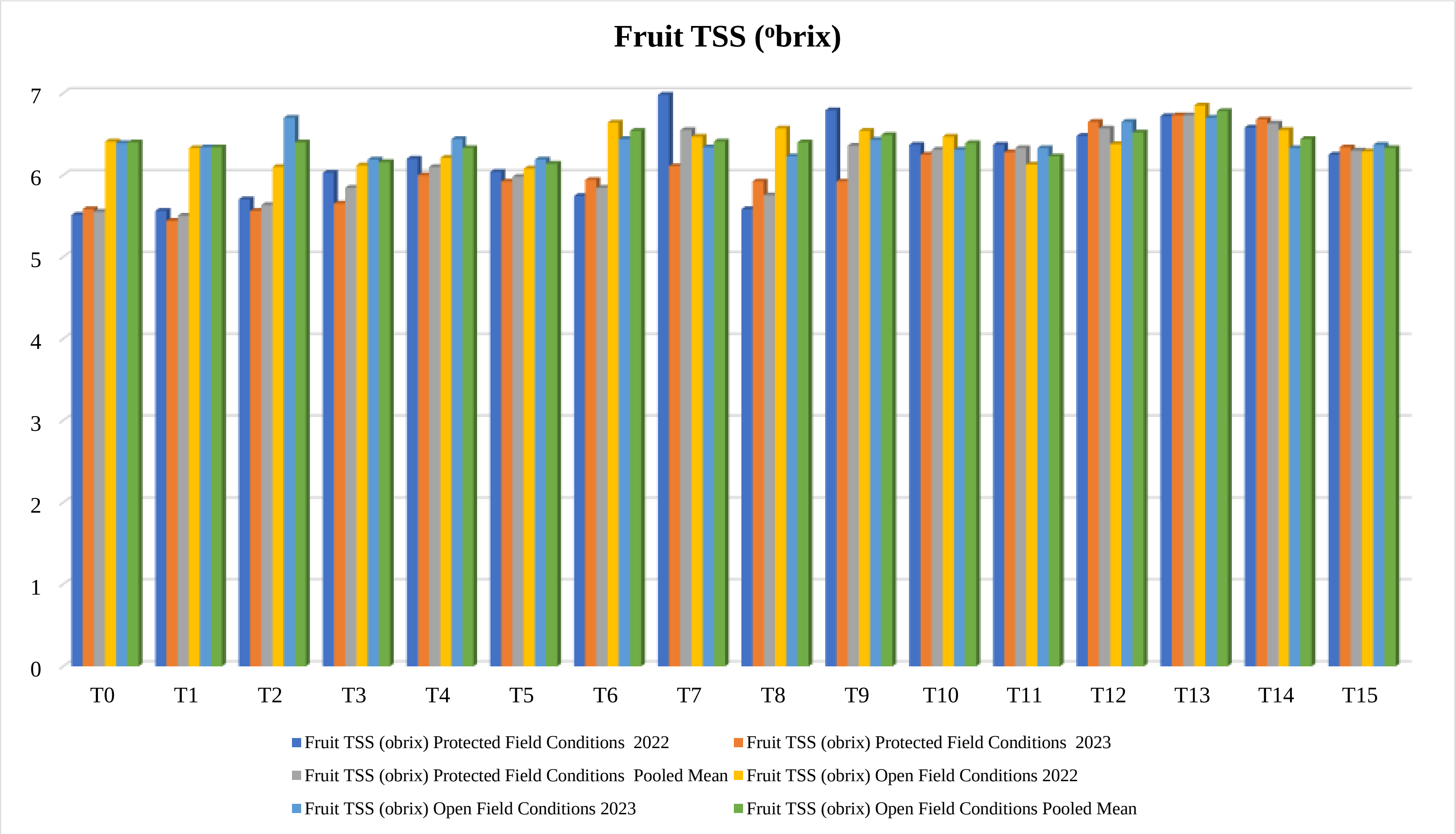

Figure 4.22: Effect of Nano- ZnO and FeO on Fruit TSS (º brix) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.1.23 Acidity (%)

The study of the Table 4.23 revealed significant variations on the Data of fruit acidity growing under protected conditions with the application of different levels of nano-ZnO and FeO. During (2022-23) the maximum (0.72 %) acidity was recorded under T_9 (50 ppm ZnO + 150 ppm FeO) followed by T_{15} (150 ppm ZnO + 150 ppm FeO) while the minimum (0.51 %) was observed under T_0 (control) for first year research trial. In the second year (2023-24) the maximum acidity (0.68%) was noticed under the treatment T_{14} (150 ppm ZnO + 100 ppm FeO) followed by 0.67% under T_9 (50 ppm ZnO + 150 ppm FeO) while lowest (0.47%) was noticed under the treatment T_0 (control). The pooled analysis of both the years (2022-23 and 2023-24) maximum (0.70%) acidity was found under T_9 (50 ppm ZnO + 150 ppm FeO) followed by 0.69% under T_{15} (150 ppm ZnO + 150 ppm FeO) and minimum (0.50%) was recorded under treatment T_1 (50 ppm ZnO).

The Data pertaining on fruit acidity under natural growing conditions presented in Table 4.23 and represented graphically in Figure 4.23 indicates that significant variations exist among all the treatments with the application of Nano-ZnO and FeO at different levels. During (2022-23) maximum (0.70 %) acidity was noted under T_5 (100ppm FeO) followed by T_{15} (150 ppm ZnO + 150 ppm FeO) while the minimum (0.52 %) was recorded under T_1 (50 ppm ZnO). In the second-year (2023-24) maximum acidity (0.72%) was recorded under the treatment T_{13} (150 ppm ZnO + 50 ppm Fe) followed by 0.67% under T_9 (50 ppm ZnO + 150 ppm FeO) and minimum (0.43%) acidity was recorded under the treatment T_0 (control). The pooled analysis of both the years (2022-23 and 2023-24) revealed the maximum (0.71%) acidity under T_{13} (150 ppm ZnO + 50 ppm Fe) followed by T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (0.48) was recorded under treatment T_0 (control).

It is obvious that zinc and iron optimizing fruit acidity in strawberries by enhancing nutrient uptake and metabolic efficiency. This might be due to zinc's ability to increase the availability of other micronutrients, which are essential for activating enzymes involved in the synthesis of organic acids, directly boosting acid production in the fruit. Similarly, iron seems to enhance iron uptake, supporting chlorophyll formation and overall metabolic processes, which improves the plant's energy status.

This increased metabolic activity is prominent in its contribution to higher production of organic acids, leading to better fruit acidity. These observations align with the findings of Dimkpa *et al.,* (2016); Verma *et al.,* (2013); Xu *et al.,* (2008); Patel *et al.,* (2019) and Mishra *et al.*, (2016).

Table 4.23: Effect of Nano- ZnO and FeO on Acidity (%) of Strawberry (*Fragaria × ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Acidity (%)						
Treatments	Protected Field Conditions			Open Field Conditions		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
T_0	0.55	0.47	0.51	0.53	0.43	0.48
T_1	0.51	0.48	0.50	0.52	0.46	0.49
T_2	0.63	0.53	0.58	0.63	0.63	0.63
T_3	0.64	0.56	0.60	0.62	0.64	0.63
T_4	0.68	0.66	0.67	0.68	0.55	0.62
T_5	0.71	0.68	0.70	0.70	0.63	0.66
T_6	0.64	0.62	0.63	0.65	0.63	0.64
T_7	0.53	0.61	0.57	0.66	0.52	0.59
T_8	0.65	0.63	0.64	0.63	0.54	0.58
T_9	0.72	0.67	0.69	0.67	0.67	0.67
T_{10}	0.60	0.61	0.61	0.62	0.56	0.59
T_{11}	0.65	0.55	0.60	0.63	0.47	0.55
T_{12}	0.63	0.63	0.63	0.65	0.66	0.66
T_{13}	0.68	0.64	0.66	0.69	0.72	0.71
T_{14}	0.63	0.68	0.65	0.69	0.47	0.58
T_{15}	0.71	0.67	0.69	0.69	0.57	0.63
C.D.	0.077	0.102	0.090	0.091	0.165	0.128
SE(m)	0.027	0.035	0.031	0.031	0.057	0.044
SE(d)	0.038	0.050	0.044	0.044	0.080	0.062
C.V.	7.266	7.325	7.246	6.450	7.131	6.751

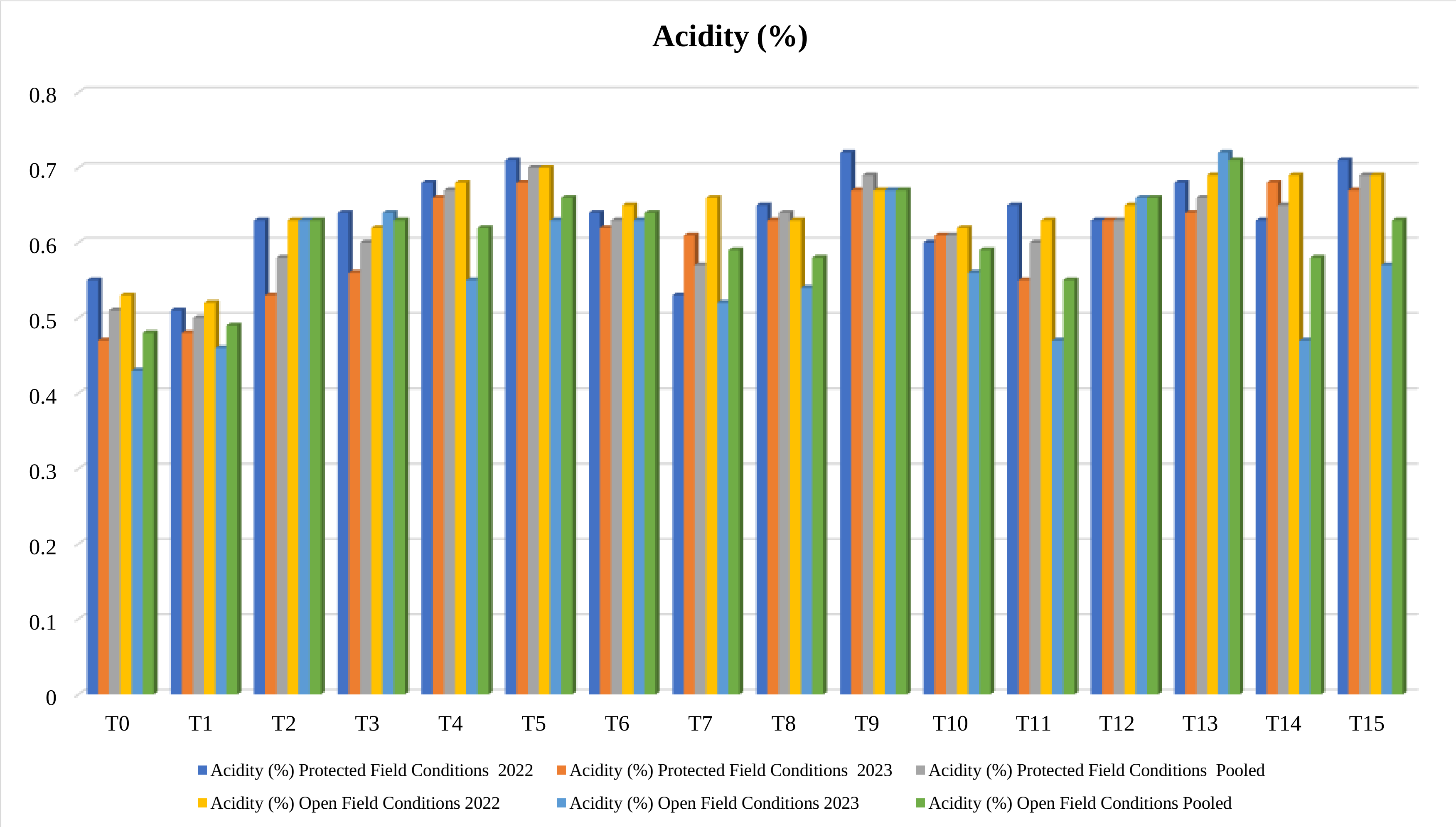

Figure 4.23: Effect of Nano- ZnO and FeO on Acidity (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.1.24 Total sugar (%)

The Data pertaining on total sugars under protected conditions presented in Table 4.24 described significant variations exist among all the treatments with the application of Nano-ZnO and FeO. During (2022-23) maximum (7.93%) total sugar was observed under the treatment T_7 (50 ppm ZnO + 50 ppm FeO) followed by 7.78 % under T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (6.51%) total sugar was reported under treatment T_2 (100ppm ZnO). In the second-year trial (2023-24) maximum (7.25 %) total sugar was noted under the treatment T_{12} (100 ppm ZnO + 150 ppm FeO) followed by 7.23 % under the treatment T_6 (150 FeO) while the minimum (6.59 %) was observed under treatment T_0 (control). The pooled Data for both the years (2022-23 and 2023-24) recorded the utmost (7.46%) total sugar under the treatment T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum total sugar (6.85%) was reported under treatment T_0 (control).

The study of the Table 4.24 indicated significant variations among the treatments on total sugars with the application of Nano-ZnO and FeO at different levels. During (2022-23) maximum (7.94%) total sugar was reported under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) followed by 7.89 % under T_{15} (150 ppm ZnO + 150 ppm FeO) while the lowest (6.74%) total sugar was recorded in treatment T_0 (control) for the first year research trail. In the second-year trial (2023-24) the maximum (7.26 %) total sugar was observed under the treatment T_1 (50ppm ZnO) followed by 7.07 % under T_{10} (100 ppm ZnO + 50 ppm FeO) while the minimum (6.92 %) was observed under treatment T_0 (control). The pooled Data for both the years (2022-23 and 2023-24) recorded the utmost (7.48%) total sugar under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (6.83%) total sugar was noted under treatment T_0 (control).

The application of zinc and iron significantly enhances the total sugars in strawberry fruits likely due to their roles in improving photosynthetic efficiency and enzyme activities related to sugar metabolism. Zinc contributes to better chlorophyll synthesis, while iron supports the transport and utilization of photosynthates. Together, these factors boost sugar accumulation in the fruit. Additionally, increased metabolic activity leads to higher production of organic acids, further contributing to the improved fruit sugars. These findings align with similar investigations reported by Khan *et al.,* (2020); Raliya *et al.,* (2013); Sabahat *et al.,* (2021); Saini *et al.,* (2021); Sharma *et al.,* (2021) and Singh *et al.,* (2013).

Table 4.24: Effect of Nano- ZnO and FeO on Total sugars (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Total sugars (%)						
	Protected Field Conditions			Open Field Conditions		
Treatments	**2022-23**	**2023-24**	**Pooled Mean**	**2022-23**	**2023-24**	**Pooled Mean**
T_0	7.11	6.59	6.85	6.74	6.92	6.83
T_1	7.12	6.61	6.87	7.01	7.26	7.14
T_2	6.51	6.76	6.64	6.76	7.01	6.89
T_3	7.15	6.51	6.83	6.96	6.98	6.97
T_4	7.28	6.94	7.11	7.15	6.97	7.06
T_5	7.59	7.12	7.36	7.48	6.91	7.20
T_6	7.06	7.23	7.15	7.39	6.92	7.15
T_7	7.93	7.20	7.57	7.88	7.06	7.47
T_8	7.28	6.98	7.13	7.78	7.07	7.43
T_9	7.78	7.13	7.46	7.94	7.02	7.48
T_{10}	7.70	7.13	7.42	7.78	7.07	7.43
T_{11}	7.44	7.01	7.23	7.74	6.92	7.33
T_{12}	7.02	7.25	7.14	7.00	6.94	6.97
T_{13}	7.45	7.16	7.31	7.94	7.02	7.48
T_{14}	7.13	7.11	7.12	7.67	7.04	7.36
T_{15}	7.46	7.18	7.32	7.89	7.00	7.44
C.D.	0.577	0.300	0.439	0.656	0.512	0.584
SE(m)	0.199	0.103	0.151	0.226	0.088	0.157
SE(d)	0.281	0.146	0.214	0.319	0.125	0.222
C.V.	4.704	2.561	3.633	5.256	2.177	3.717

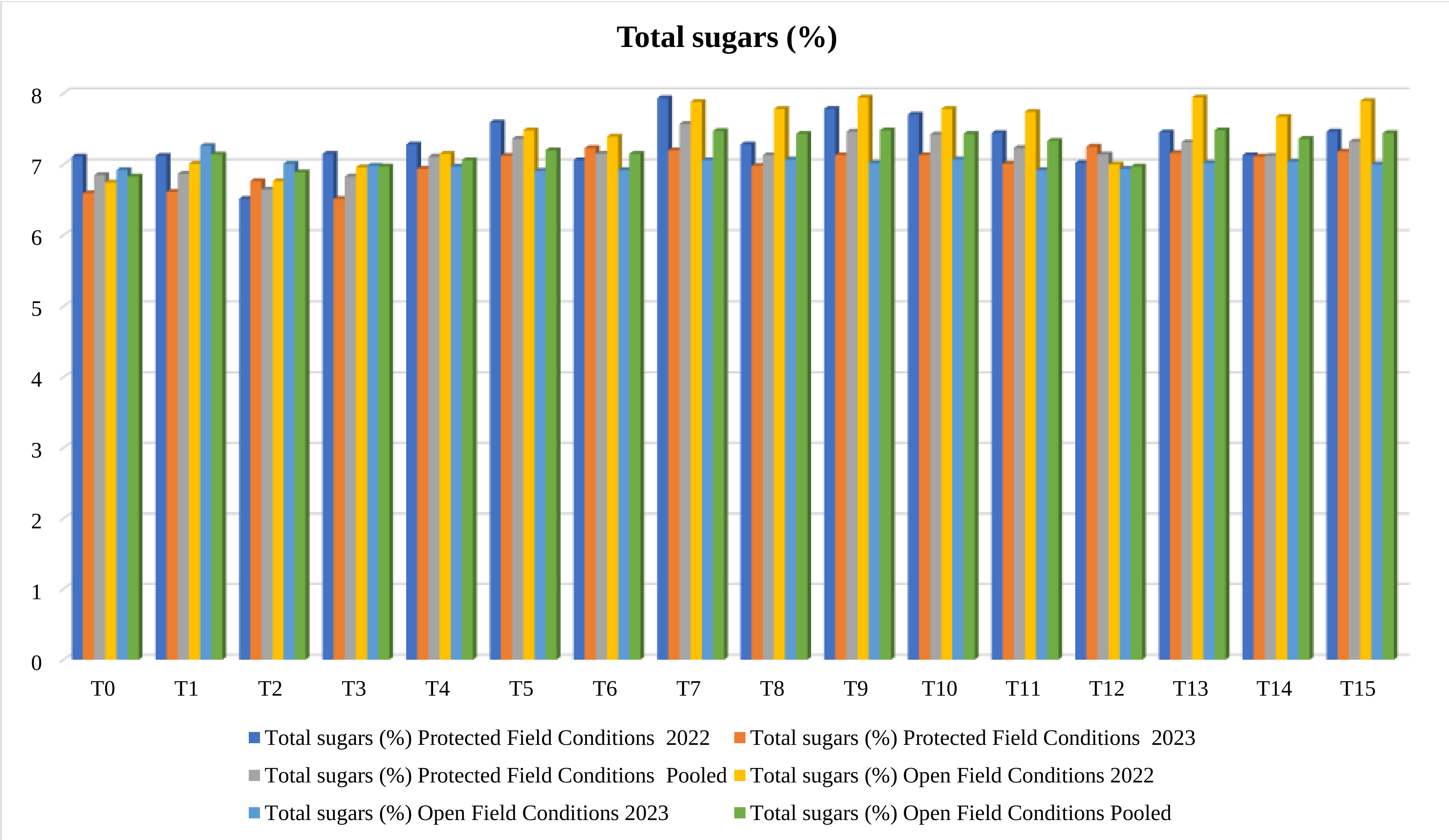

Figure 2.24: Effect of Nano- ZnO and FeO on Total sugars (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.1.25 Reducing sugar (%)

The Nano-ZnO and FeO at different levels showed significant variations on the Data pertaining to reducing sugars under protected conditions, as presented in Table 4.25. During (2022-23) the maximum (4.92%) reducing sugar was recorded in the treatment T_7 (50 ppm ZnO + 50 ppm FeO) followed by 4.77 % under T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (4.44%) reducing sugar was reported under treatment T_0 (control). In the second-year trial (2023-24) utmost (4.76 %) reducing sugar was noticed under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) followed by 4.75 % under treatment T_8 (50 ppm ZnO + 100 ppm FeO) and minimum (4.21 %) was observed under treatment T_0 (control). The pooled Data for both the years (2022-23 and 2023-24) recorded the maximum (4.78 %) reducing sugar under the treatment T_7 (50 ppm ZnO + 50 ppm FeO) followed by 4.62 % under T_9 (50 ppm ZnO + 150 ppm FeO) and minimum (3.82 %) reducing sugar was reported under treatment T_2 (100ppm ZnO).

The study of the Table 4.25 revealed significant variations on reducing sugar (%) among all the treatments under open field condition. During (2022-23) the maximum (4.85%) reducing sugar was reported in the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) followed by 4.80% under treatment T_7 (50 ppm ZnO + 50 ppm FeO) while the minimum (3.74 %) reducing sugar was recorded under treatment T_2 (100ppm ZnO). In the second-year trial (2023-24) maximum (4.75 %) reducing sugar was observed under the treatment T_7 (50 ppm ZnO + 50 ppm FeO) followed by 4.74% under treatment T_{13} (150 ppm ZnO + 50 ppm FeO) and the minimum (4.07 %) reducing sugar was observed under treatment T_2 (100 ppm ZnO). The pooled Data for both the years (2022-23 and 2023-24) recorded the maximum (4.80 %) reducing sugar under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) followed by T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (3.91 %) reducing sugar was reported under treatment T_2 (100ppm ZnO).

It is obvious that Zn and Fe plays a significant role in enhancing nutrient absorption and metabolic activity in strawberries, which likely contributes to higher sugar content in the fruits. It seems that Zn's ability to activate key enzymes involved in organic acid production is crucial, while Fe appears to boost iron uptake, supporting chlorophyll production and overall metabolic efficiency. This enhanced metabolic activity likely results in increased synthesis of enzymes that improve fruit sugars. The combined impact of these elements seems to lead to more efficient sugar production and regulation, ultimately resulting in strawberries with enhanced flavor and longer shelf life. This is prominent in the findings of Khan *et al.,* (2020) and Bakshi *et al.,* (2013); Hafeez *et al.,* (2013); Kian *et al.,* (2024) and Patel *et al.,* (2021) who observed similar effects.

Table 4.25: Effect of Nano- ZnO and FeO on reducing sugars (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Reducing sugars (%)						
	Protected Field Conditions			Open Field Conditions		
Treatments	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
T_0	4.44	4.21	4.33	3.75	4.11	3.93
T_1	4.12	4.03	4.08	4.04	4.20	4.12
T_2	3.53	4.12	3.83	3.74	4.07	3.91
T_3	4.46	4.13	4.30	4.05	4.08	4.07
T_4	4.29	4.11	4.20	4.16	4.48	4.32
T_5	4.57	4.35	4.46	4.47	4.37	4.42
T_6	4.07	4.64	4.36	4.33	4.38	4.36
T_7	4.92	4.63	4.78	4.80	4.75	4.78
T_8	4.29	4.75	4.52	4.71	4.37	4.54
T_9	4.77	4.47	4.62	4.85	4.61	4.73
T_{10}	4.69	4.53	4.61	4.69	4.49	4.59
T_{11}	4.42	4.26	4.34	4.67	4.64	4.66
T_{12}	4.08	4.44	4.26	4.29	4.31	4.30
T_{13}	4.46	4.76	4.61	4.85	4.74	4.80
T_{14}	4.15	4.56	4.36	4.69	4.66	4.68
T_{15}	4.44	4.42	4.43	4.68	4.66	4.67
C.D.	0.592	0.193	0.393	0.691	0.337	0.514
SE(m)	0.204	0.067	0.136	0.238	0.116	0.177
SE(d)	0.288	0.094	0.191	0.337	0.164	0.251
C.V.	3.108	2.620	2.864	4.322	3.321	3.822

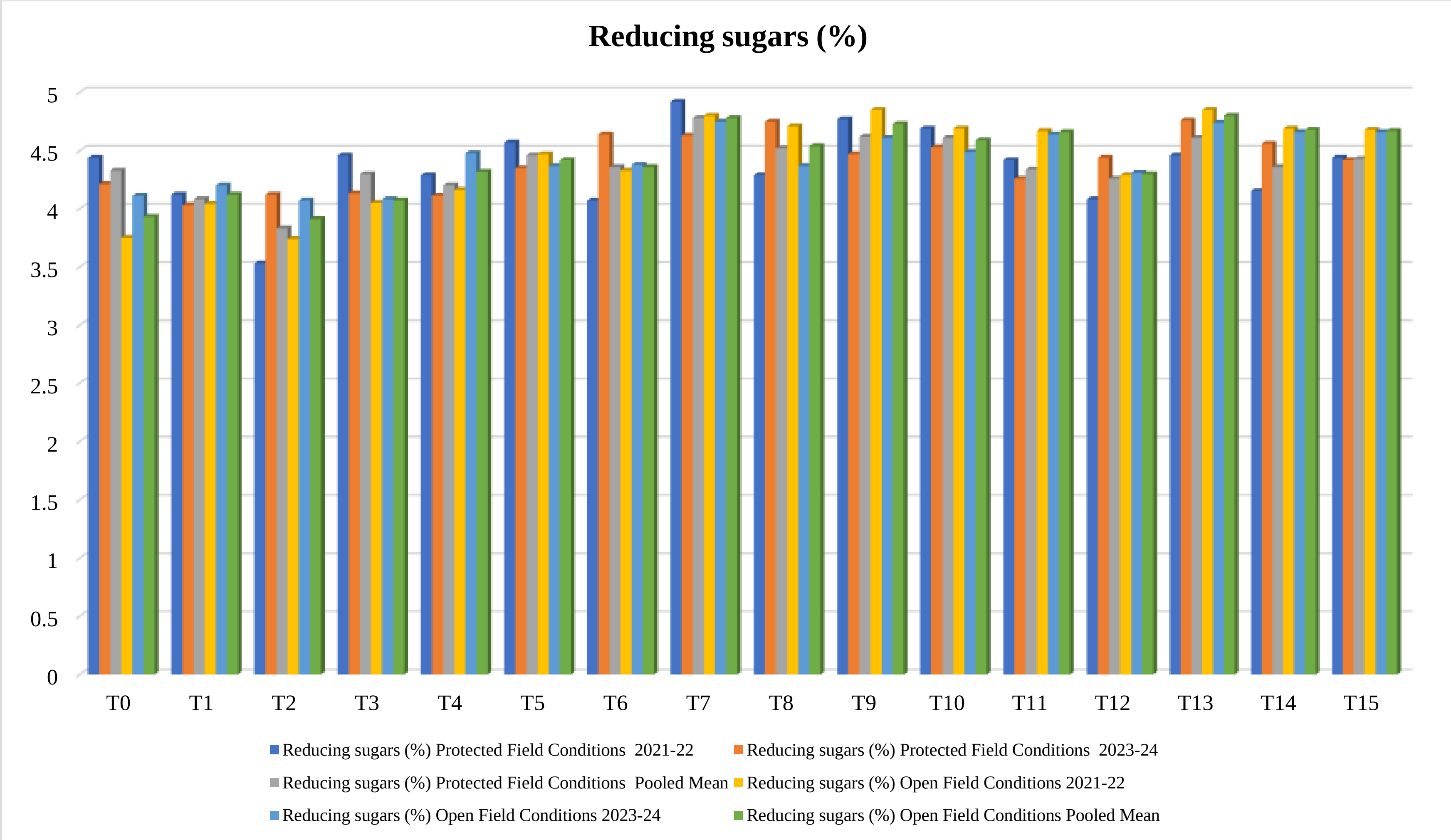

Figure 4.25: Effect of Nano- ZnO and FeO on reducing sugars (%) of Strawberry (Fragaria × ananassa Duch.) cv. Winter Dawn under protected and open conditions

4.1.26 Non-reducing sugar (%)

It is evident from the Table 4.26 that different levels of Nano-ZnO and FeO has significant variation among all the treatments regarding the non-reducing sugars under protected conditions. In the 2022-23 trial, the highest non-reducing sugar content of 3.03% was found with treatment T4 (50 ppm FeO), closely followed by 3.02% with T11 (100 ppm ZnO + 100 ppm FeO). The lowest non-reducing sugar content, 2.67%, was recorded in the control group (T0). In the following year (2023-24), the highest non-reducing sugar content of 2.95% was observed with T4, with T5 (100 ppm FeO) showing 2.84%. The control group (T0) had the lowest non-reducing sugar content at 2.38%. Combining Data from both years, the trend in non-reducing sugar content remained consistent with the highest values (2.94 %) non-reducing sugar under the treatment T_5 (100 ppm FeO) followed by 2.93 % under T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (2.53 %) non-reducing sugar was reported under treatment T0 (control).

The Data on non-reducing sugar content under open field conditions, as detailed in Table 4.26, showed significant differences among treatments with varying levels of Nano-ZnO and FeO. In the 2022-23 trial, the highest non-reducing sugar content of 3.09% was found with treatment T_{13} (150 ppm ZnO + 50 ppm FeO), followed by 3.08% with T_7 (50 ppm ZnO + 50 ppm FeO). The lowest content of 2.97% was recorded with treatment T_1 (50 ppm ZnO). In the second-year trial (2023-24), the highest non-reducing sugar content of 3.07% was observed with T_1 (50 ppm FeO), while 2.94% was noted with T_2 (100 ppm ZnO). The lowest content of 2.28% was found with treatment T_{11} (100 ppm ZnO + 100 ppm FeO). Combining Data from both years, the highest average non-reducing sugar content of 3.02% was observed with T_1, followed by 2.98% with T_2. The lowest average content of 2.67% was recorded with T_{11}.

The zinc and iron optimize non-reducing sugar levels in strawberry fruits by boosting nutrient assimilation and metabolic efficiency. The heightened availability of these nutrients' aids in the synthesis and regulation of complex sugars. Zinc enhances enzymatic functions essential for sugar metabolism, while iron supports overall plant vitality and energy production, resulting in optimal levels of non-reducing sugars in the fruit. The results from the present study are in the conformity with the findings of Prasad *et al.,* (2014); Raliya *et al.,* (2013); Reddy *et al.,* (2023); Verma *et al.,* (2018); Zhang *et al.,* (2019).

Table 4.26: Effect of Nano- ZnO and FeO on non-reducing sugars (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Non reducing sugars (%)						
Treatments	Protected Field Conditions			Open Field Conditions		
	2022-23	2023-24	Pooled Mean	2022-23	2023-24	Pooled Mean
T_0	2.67	2.38	2.53	2.99	2.81	2.90
T_1	2.98	2.65	2.82	2.97	3.07	3.02
T_2	2.99	2.64	2.82	3.01	2.94	2.98
T_3	2.69	2.38	2.54	2.91	2.90	2.90
T_4	2.88	2.95	2.92	2.99	2.49	2.74
T_5	3.03	2.84	2.94	3.01	2.54	2.78
T_6	2.99	2.60	2.80	3.06	2.53	2.80
T_7	3.03	2.76	2.90	3.08	2.30	2.69
T_8	2.97	2.46	2.72	3.07	2.70	2.89
T_9	3.01	2.66	2.84	3.09	2.41	2.75
T_{10}	2.98	2.70	2.84	3.09	2.58	2.84
T_{11}	3.02	2.83	2.93	3.06	2.28	2.67
T_{12}	2.93	2.71	2.82	2.71	2.63	2.67
T_{13}	2.89	2.75	2.82	3.09	2.28	2.69
T_{14}	2.91	2.66	2.79	2.98	2.38	2.68
T_{15}	3.02	2.75	2.89	3.22	2.34	2.78
C.D.	1.435	1.321	1.378	0.412	0.435	0.424
SE(m)	0.121	0.129	0.125	0.107	0.150	0.129
SE(d)	0.171	0.183	0.177	0.151	0.212	0.182
C.V.	7.119	8.378	7.749	6.134	5.081	5.568

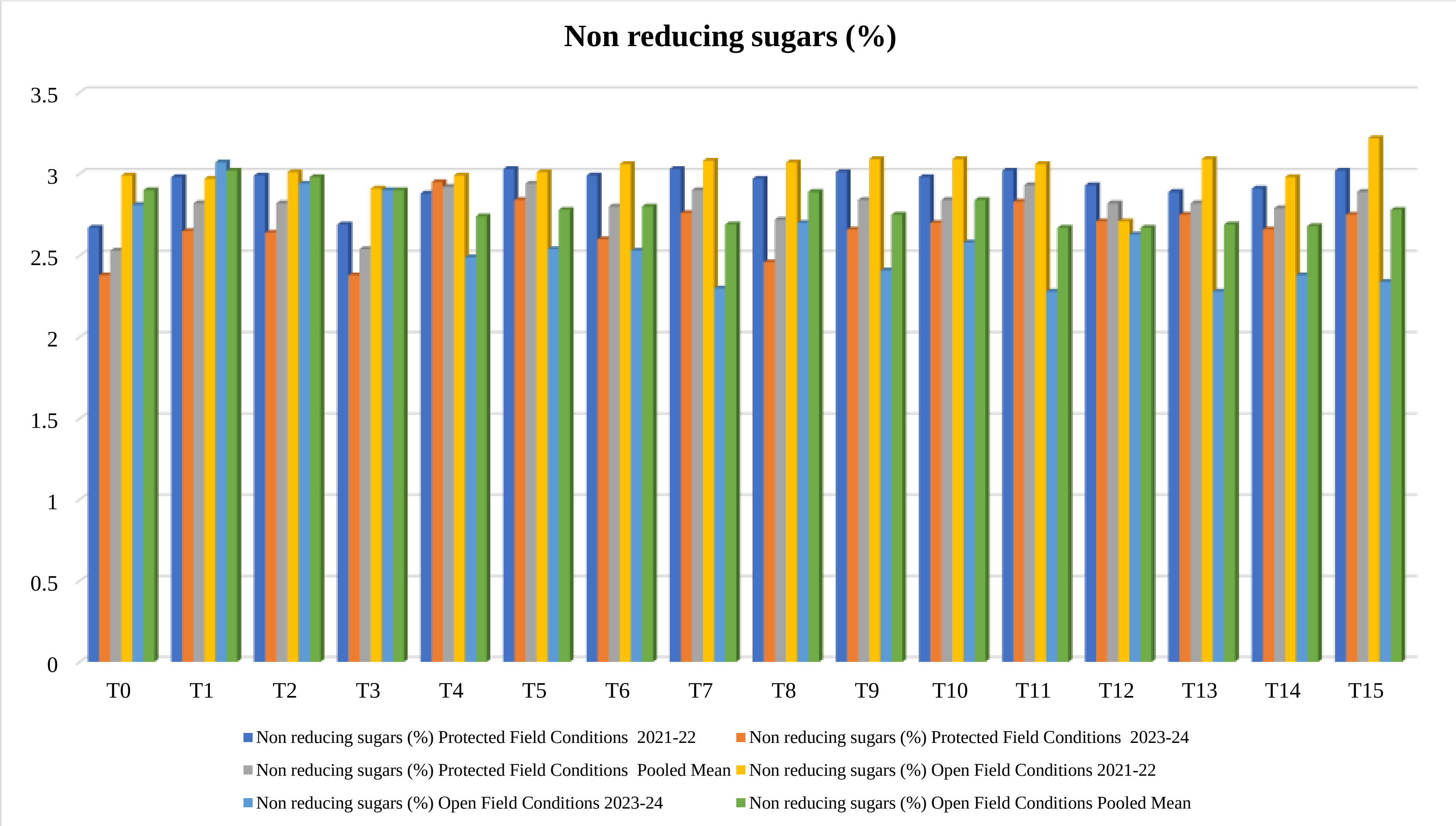

Figure 4.26: Effect of Nano- ZnO and FeO on non-reducing sugars (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.1.27 Ascorbic acid (mg per 100 g)

The Data collected for ascorbic acid (mg per 100 g) under protected conditions presented in Table 4.27 and represented graphically in Figure 4.27 revealed significant variations among the treatments. During (2022-23) the maximum (51.96 mg per 100 g) ascorbic acid was recorded under the treatment T_9 (50 ppm ZnO + 150 ppm FeO) followed by 51.74 mg per 100 g under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) while the minimum (49.19 mg per 100 g) ascorbic acid was reported under treatment T_1 (50ppm ZnO). In the second-year trial (2023-24) maximum (53.15 mg per 100 g) ascorbic acid was found under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) followed by 51.80 mg per 100 g under T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (48.75 mg per 100 g) was observed under treatment T_0 (control). The pooled Data for both the years (2022-23 and 2023-24) recorded the utmost (52.16 mg per 100 g) ascorbic acid under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) followed by 51.88 mg per 100 g under treatment T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (48.83 mg per 100 g) ascorbic acid was reported under treatment T_1 (50ppm ZnO).

The Data on ascorbic acid of strawberry under open field conditions presented in Table 4.27 revealed significant variations were found among the treatments with the application of different levels of Nano-ZnO and FeO. During (2022-23) maximum (52.84 mg per 100 g) ascorbic acid was noted under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 52.32 mg per 100 g under T_{14} (150 ppm ZnO + 100 ppm FeO) while the minimum (48.64 mg per 100 g) ascorbic acid was reported under treatment T_0 (control). In the second-year trial (2023-24) maximum (49.95 mg per 100 g) ascorbic acid was found under the treatment T_6 (150ppm FeO) followed by 49.32 mg per 100 g under T_{15} (150 ppm ZnO + 150 ppm FeO) while the minimum (47.45 mg per 100 g) was observed under treatment T_0 (control). The pooled Data for both the years (2022-23 and 2023-24) recorded the utmost (51.08 mg per 100 g) ascorbic acid was observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by T_{14} (150 ppm ZnO + 100 ppm FeO) and minimum (48.05 mg per 100 g) ascorbic acid was reported under treatment T_0 (control).

The application of zinc and iron has a significant impact on the ascorbic acid content of strawberry fruits due to their roles in optimizing photosynthetic efficiency and enzyme activities associated with ascorbic acid metabolism. Zinc aids in chlorophyll synthesis, thereby improving photosynthesis and increasing the availability of reducing sugars needed for ascorbic acid production. Concurrently, iron facilitates the transport and utilization of photosynthates, which supports the synthesis and accumulation of ascorbic acid in the fruit. The combined effects of these nano nutrients lead to higher ascorbic acid levels, which is further supported by the overall increase in metabolic activity, resulting in enhanced fruit quality and nutritional value. The results from the present study are in conformity with the findings of Bakshi *et al.,* (2013); Chen *et al.,* (2018); Khan *et al.,* (2018); Naderi *et al.,* (2013); Nitiin *et al.,* (2012).

Table 4.27: Effect of Nano- ZnO and FeO on Ascorbic acid (mg/100g) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Ascorbic acid (mg/100g)						
Treatments	**Protected Field Conditions**			**Open Field Conditions**		
	2022-23	**2023-24**	**Pooled Mean**	**2022-23**	**2023-24**	**Pooled Mean**
T_0	49.41	48.45	48.93	48.64	47.45	48.05
T_1	49.19	48.47	48.83	48.76	47.47	48.12
T_2	50.35	49.48	49.92	49.35	48.61	48.98
T_3	51.10	51.19	51.15	50.52	47.67	49.10
T_4	51.46	51.56	51.51	50.57	48.39	49.48
T_5	51.69	50.42	51.06	50.94	47.61	49.28
T_6	51.15	49.74	50.45	50.92	49.95	50.44
T_7	49.64	51.05	50.35	51.60	48.62	50.11
T_8	50.55	49.04	49.80	50.52	48.51	49.52
T_9	51.96	51.80	51.88	51.79	48.63	50.21
T_{10}	50.09	48.70	49.40	51.41	48.45	49.93
T_{11}	51.42	51.21	51.32	51.81	48.24	50.03
T_{12}	51.18	49.71	50.45	51.71	47.96	49.84
T_{13}	51.18	53.15	52.17	51.86	49.07	50.47
T_{14}	50.48	49.46	49.97	52.32	48.62	50.47
T_{15}	51.74	51.66	51.70	52.84	49.32	51.08
C.D.	1.506	1.612	1.559	1.733	1.291	1.512
SE(m)	0.519	0.555	0.537	0.597	0.445	0.521
SE(d)	0.734	0.785	0.760	0.845	0.629	0.737
C.V.	1.770	1.912	1.841	2.029	1.592	1.811

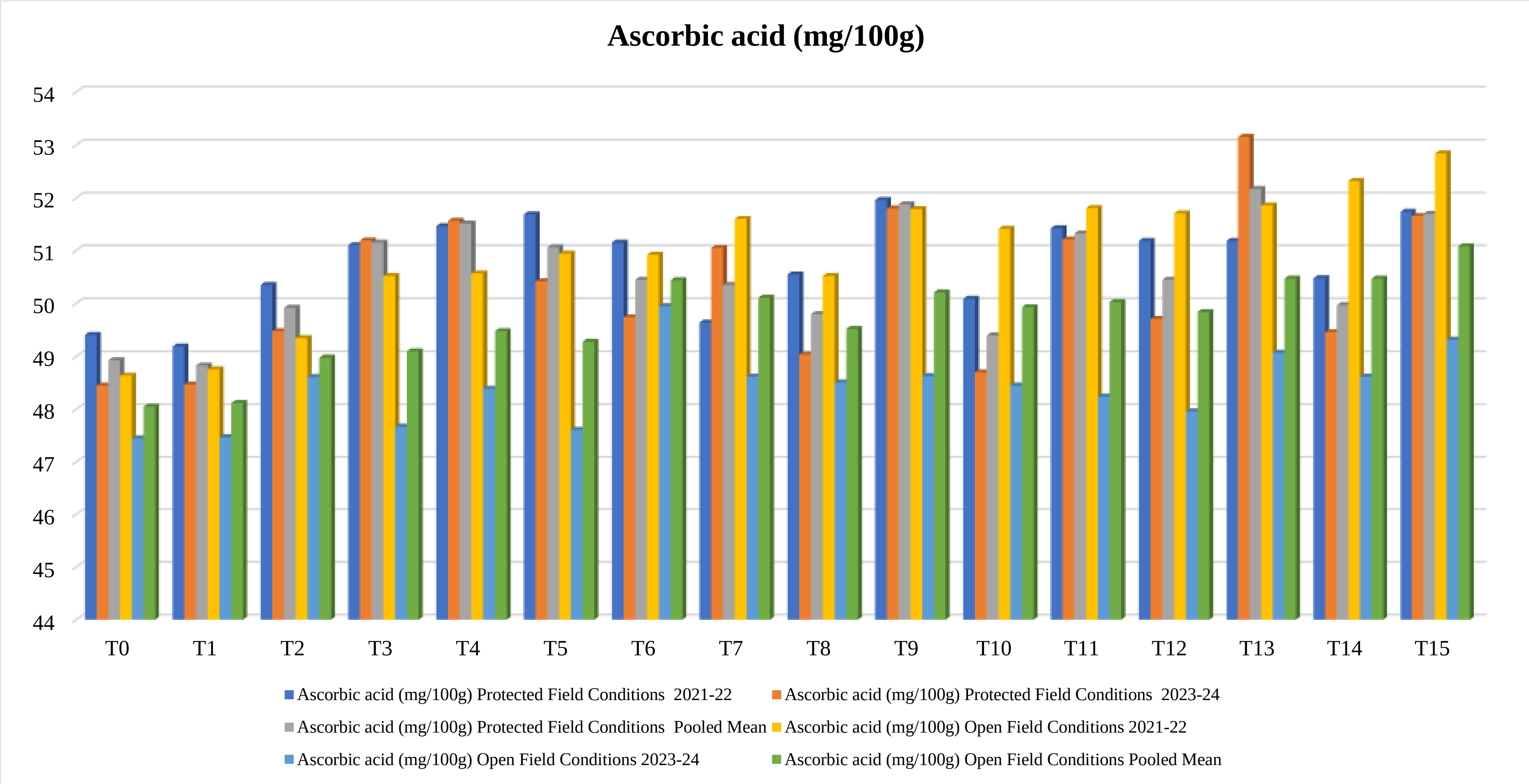

Figure 4.27: Effect of Nano- ZnO and FeO on Ascorbic acid (mg/100g) of Strawberry (Fragaria × ananassa Duch.) cv. Winter Dawn under protected and open conditions

4.1.28 Total Flavonoids (mg per 100 g)

It is evident from the Table 4.28 that different levels of ZnO and FeO influence the total flavonoids under protected conditions at different levels. During (2022-23) the maximum (164.1 mg per 100 g) total flavonoids was observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 160.8 mg per 100 g under T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (121.2 mg per 100 g) total flavonoids was reported under treatment T_0 (control) for first year research trial. In the second-year trial (2023-24) maximum (159.6 mg per 100 g) total flavonoids was reported under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 156.2 mg per 100 g under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (121.9 mg per 100 g) was observed under treatment T_0 (control). The pooled Data for both the years (2022-23 and 2023-24) recorded the utmost (161.83 mg per 100 g) total flavonoids under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 158.98 mg per 100 g under T_9 (50 ppm ZnO + 150 ppm FeO) and minimum (121.57 mg per 100 g) total flavonoids was reported under treatment T_0 (control).

The Data pertaining to total flavonoids under open field conditions presented in Table 4.28 indicated significant variations exist among the treatments by the application of Nano-ZnO and FeO. During (2022-23) maximum (151.0 mg per 100 g) total flavonoids was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 148.9 mg per 100 g under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (121.6 mg per 100 g) total flavonoids was reported under treatment T_0 (control). In the second-year trial (2023-24) maximum (151.5 mg per 100 g) total flavonoids was noticed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 146.6 mg per 100 g under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (123.6 mg per 100 g) was observed under treatment T_0 (control). The pooled Data for both the years (2022-23 and 2023-24) recorded the utmost (151.24 mg per 100 g) total flavonoids under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 145.32 mg per 100 g under T_{11} (100 ppm ZnO + 100 ppm FeO) and minimum (122.59 mg per 100 g) total flavonoids was reported under treatment T_0 (control).

It is obvious that the enhancement of total flavonoid content in strawberry fruits through the application of nano zinc and iron is due to their role in upregulating key enzymes in the flavonoid biosynthesis pathway. Specifically, nano zinc boosts the activity of phenylalanine ammonia-lyase (PAL), while nano iron facilitates the function of chalcone synthase, collectively leading to increased flavonoid accumulation. Similar results have been reported by Singh *et al.,* (2020); Prasad *et al.,* (2014); Reddy *et al.,* (2021) and Gupta & Mehta (2018), further confirming this mechanism.

Table 4.28: Effect of Nano- ZnO and FeO on Total flavonoids (mg/100g) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Total flavonoids (mg/100g)						
	Protected Field Conditions			**Open Field Conditions**		
Treatments	**2022-23**	**2023-24**	**Pooled Mean**	**2022-23**	**2023-24**	**Pooled Mean**
T_0	121.2	122.0	121.6	121.6	123.6	122.6
T_1	126.8	128.8	127.8	127.5	125.6	126.6
T_2	124.1	126.9	125.5	123.7	125.4	124.6
T_3	132.1	129.6	130.9	132.4	131.8	132.1
T_4	133.1	132.5	132.8	135.6	135.5	135.6
T_5	143.9	142.5	143.2	135.0	137.3	136.2
T_6	135.6	137.5	136.6	125.9	133.5	129.7
T_7	141.8	142.5	142.2	134.4	135.4	134.9
T_8	135.1	135.6	135.4	130.9	133.9	132.4
T_9	160.8	157.2	159.0	134.8	133.6	134.2
T_{10}	153.6	153.4	153.5	139.3	138.7	139.0
T_{11}	147.3	156.2	151.8	148.9	141.4	145.2
T_{12}	141.8	148.6	145.2	141.3	137.8	139.6
T_{13}	142.5	144.7	143.6	142.1	146.6	144.4
T_{14}	143.2	152.7	148.0	139.2	141.2	140.2
T_{15}	164.1	159.5	161.8	151.0	151.5	151.3
C.D.	4.819	1.994	3.407	3.469	2.262	2.866
SE(m)	1.661	0.687	1.174	0.641	0.779	0.710
SE(d)	2.348	0.972	1.660	1.563	1.102	1.333
C.V.	2.048	0.839	1.444	1.945	0.994	1.470

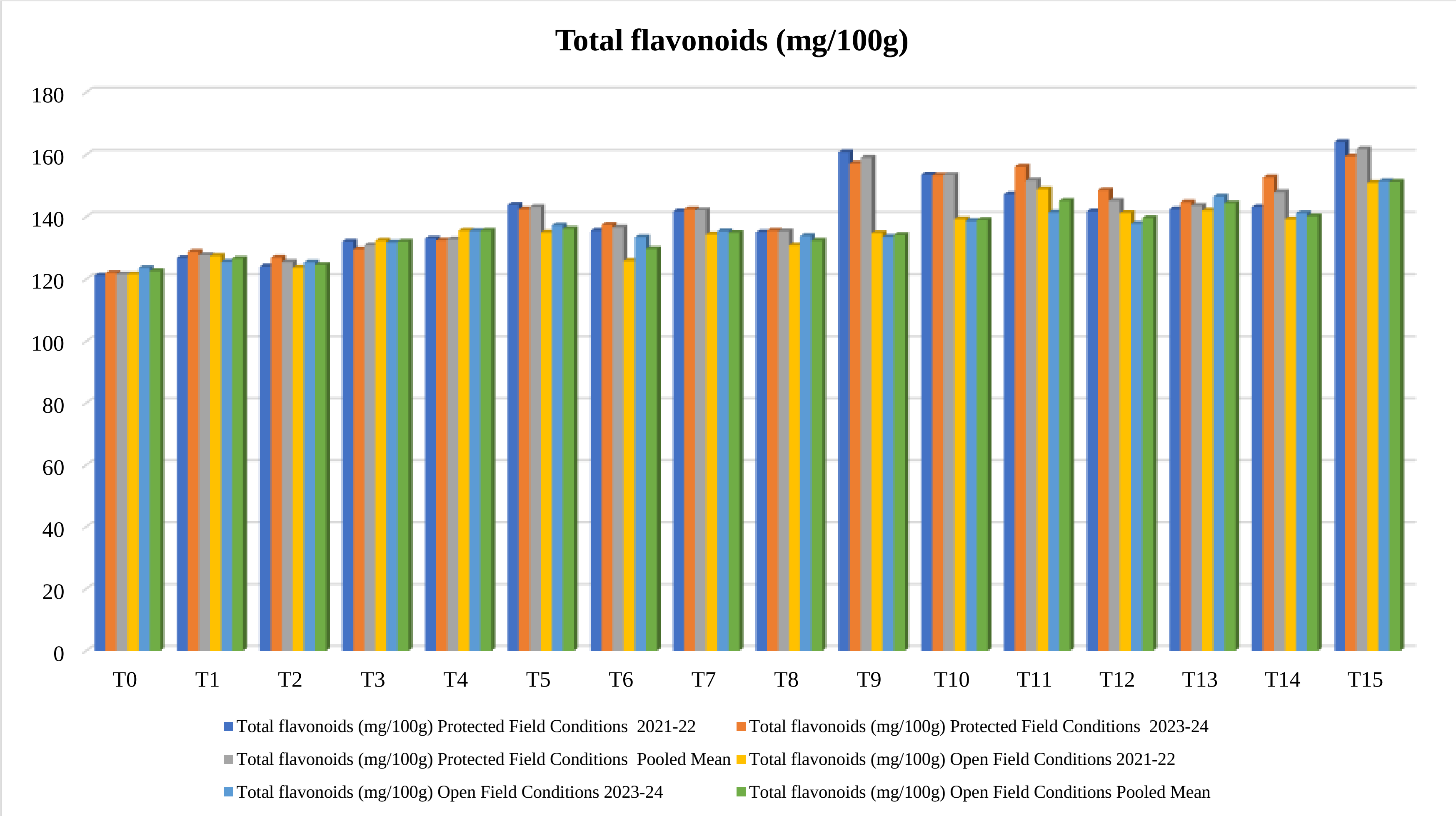

Figure 4.28: Effect of Nano- ZnO and FeO on Total flavonoids (mg/100g) of Strawberry (Fragaria × ananassa Duch.) cv. Winter Dawn under protected and open conditions

4.1.29 Total phenols (mg per 100 g)

The study of the Table 4.29a revealed that Data on total phenols of strawberry under protected and open conditions is tabulated in Table 4.29 had significant variations among the treatments with the application of Nano-ZnO and FeO at different levels. During (2022-23) maximum (69.87 mg per 100 g) total phenols was reported under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 69.64 mg per 100 g under T_{12} (100 ppm ZnO + 150 ppm FeO) while the minimum (64.56 mg per 100 g) total flavonoids was observed under treatment T_4 (50ppm FeO) for the first year research trial. In the second-year trial (2023-24) maximum (70.46 mg per 100 g) total phenols was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 69.64 mg per 100 g under T_{10} (100 ppm ZnO + 50 ppm FeO) while the minimum (65.15mg per 100 g) was observed under treatment T_0 (control). The pooled Data for both the years (2022-23 and 2023-24) recorded the utmost (70.17 mg per 100 g) total phenols under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 69.64 mg per 100 g under T_{10} (100 ppm ZnO + 50 ppm FeO) while the minimum (65.66 mg per 100 g) total flavonoids was reported under treatment T_0 (control).

The results pertaining to effect of Nano-ZnO and FeO on total phenols presented in Table 4.29b indicated significant variations were found among the treatments with the application of Nano-ZnO and FeO. During (2022-23) maximum total phenols was observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 69.64 mg per 100 g under T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (65.34 mg/100g) total phenols was recorded under the treatment T_0 (control). In the second-year trial (2023-24) revealed the maximum (69.56 mg per 100 g) total phenols under the treatment T_{10} (100 ppm ZnO + 50 ppm FeO) followed by 69.25 mg per 100 g under T_{15} (150 ppm ZnO + 150 ppm FeO) T_3 (150ppm ZnO) was found with 66.47 mg per 100 g of phenols which remained minimum.

The increase in total phenols in strawberries with the application of zinc and iron occurs due to several interrelated mechanisms. These micronutrients enhance the uptake of essential micronutrients and activate antioxidant defense systems, such as superoxide dismutase and catalase, which mitigate oxiDAPive stress and protect phenolic compounds from degraDAPion. Additionally, they stimulate the phenylpropanoid biosynthetic pathway by upregulating enzymes like phenylalanine ammonia-lyase, leading to increased synthesis of phenolic compounds. The nanoparticles also influence gene expression related to secondary metabolism, boosting the production of phenolic compounds. Consequently, the combined effects of enhanced nutrient availability, improved antioxidant defense, and stimulated metabolic pathways result in a higher total phenolic content in strawberries. These results are consistent with previous studies by Sharma *et al.,* (2019), Raliya *et al.*, (2013), Sajid *et al.,* (2012), Zhang *et al.,* (2019), and Verma & Kumar (2018).

Table 4.29: Effect of Nano- ZnO and FeO on Total phenolics (mg/100g) of Strawberry (Fragaria × ananassa Duch.) cv. Winter Dawn under protected and open conditions

Total phenolics (mg/100g)						
	Protected Field Conditions			Open Field Conditions		
Treatments	**2022-23**	**2023-24**	**Pooled Mean**	**2022-23**	**2023-24**	**Pooled Mean**
T_0	66.16	65.15	65.66	65.34	67.64	66.49
T_1	67.16	66.17	66.67	66.67	65.78	66.23
T_2	67.87	68.35	68.11	67.43	66.47	66.95
T_3	68.64	69.46	69.05	66.56	66.56	66.56
T_4	64.56	68.16	66.36	67.54	68.64	68.09
T_5	67.78	67.36	67.57	66.89	68.93	67.91
T_6	66.67	69.53	68.10	69.64	67.57	68.61
T_7	67.83	66.49	67.16	68.65	68.94	68.80
T_8	68.67	67.54	68.11	69.64	69.24	69.44
T_9	69.64	66.56	68.10	66.45	68.14	67.30
T_{10}	70.17	69.64	69.91	67.64	69.56	68.60
T_{11}	71.25	68.45	69.85	68.45	66.65	67.55
T_{12}	69.64	66.47	68.06	67.94	68.65	68.30
T_{13}	68.56	67.56	68.06	69.64	67.54	68.59
T_{14}	67.45	69.54	68.50	68.64	68.64	68.64
T_{15}	69.87	70.46	70.17	69.75	69.25	69.50
C.D.	0.537	1.515	1.026	0.143	1.743	0.943
SE(m)	0.676	0.522	0.599	0.244	0.600	0.422
SE(d)	0.956	0.738	0.847	0.345	0.849	0.597
C.V.	4.443	3.494	3.969	1.608	3.772	2.690

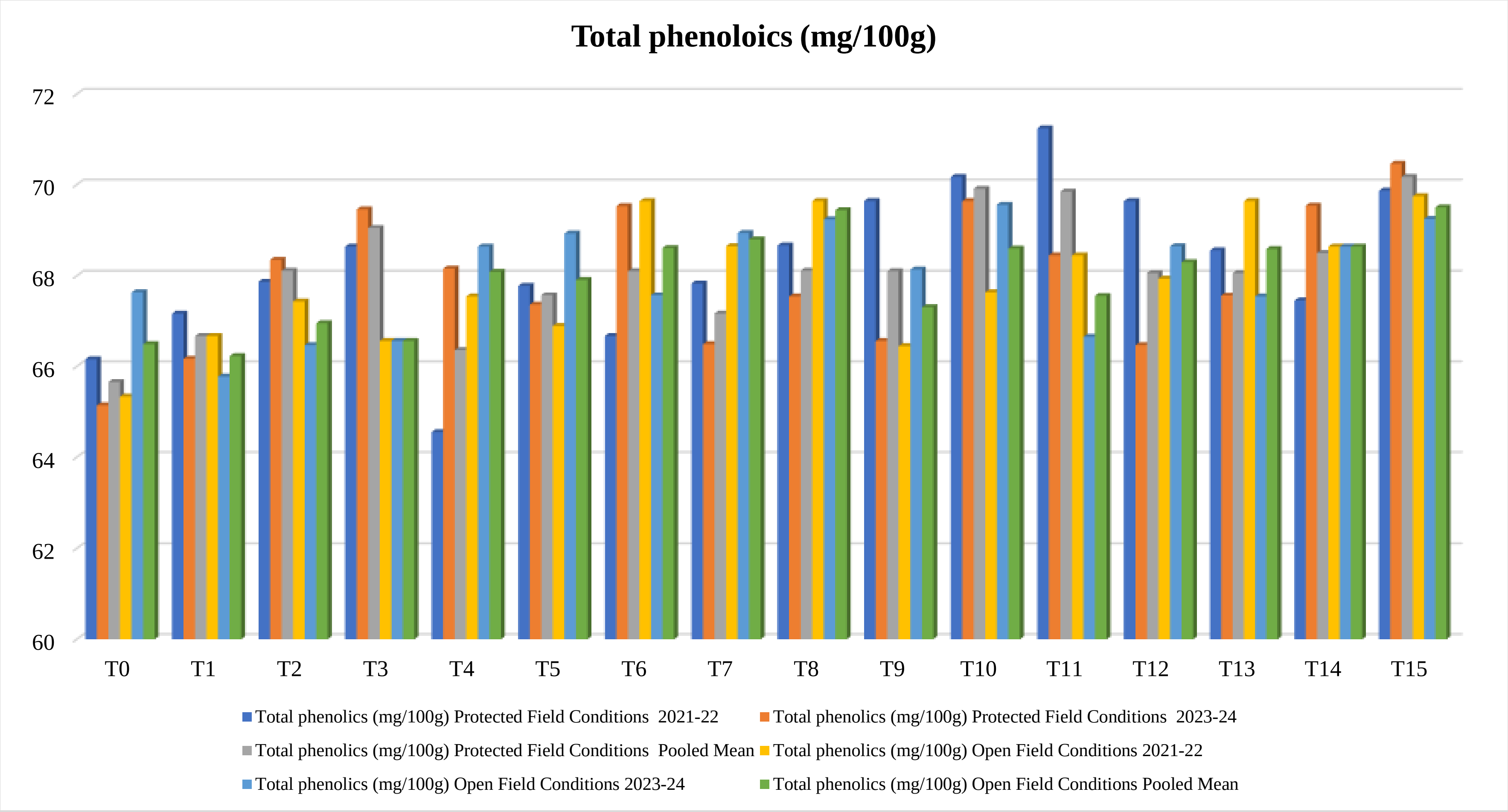

Figure 4.29: Effect of Nano- ZnO and FeO on Total phenolics (mg/100g) of Strawberry (Fragaria × ananassa Duch.) cv. Winter Dawn under protected and open conditions

4.1.30 Anthocyanin content (mg per 100 g)

The results pertaining to effect of ZnO and FeO at different levels on anthocyanin content elaborated in Table 4.30a revealed significant variation exist among all the treatments under protected field condition. During (2022-23) maximum (0.190 mg per 100 g) anthocyanin content was observed under the treatment T_{10} (100 ppm ZnO + 50 ppm FeO) followed by (0.180 md/100 g) under T_{15} (150 ppm ZnO + 150 ppm FeO) while the minimum (0.150 mg/100g) was noted under the treatment T_2 (100 ppm ZnO) while the control (T_0) was found with 0.151 mg100g of anthocyanin content. In the second-year trial (2023-24) maximum (0.191 mg/100g) anthocyanin content was noticed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 0.190 mg/100 g under T_8 (50 ppm ZnO + 100 ppm FeO) while the control was found with 0.120 mg/100g of anthocyanin content which remained minimum. The pooled Data for both the years (2022-23 and 2023-24) revealed the maximum anthocyanin content (0.186 mg/100g) under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 0.181 mg/100g under T_8 (50 ppm ZnO + 100 ppm FeO) while the minimum (0.136 mg/ 100g) was noticed under treatment (T_0).

It is evident from the Table 4.30b influence of different levels of ZnO and FeO on anthocyanin content under natural growing conditions had significant variation. During (2022-23) maximum (0.191 mg per 100 g) anthocyanin content was noted under the treatment T_6 (150ppm FeO) followed by (0.190 md/100 g) under T_3 (150ppm ZnO) while the minimum (0.140 mg/100g) was noted under the treatment T_7 (50 ppm ZnO + 50 ppm FeO) while the control (T_0) was found with 0.161 mg100g of anthocyanin content. In the second-year trial (2023-24) maximum (0.194 mg/100g) anthocyanin content was recorded under the treatment T_{10} (100 ppm ZnO + 50 ppm FeO) followed by 0.191 mg/100 g under T_{15} (150 ppm ZnO + 150 ppm FeO) while the control was found with 0.150 mg/100g of anthocyanin content against T_5 (100ppm FeO) having 0.150 mg/100g anthocyanin content which remained minimum. The pooled Data for both the years (2022-23 and 2023-24) revealed the maximum (0.186 mg/100g) anthocyanin content was reported under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 0.186 mg/100g under T_3 (150 ppm ZnO) and minimum (0.141 mg/ 100g) was noticed under treatment (T_7).

The enhancement of anthocyanin content in strawberry fruits through the application of zinc and iron is attributed to their roles in upregulating anthocyanin biosynthetic enzymes. Zinc increases the activity of enzymes like UDP-glucose: flavonoid 3-O-glucosyltransferase (UFGT), while iron supports the activation of dihydroflavonol 4-reductase (DFR), collectively enhancing anthocyanin accumulation. The present results are coincide with the studies of Yoon *et al.,* (2017); Rawat *et al.,* (2010); Saini *et al.,* (2021); Tripathi *et al.,* (2018) and Patel and Singh (2020).

Table 4.30: Effect of Nano- ZnO and FeO on Anthocyanin content (mg/100g) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Anthocyanin content (mg/100g)						
	Protected Field Conditions			**Open Field Conditions**		
Treatments	**2022-23**	**2023-24**	**Pooled Mean**	**2022-23**	**2023-24**	**Pooled Mean**
T_{0}	0.151	0.120	0.136	0.161	0.154	0.158
T_{1}	0.163	0.150	0.157	0.171	0.162	0.167
T_{2}	0.150	0.140	0.145	0.183	0.174	0.179
T_{3}	0.170	0.162	0.166	0.190	0.181	0.186
T_{4}	0.180	0.130	0.155	0.170	0.190	0.180
T_{5}	0.174	0.150	0.162	0.172	0.150	0.161
T_{6}	0.163	0.170	0.167	0.191	0.170	0.181
T_{7}	0.150	0.180	0.165	0.140	0.142	0.141
T_{8}	0.171	0.190	0.181	0.162	0.170	0.166
T_{9}	0.180	0.170	0.175	0.153	0.180	0.167
T_{10}	0.190	0.172	0.181	0.180	0.194	0.187
T_{11}	0.170	0.160	0.165	0.140	0.151	0.146
T_{12}	0.160	0.182	0.171	0.172	0.160	0.166
T_{13}	0.151	0.160	0.156	0.181	0.173	0.177
T_{14}	0.162	0.170	0.166	0.179	0.181	0.180
T_{15}	0.180	0.191	0.186	0.182	0.191	0.187
C.D.	3.341	1.651	2.496	2.508	1.649	2.079
SE(m)	1.151	0.569	0.860	0.864	0.568	0.716
SE(d)	1.628	0.805	1.217	1.222	0.804	1.013
C.V.	5.507	2.814	4.161	4.190	2.752	3.471

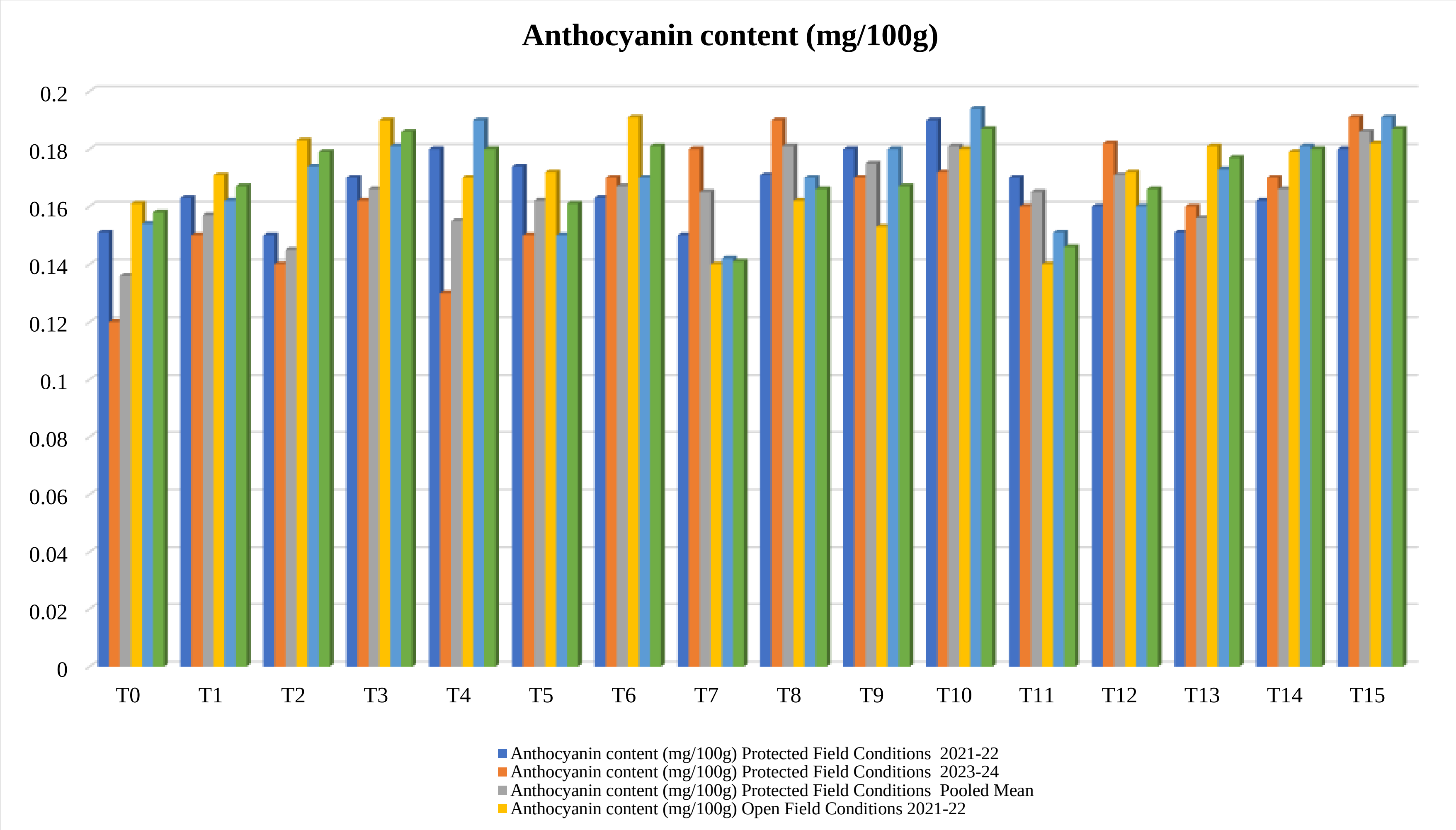

Figure 4.30: Effect of Nano- ZnO and FeO on Anthocyanin content (mg/100g) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.1.31 Soluble protien (%)

Table 4.31 presents the effect of various concentrations of Nano-ZnO and FeO on soluble protein under protected conditions. In the 2022-23 trial, the highest soluble protein content of 2.67% was recorded with treatment T_{15} (150 ppm ZnO + 150 ppm FeO), followed by 2.52% with T_{11} (100 ppm ZnO + 100 ppm FeO). The lowest content of 2.34% was observed with the control treatment (T_0). In the 2023-24 trial, the highest soluble protein content of 2.75% was found with T_{15}, while T_{14} (150 ppm ZnO + 100 ppm FeO) showed 2.72%. The minimum content of 2.35% was noted with T_5 (100 ppm FeO), and the control (T_0) had 2.36%. Combining the Data from both years, the highest average soluble protein content of 2.71% was observed with T_{15}, followed by 2.59% with T_{14}. The lowest average content of 2.35% was recorded with the control treatment.

It is evident from the Table 4.31 different levels of ZnO and FeO had significant variation among all the treatments and influence soluble protein under natural growing condition. During (2022-23) the maximum (2.65 %) soluble protein was observed under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 2.54 % under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (2.29 %) was found under the treatment T_0 (control). In the second-year trial (2023-24) maximum (2.73 %) soluble protein was recorded under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 2.70 % under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (2.41 %) was found under the treatment T_5 (100ppm FeO) and the control T_0 was recorded with 2.53 per cent soluble protein. The pooled Data for both the years (2022-23 and 2023-24) revealed the maximum (2.69 %) soluble protein under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 2.62 % under T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (2.38 %) was found under the treatment T_2 (100ppm ZnO).

It is obvious that the application of Nano-ZnO and FeO enhances the soluble protein percentage in strawberries due to several underlying mechanisms, which are critical for protein synthesis and metabolism. By stimulating the activity of key enzymes involved in protein biosynthesis and stress response, such as proteases and ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO), they ultimately contribute to increased protein accumulation. Additionally, Zn and Fe nanoparticles activate stress-responsive signaling pathways and transcription factors, which are helpful in upregulating the expression of genes involved in protein synthesis. Enhanced antioxidant defense mechanisms, induced by these nanoparticles, further protect proteins from degraDAPion, ultimately contributing to a higher percentage of soluble proteins in strawberries. The present results are coincide with the findings of Kumar *et al.,* (2018); Rathore *et al.,* (2003); Verma *et al.,* (2018); Yadav *et al.,* (2011); Raliya *et al.,* (2013); Reddy *et al.,* (2021); Shukla *et al.,* (2016) and Zhang and Li (2019).

Table 4.31: Effect of Nano- ZnO and FeO on Soluble protein (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

Soluble protein (%)						
	Protected Field Conditions			Open Field Conditions		
Treatments	**2022-23**	**2023-24**	**Pooled Mean**	**2022-23**	**2023-24**	**Pooled Mean**
T_0	2.34	2.36	2.35	2.29	2.53	2.41
T_1	2.46	2.45	2.46	2.41	2.66	2.54
T_2	2.48	2.55	2.51	2.32	2.44	2.38
T_3	2.43	2.56	2.49	2.37	2.55	2.46
T_4	2.37	2.63	2.50	2.40	2.43	2.42
T_5	2.39	2.35	2.37	2.45	2.41	2.43
T_6	2.49	2.55	2.52	2.43	2.54	2.49
T_7	2.40	2.61	2.51	2.46	2.43	2.45
T_8	2.41	2.66	2.54	2.39	2.56	2.48
T_9	2.44	2.64	2.54	2.42	2.55	2.49
T_{10}	2.48	2.65	2.57	2.39	2.53	2.46
T_{11}	2.52	2.55	2.53	2.54	2.70	2.62
T_{12}	2.43	2.45	2.44	2.41	2.46	2.44
T_{13}	2.45	2.64	2.55	2.45	2.45	2.45
T_{14}	2.46	2.72	2.59	2.43	2.44	2.44
T_{15}	2.67	2.75	2.71	2.65	2.73	2.69
C.D.	0.142	0.173	0.158	0.158	0.185	0.172
SE(m)	0.049	0.060	0.055	0.054	0.064	0.059
SE(d)	0.069	0.084	0.077	0.077	0.090	0.084
C.V.	3.464	4.017	3.741	3.881	4.382	4.132

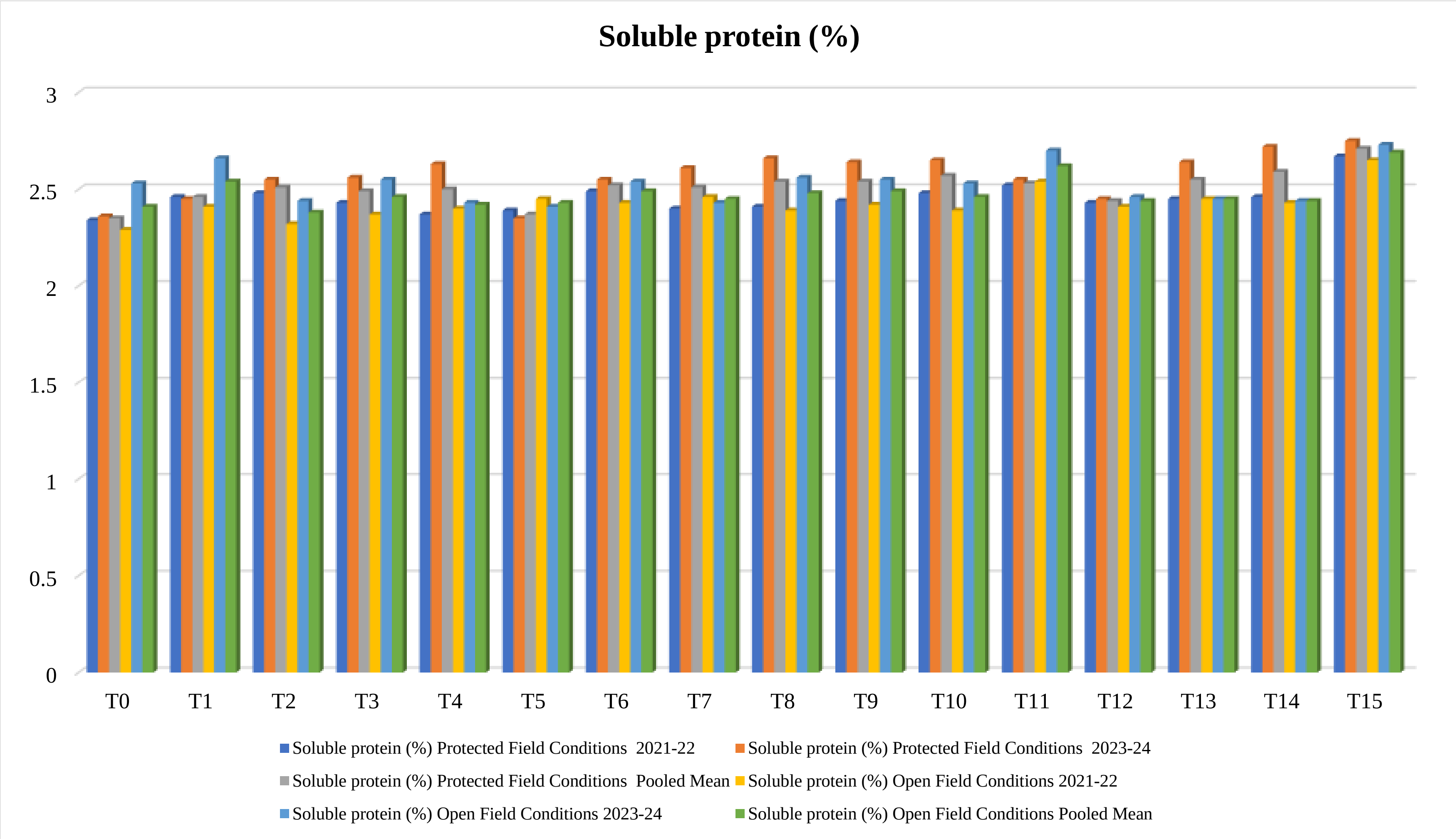

Figure 4.31: Effect of Nano- ZnO and FeO on Soluble protein (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected and open conditions

4.2 Shelf-Life Parameters

4.2.1 Physical loss in weight (PLW %)

The study of Table 4.32a and Figure 4.32a revealed that, significant variations exist on PLW (%) across all treatments at 3rd, 6th, and 9th day of storage for protected field condition with the application of different levels of Nano-ZnO and Nano-FeO.

The PLW (%) on the 9th day during the first-year trial (2022-23), observations showed increasing treatment where the maximum (6.07%) PLW was recorded under the treatment T_0 (control) while the minimum (1.91%) was noticed under T_{15} (150 ppm ZnO + 150 ppm FeO) followed by 3.04 % under T_5 (100ppm FeO). In the second year trial (2023-24) recorded the same increasing pattern with the maximum (4.39%) value of PLW under the treatment T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (1.76%) was noted in the treatment T_5 (100ppm FeO) followed by 2.25 % under treatment T_3 (150ppm ZnO). The pooled analysis (2022-23 and 2023-24) revealed the maximum (6.07%) PLW under T_0 (control) while the minimum (2.40%) was noted in T_5 (100ppm FeO) followed by 2.57 % under T_{15} (150 ppm ZnO + 150 ppm FeO).

It is evident from the table 4.32 that different levels of ZnO and FeO had significant variations among the treatments under open field condition. The PLW (%) on the 9th day during the first-year trial (2022-23), showed increasing trend where the maximum (3.35%) PLW was recorded under the treatment T_{11} (100 ppm ZnO + 100 ppm FeO) while the minimum (1.11%) was noticed under T_5 (100ppm FeO) followed by 1.11 % under T_5 (100ppm FeO). In the second-year trial (2023-24) observed the same increasing pattern with the maximum (2.31%) PLW under the treatment T_0 (control) while the minimum (0.83%) was noticed under the treatment T_4 (50ppm FeO) followed by 0.99 % under T_3 (150ppm ZnO). The pooled analysis (2022-23 and 2023-24) revealed the maximum (2.21%) PLW under T_0 (control) while the minimum (1.19%) was noted in T_5 (100ppm FeO) followed by 1.24 % under T_2 (100ppm ZnO).

The decrease in postharvest weight loss in strawberries with the application of Zn and Fe can be attributed to their roles in enhancing cell wall integrity and reducing respiration rates. Zinc strengthens the cell wall by promoting the synthesis of structural components such as pectin and cellulose, which enhance cell wall rigidity and reduce moisture loss. Concurrently, nano Fe improves mitochondrial efficiency, which decreases respiration rates and metabolic activity, thereby minimizing the rate of water loss and senescence. This dual action leads to a more stable cell structure and reduces metabolic demand, resulting in lower mass loss during storage. The combined effects of enhanced cell wall fortification and reduced respiration contribute to a significant decrease in PLW in strawberries. The results are in conformity with the findings of Ahmed *et al.,* (2017); Tripathi *et al.,* (2018); Reddy *et al.,* (2021); Saini *et al.,* (2021); Singh *et al.,* (2010) Yadav *et al.,* (2011) and Xu *et al.,* (2018).

Table 4.32a: Effect of Nano- ZnO and FeO on PLW (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day interval

PLW % (Days Interval) (Protected)												
Treatments	**0 Day**			**3 Day**			**6 Day**			**9 Day**		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**
T$_{0}$	0.00^{a}	0.00^{a}	0.00^{a}	2.79^{b}	1.09^{a}	1.94^{ab}	5.85^{d}	1.80^{ab}	3.83^{b}	8.39^{d}	3.75^{a}	6.07^{d}
T$_{1}$	0.00^{a}	0.00^{a}	0.00^{a}	1.22^{ab}	1.04^{a}	1.13^{a}	2.68^{abc}	2.25^{ab}	2.47^{ab}	3.99^{bc}	3.12^{a}	3.56^{abc}
T$_{2}$	0.00^{a}	0.00^{a}	0.00^{a}	1.08^{ab}	0.65^{a}	0.87^{ab}	2.27^{ab}	1.30^{ab}	1.79^{a}	3.40^{ab}	2.53^{a}	2.97^{ab}
T$_{3}$	0.00^{a}	0.00^{a}	0.00^{a}	1.22^{ab}	0.54^{a}	0.88^{ab}	2.76^{abc}	1.16^{bc}	1.96^{ab}	3.83^{bc}	2.25^{a}	3.04^{ab}
T$_{4}$	0.00^{a}	0.00^{a}	0.00^{a}	1.97^{ab}	0.63^{a}	1.30^{a}	2.58^{ab}	1.41^{ab}	2.00^{ab}	3.37^{ab}	2.63^{a}	3.00^{ab}
T$_{5}$	0.00^{a}	0.00^{a}	0.00^{a}	1.09^{ab}	0.53^{a}	0.81^{a}	2.23^{ab}	1.15^{ab}	1.69^{a}	3.04^{ab}	1.76^{a}	2.40^{a}
T$_{6}$	0.00^{a}	0.00^{a}	0.00^{a}	1.54^{ab}	0.63^{a}	1.09^{a}	2.26^{ab}	1.22^{ab}	1.74^{a}	3.12^{ab}	2.31^{a}	2.72^{ab}
T$_{7}$	0.00^{a}	0.00^{a}	0.00^{a}	1.35^{ab}	0.62^{a}	0.99^{a}	2.74^{abc}	1.59^{ab}	2.17^{ab}	4.21^{bc}	2.69^{a}	3.45^{ab}
T$_{8}$	0.00^{a}	0.00^{a}	0.00^{a}	1.91^{ab}	0.57^{a}	1.24^{a}	3.53^{abc}	1.03^{a}	2.28^{ab}	4.31^{bc}	3.56^{a}	3.94^{abc}
T$_{9}$	0.00^{a}	0.00^{a}	0.00^{a}	2.19^{ab}	0.32^{a}	1.26^{a}	4.65^{cd}	0.98^{a}	2.82^{b}	5.63^{c}	4.39^{a}	5.01^{cd}
T$_{10}$	0.00^{a}	0.00^{a}	0.00^{a}	1.92^{ab}	0.70^{a}	1.31^{a}	3.03^{abc}	1.42^{ab}	2.23^{ab}	4.89^{bc}	2.55^{a}	3.72^{abc}
T$_{11}$	0.00^{a}	0.00^{a}	0.00^{a}	1.61^{ab}	0.93^{a}	1.27^{a}	0.11^{bc}	1.80^{ab}	0.96^{ab}	3.98^{bc}	3.24^{a}	3.61^{abc}
T$_{12}$	0.00^{a}	0.00^{a}	0.00^{a}	1.81^{ab}	0.65^{a}	1.23^{a}	3.00^{abc}	1.59^{ab}	2.30^{ab}	3.66^{ab}	2.74^{a}	3.20^{ab}
T$_{13}$	0.00^{a}	0.00^{a}	0.00^{a}	1.29^{ab}	0.40^{a}	0.85^{a}	2.93^{abc}	1.00^{a}	1.97^{ab}	3.95^{bc}	2.55^{a}	3.25^{ab}
T$_{14}$	0.00^{a}	0.00^{a}	0.00^{a}	1.17^{ab}	1.10^{a}	1.14^{a}	3.44^{abc}	1.67^{ab}	2.56^{ab}	4.45^{bc}	3.92^{a}	4.19^{bc}
T$_{15}$	0.00^{a}	0.00^{a}	0.00^{a}	0.73^{a}	1.74^{a}	1.24^{a}	1.51^{a}	2.32^{c}	1.92^{ab}	1.91^{a}	3.23^{a}	2.57^{a}

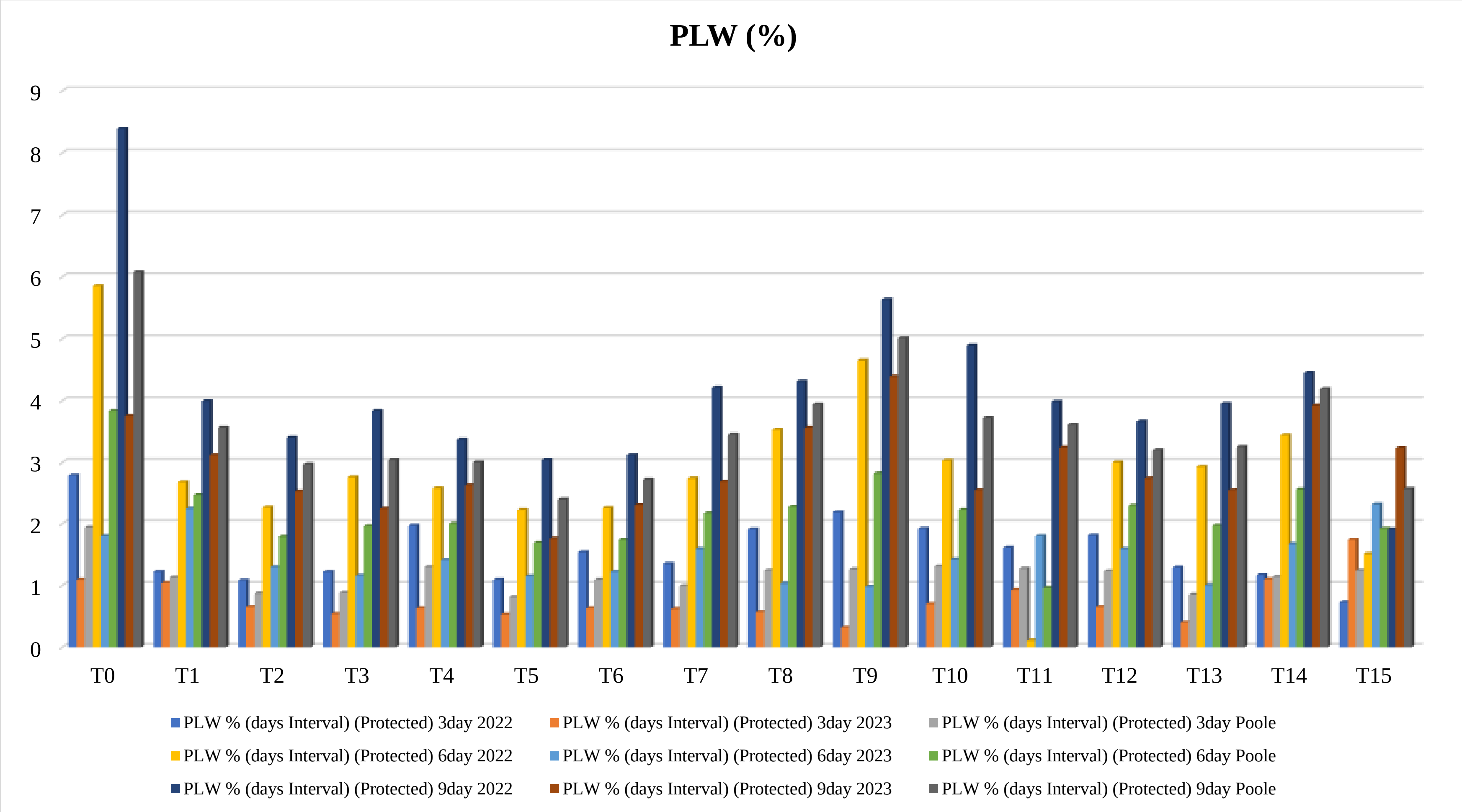

Figure 4.32a: Effect of Nano- ZnO and FeO on PLW (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day intervals

Table 4.32b: Effect of Nano- ZnO and FeO on PLW (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day interval

PLW % (Days Interval) (Open)												
Treatments	**0 Day**			**3 Day**			**6 Day**			**9 Day**		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**
T0	0.00^{a}	0.00^{a}	0.00^{a}	1.25^{a}	1.92^{ab}	1.59^{ab}	1.59^{ab}	1.17^{abc}	1.38^{a}	2.10^{abc}	2.31^{b}	2.21^{ab}
T1	0.00^{a}	0.00^{a}	0.00^{a}	1.24^{a}	1.01^{a}	1.13^{ab}	1.82ab	1.41^{abc}	1.62^{a}	2.29^{abc}	1.55^{ab}	1.92^{ab}
T2	0.00^{a}	0.00^{a}	0.00^{a}	1.36^{a}	0.74^{a}	1.05^{ab}	1.25ab	1.92^{b}	1.59^{a}	1.22^{ab}	1.25^{ab}	1.24^{a}
T3	0.00^{a}	0.00^{a}	0.00^{a}	0.84^{a}	2.05^{ab}	1.45^{ab}	1.82ab	1.00^{abc}	1.41^{a}	2.08^{abc}	0.99^{ab}	1.54^{ab}
T4	0.00^{a}	0.00^{a}	0.00^{a}	1.21^{a}	3.05^{b}	2.13^{b}	2.80b	1.27^{abc}	2.04^{a}	2.48^{abc}	0.83^{a}	1.66^{ab}
T5	0.00^{a}	0.00^{a}	0.00^{a}	0.95^{a}	1.37^{ab}	1.16^{ab}	1.48ab	1.35^{abc}	1.42^{a}	1.11^{a}	1.27^{ab}	1.19^{a}
T6	0.00^{a}	0.00^{a}	0.00^{a}	1.19^{a}	1.11^{ab}	1.15^{ab}	1.87ab	1.58^{abc}	1.73^{a}	1.90^{abc}	1.39^{ab}	1.65^{ab}
T7	0.00^{a}	0.00^{a}	0.00^{a}	0.97^{a}	1.14^{ab}	1.06^{ab}	1.16ab	1.59^{abc}	1.38^{a}	2.21^{abc}	1.34^{ab}	1.78^{ab}
T8	0.00^{a}	0.00^{a}	0.00^{a}	0.80^{a}	1.55^{ab}	1.18^{ab}	1.50ab	1.08^{ab}	1.29^{a}	2.04^{abc}	2.21^{ab}	2.13^{ab}
T9	0.00^{a}	0.00^{a}	0.00^{a}	1.20^{a}	1.76^{ab}	1.48^{ab}	2.42ab	1.09^{ab}	1.76^{a}	1.86^{abc}	1.46^{ab}	1.66^{ab}
T$_{10}$	0.00^{a}	0.00^{a}	0.00^{a}	1.29^{a}	1.15^{ab}	1.22^{ab}	1.91ab	1.02^{a}	1.47^{a}	2.96^{bc}	0.89^{ab}	1.93^{ab}
T$_{11}$	0.00^{a}	0.00^{a}	0.00^{a}	1.81^{a}	2.07^{ab}	1.94^{ab}	0.87a	1.48^{abc}	1.18^{a}	3.35^{c}	1.26^{ab}	2.31^{ab}
T$_{12}$	0.00^{a}	0.00^{a}	0.00^{a}	1.43^{a}	1.71^{ab}	1.57^{ab}	1.13ab	1.88^{abc}	1.51^{a}	3.25^{c}	1.70^{ab}	2.48^{b}
T$_{13}$	0.00^{a}	0.00^{a}	0.00^{a}	0.70^{a}	1.23^{ab}	0.97^{a}	1.39ab	0.94^{a}	1.17^{a}	3.18^{c}	1.92^{ab}	2.55^{b}
T$_{14}$	0.00^{a}	0.00^{a}	0.00^{a}	1.46^{a}	1.54^{ab}	1.50^{ab}	2.77b	0.95^{a}	1.86^{a}	2.78^{abc}	1.39^{ab}	2.09^{ab}
T$_{15}$	0.00^{a}	0.00^{a}	0.00^{a}	0.87^{a}	3.07^{b}	1.97^{ab}	2.17ab	1.16^{abc}	1.67^{a}	1.72^{abc}	1.64^{ab}	1.68^{ab}

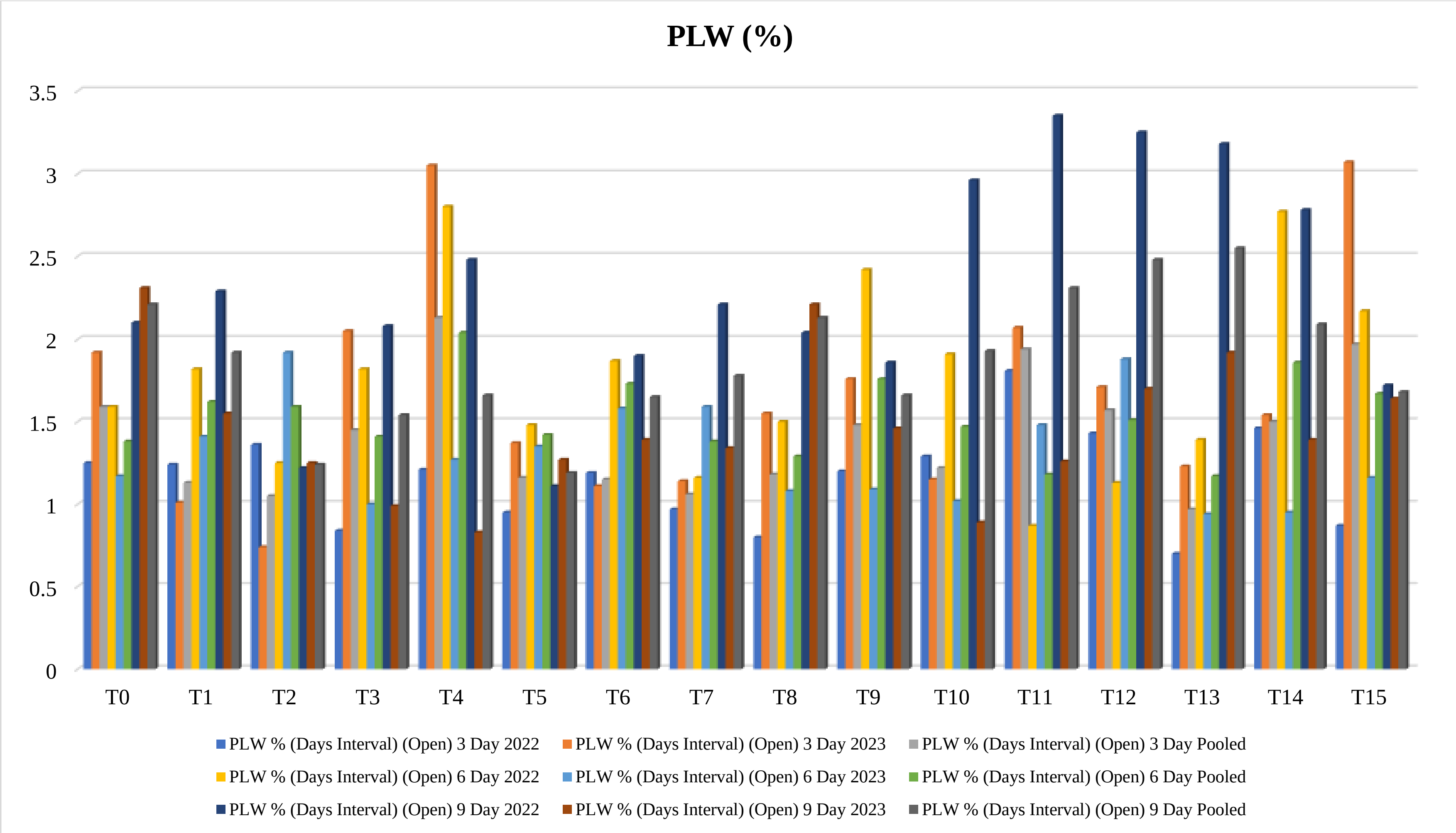

Figure 4.32b Effect of Nano- ZnO and FeO on PLW (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day intervals

4.2.2 Total soluble solid (TSS °brix)

The studt of the Data presented in Table 4.33a r on TSS evealed significant variations among all the treatments with different levels of Nano-ZnO and FeO under protected and open field conditions. For protected field conditions, TSS (%) on the 9th day during (2022-23), observations showed an increasing trend where the maximum TSS (7.28 °brix) was noted in treatment T_0 (100 % RDF) while the minimum (7.10 °brix) was noticed under T_{12} (100 ppm ZnO + 150 ppm FeO). During (2023-24) showed the same increasing pattern with the maximum (7.20 °brix) value of TSS was recorded under the treatment T_{14} (150 ppm ZnO + 100 ppm FeO) while the minimum (6.37 °brix) was noticed under the treatment T_0 (100 % RDF). The pooled analysis (2022-23 and 2023-24) revealed the maximum (7.23 °brix) TSS under T_1 (150ppm ZnO+ 100ppm FeO) while the minimum (6.83 °brix) was noted in T_0 (100 % RDF).

The TSS (°brix) on the 9th day for open field conditions, during (2022-23), observations showed an increasing trend where the maximum (7.67 °brix) TSS was recorded under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (6.94 °brix) was noticed under T_5 (100 ppm FeO). During (2023-24) showed the same increasing pattern with the maximum (7.56 °brix) value of TSS under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (7.05 °brix) was noticed under the treatment T_1 (50 ppm ZnO). The pooled analysis (2022-23 and 2023-24) revealed the maximum (7.62 °brix %) TSS °brix under T_{13} (150ppm ZnO+ 50ppm FeO) while the minimum (7.22 °brix) was recorded in T_{15} (150ppm ZeO + 150 ppm FeO).

The extension of shelf life in strawberry fruits through the application of zinc and iron, as measured by Total Soluble Solids (^{0}brix) at various intervals, is attributed to their roles in maintaining fruit quality. Zinc enhances enzyme stability and reduces senescence, while iron supports efficient photosynthesis and carbohydrate metabolism, which together help to preserve TSS levels over time and extend shelf life. The present results obtained are in line with the findngs of work undertaken by Bharati *et al.,* (2020); Taha *et al.,* (2017); Raliya *et al.,* (2013); Sajid *et al.,* (2012); Tripathi *et al.,* (2018); Singh *et al.,* (2010) and Lee & Kim (2018).

Table 4.33a: Effect of Nano- ZnO and FeO on TSS (ºbrix) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day interval

Treatments	TSS (ºbrix) (Protected)											
	0 Day			3 Day			6 Day			9 Day		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_0	5.51^{a}	5.58^{ab}	5.55^{ab}	5.53^{a}	5.62^{ab}	5.58^{a}	6.25^{ab}	5.68^{ab}	5.97^{ab}	7.28^{a}	6.37^{a}	6.83^{a}
T_1	5.56^{a}	5.44^{a}	5.50^{a}	5.58^{a}	5.49^{a}	5.54^{a}	5.98^{a}	5.58^{a}	5.78^{a}	7.22^{a}	6.68^{abc}	6.95^{abc}
T_2	5.70^{ab}	5.56^{ab}	5.63^{ab}	5.69^{ab}	5.59^{ab}	5.64^{a}	6.13^{a}	5.65^{ab}	5.89^{ab}	7.18^{a}	6.57^{ab}	6.88^{ab}
T_3	6.03^{bc}	5.65^{abc}	5.84^{bcd}	6.05^{bc}	5.69^{a}	5.87^{abc}	6.20^{ab}	6.11^{abc}	6.16^{abc}	7.23^{a}	7.19^{c}	7.21^{c}
T_4	6.20^{bc}	6.00^{bcd}	6.10^{de}	6.23^{cde}	6.07^{ab}	6.15^{cde}	6.74^{cd}	6.18^{bc}	6.46^{cde}	7.24^{a}	6.75^{abc}	7.00^{abc}
T_5	6.04^{bc}	5.92^{abcd}	5.98^{cd}	6.09^{bcd}	5.99^{abc}	6.04^{bcd}	6.38^{abc}	6.14^{bc}	6.26^{bcd}	7.18^{a}	6.89^{abc}	7.04^{abc}
T_6	5.74^{ab}	5.94^{abcd}	5.84^{bcd}	5.75^{ab}	5.98^{bcd}	5.87^{abc}	6.17^{a}	6.11^{abc}	6.14^{abc}	7.12^{a}	6.91^{bc}	7.02^{abc}
T_7	6.98^{e}	6.11^{cd}	6.55^{fg}	6.99^{f}	6.14^{abcd}	6.57^{gh}	7.15^{d}	6.53^{cde}	6.84^{ef}	7.15^{a}	7.02^{bc}	7.09^{abc}
T_8	5.58^{a}	5.92^{abcd}	5.75^{abc}	5.60^{a}	5.97^{abcd}	5.79^{ab}	5.95^{a}	6.10^{abc}	6.03^{ab}	7.16^{a}	6.75^{abc}	6.96^{abc}
T_9	6.79^{cde}	5.92^{abcd}	6.36^{ef}	6.81^{fg}	5.97^{cd}	6.39^{ef}	6.95^{d}	6.37^{cd}	6.66^{def}	7.22^{a}	7.01^{bc}	7.12^{abc}
T_{10}	6.37^{bcd}	6.25^{de}	6.31^{ef}	6.40^{cdef}	6.30^{abcd}	6.35^{de}	6.67^{bcd}	6.61^{cde}	6.64^{def}	7.15^{a}	7.04^{bc}	7.10^{abc}
T_{11}	6.37^{bcd}	6.28^{de}	6.33^{ef}	6.41^{cdef}	6.34^{abcd}	6.38^{ef}	6.77^{cd}	6.51^{cde}	6.64^{def}	7.23^{a}	6.86^{abc}	7.05^{abc}
T_{12}	6.48^{cd}	6.65^{e}	6.57^{fg}	6.50^{def}	6.69^{de}	6.60^{fg}	6.84^{cd}	6.85^{de}	6.85^{ef}	7.10^{a}	7.16^{c}	7.13^{abc}
T_{13}	6.72^{cde}	6.73^{e}	6.73^{g}	6.78^{fg}	6.77^{de}	6.78^{g}	7.00^{d}	6.99^{e}	7.00^{f}	7.24^{a}	7.18^{c}	7.21^{c}
T_{14}	6.58^{bcd}	6.68^{e}	6.63^{fg}	6.61^{efg}	6.72^{e}	6.67^{fg}	6.78^{cd}	6.85^{de}	6.82^{ef}	7.25^{a}	7.20^{c}	7.23^{c}
T_{15}	6.25^{bcd}	6.34^{e}	6.30^{ef}	6.28^{cde}	6.43^{e}	6.36^{def}	6.39^{abc}	6.54^{cde}	6.47^{cde}	7.17^{a}	6.91^{bc}	7.04^{abc}

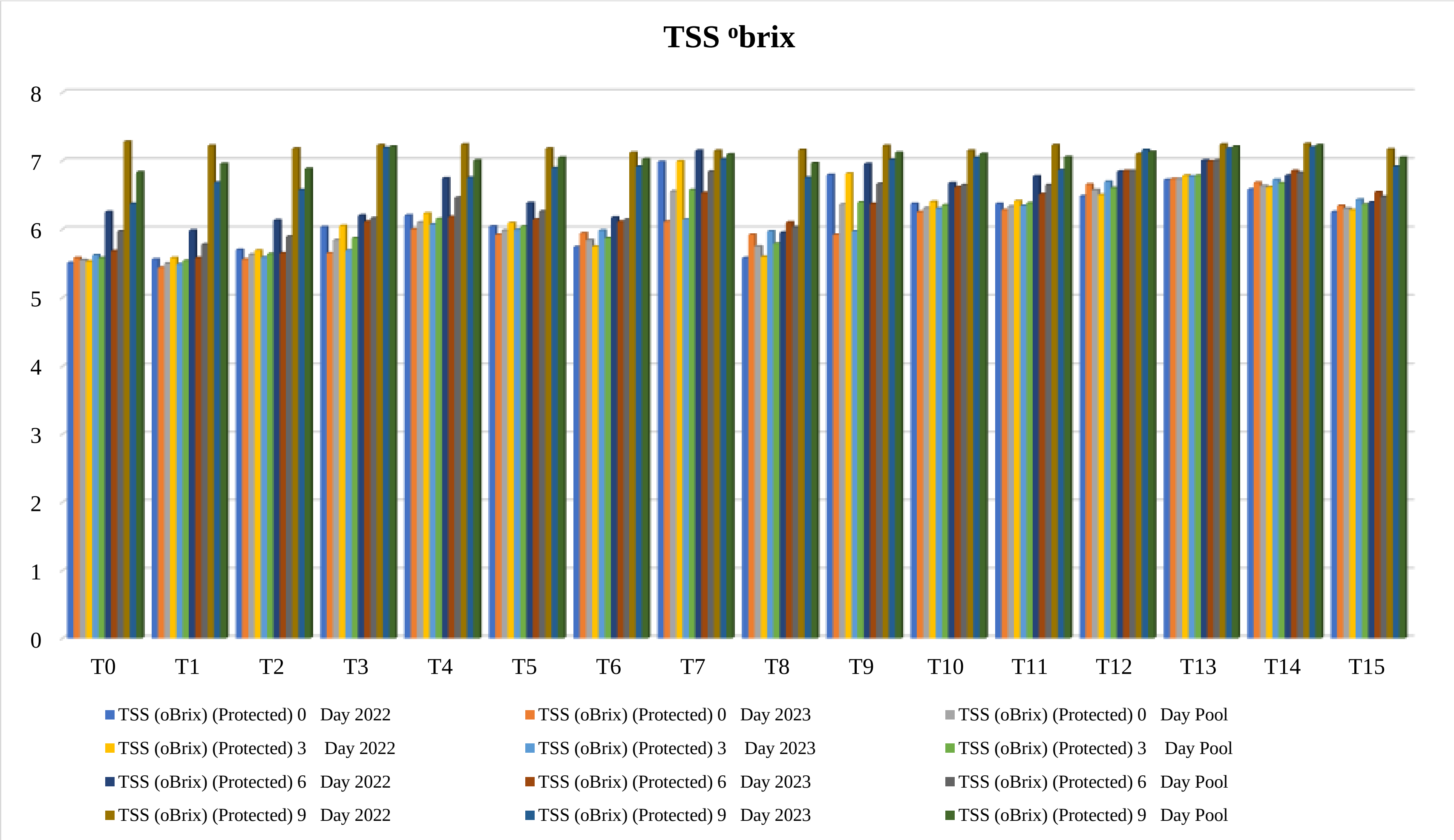

Figure 4.33a: Effect of Nano- ZnO and FeO on TSS (ºbrix) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day interval

Table 4.33b: Effect of Nano- ZnO and FeO on TSS (ºbrix) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day interval

Treatments	TSS (ºbrix) (Open)											
	0 Day			3 Day			6 Day			9 Day		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_{0}	6.41^{a}	6.39^{a}	6.40^{ab}	6.45^{ab}	6.59^{ab}	6.52^{abc}	6.76^{abc}	6.67^{abc}	6.72^{abc}	7.50^{ab}	7.32^{abcd}	7.41^{bc}
T_{1}	6.33^{a}	6.34^{a}	6.34^{a}	6.35^{ab}	6.52^{ab}	6.44^{abc}	6.63^{abc}	6.63^{ab}	6.63^{ab}	7.42^{ab}	7.05^{ab}	7.24^{ab}
T_{2}	6.10^{a}	6.70^{c}	6.40^{ab}	6.15^{ab}	6.90^{bc}	6.53^{abc}	6.80^{abc}	6.95^{bcd}	6.88^{bc}	7.27^{ab}	7.34^{bcd}	7.31^{abc}
T_{3}	6.12^{a}	6.19^{a}	6.16^{a}	6.14^{ab}	6.49^{ab}	6.32^{ab}	6.66^{abc}	6.63^{ab}	6.65^{ab}	7.35^{ab}	7.19^{abc}	7.27^{abc}
T_{4}	6.21^{a}	6.44^{ab}	6.33^{a}	6.26^{ab}	6.70^{ab}	6.48^{abc}	6.31^{ab}	6.79^{abcd}	6.55^{ab}	7.22^{ab}	7.26^{abc}	7.24^{ab}
T_{5}	6.08^{a}	6.19^{a}	6.14^{a}	6.12^{ab}	6.38^{ab}	6.25^{a}	6.21^{a}	6.47^{a}	6.34^{a}	6.94^{a}	7.04^{a}	6.99^{a}
T_{6}	6.64^{a}	6.44^{ab}	6.54^{ab}	6.67^{ab}	6.69^{bc}	6.68^{abc}	6.81^{abc}	6.77^{abcd}	6.79^{bc}	7.61^{b}	7.45^{cd}	7.53^{bc}
T_{7}	6.47^{a}	6.34^{a}	6.41^{ab}	6.52^{ab}	6.62^{ab}	6.57^{abc}	6.88^{bc}	6.76^{abcd}	6.82^{bc}	7.52^{b}	7.26^{abcd}	7.39^{bc}
T_{8}	6.57^{a}	6.23^{a}	6.40^{ab}	6.62^{ab}	6.50^{ab}	6.56^{abc}	6.91^{bc}	6.64^{ab}	6.78^{bc}	7.55^{b}	7.40^{cd}	7.48^{bc}
T_{9}	6.54^{a}	6.43^{ab}	6.49^{ab}	6.59^{ab}	6.65^{ab}	6.62^{abc}	6.86^{bc}	6.73^{abc}	6.80^{bc}	7.27^{ab}	7.27^{abcd}	7.27^{abc}
T_{10}	6.47^{a}	6.31^{a}	6.39^{ab}	6.50^{ab}	6.51^{ab}	6.51^{abc}	6.77^{abc}	6.62^{ab}	6.70^{ab}	7.34^{ab}	7.42^{cd}	7.38^{bc}
T_{11}	6.13^{a}	6.33^{a}	6.23^{a}	6.17^{ab}	6.48^{ab}	6.33^{ab}	6.64^{abc}	6.68^{abc}	6.66^{ab}	7.47^{ab}	7.33^{abcd}	7.40^{bc}
T_{12}	6.38^{a}	6.65^{c}	6.52^{ab}	6.43^{b}	7.07^{c}	6.75^{bc}	6.64^{abc}	7.16^{d}	6.90^{bc}	7.36^{ab}	7.34^{bcd}	7.35^{bc}
T_{13}	6.85^{a}	6.70^{c}	6.78^{b}	6.91^{ab}	6.86^{bc}	6.89^{c}	7.14^{c}	7.08^{cd}	7.11^{c}	7.67^{b}	7.56^{d}	7.62^{c}
T_{14}	6.55^{a}	6.33^{a}	6.44^{ab}	6.59^{ab}	6.52^{ab}	6.56^{abc}	6.85^{bc}	6.62^{ab}	6.74^{abc}	7.47^{ab}	7.34^{bcd}	7.41^{bc}
T_{15}	6.29^{a}	6.37^{a}	6.33^{ab}	6.34^{ab}	6.43^{ab}	6.39^{ab}	6.60^{abc}	6.55^{ab}	6.58^{ab}	7.14^{ab}	7.30^{abcd}	7.22^{ab}

Figure 4.33b: Effect of Nano- ZnO and FeO on TSS (ºbrix) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day intervals

4.2.2 Spoilage percent (%)

The results pertaining to effect of nano-ZnO and FeO on spoilage % presented in table 4.34a revealed significant variations were found among all the treatments under protected and open field conditions.

During the first-year trial (2022-23), observation on the 9th day recorded the maximum (80.00%) spoilage under the treatment T_0 (control) while the minimum spoilage (66.67 %) was recorded under T_{15} (150 ppm ZnO + 150 ppm FeO). During (2023-24) recorded maximum (76.67%) spoilage under the treatment T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (63.33%) spoilage was noticed under T_{15} (150 ppm ZnO + 150 ppm FeO). The pooled analysis revealed the maximum (75.00%) spoilage under T_{13} (150 ppm ZnO + 50 ppm FeO) while minimum (65.00%) spoilage was recorded under T_{15} (150 ppm ZnO + 150 ppm FeO).

The study of the Table 4.34b indicated that Data on Spoilage (%) for open conditions had significant variations among the treatments. During the first-year trial (2022-23), observation on the 9th day recorded the maximum (83.33%) spoilage under the treatment T_0 (control) while the minimum (70.00 %) spoilage was recorded under T_{15} (150 ppm ZnO + 150 ppm FeO). During (2023-24), recorded maximum (76.67%) spoilage under the treatment T_6 (150ppm FeO) while the minimum (70.00%) spoilage was noticed under T_{15} (150 ppm ZnO + 150 ppm FeO). The pooled analysis revealed the maximum (76.67%) spoilage under T_5 (100 ppm FeO) while a minimum (70.00%) was recorded under T_{15} (150 ppm ZnO + 150 ppm FeO).

It is obvious that the reduction in the decay percentage of strawberry fruits through the application of zinc and iron is due to their critical roles in enhancing the fruit’s defense mechanisms and reducing pathogen susceptibility. Zinc improves the activity of antioxidant enzymes, ultimately strengthens the fruit’s natural defense barriers. Meanwhile, iron is helpful in boosting the production of antimicrobial compounds, thereby contributing to a reduction in fungal decay and an extension of the fruit's shelf life. These outcomes align with the findings of Kundu *et al.,* (2024); Verma *et al.,* (2018); Saini *et al.,* (2021); Tripathi *et al.,* (2018); Zahedi *et al.,* (2020); Sabahat *et al.,* (2021) and Zhang *et al.,* (2020).

Table 4.34a:. Effect of Nano- ZnO and FeO on Spoilage (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day interval

Spoilage percent (Protected)												
Treatments	**0 Day**			**3 Day**			**6 Day**			**9 Day**		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**
T$_0$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	0.00^{a}	1.67^{a}	26.67^{bc}	20.00^{ab}	23.34^{ab}	80.00	66.67^{ab}	73.34^{ab}
T$_1$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	13.33^{a}	16.67^{ab}	15.00^{a}	70.00	66.67^{ab}	68.34^{ab}
T$_2$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	20.00^{abc}	20.00^{ab}	20.00^{ab}	73.33	63.33^{ab}	68.33^{ab}
T$_3$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	0.00^{a}	1.67^{a}	23.33^{abc}	20.00^{ab}	21.67^{ab}	73.33	66.67^{ab}	70.00^{ab}
T$_4$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	1.67^{a}	16.67^{ab}	23.33^{ab}	20.00^{ab}	76.67	60.00^{ab}	68.34^{ab}
T$_5$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	23.33^{abc}	20.00^{ab}	21.67^{ab}	76.67	63.33^{ab}	70.00^{ab}
T$_6$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	26.67^{bc}	23.33^{ab}	25.00^{b}	80.00	66.67^{a}	73.34^{ab}
T$_7$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	0.00^{a}	1.67^{a}	23.33^{abc}	16.67^{ab}	20.00^{ab}	76.67	70.00^{ab}	73.34^{ab}
T$_8$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	26.67^{bc}	20.00^{ab}	23.34^{ab}	66.67	70.00^{ab}	68.34^{ab}
T$_9$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	1.67^{a}	23.33^{abc}	23.33^{ab}	23.33^{ab}	70.00	76.67^{ab}	73.34^{ab}
T$_{10}$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	26.67^{bc}	16.67^{ab}	21.67^{ab}	73.33	66.67^{ab}	70.00^{ab}
T$_{11}$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	30.00^{c}	13.33^{ab}	21.67^{ab}	80.00	70.00^{b}	75.00^{b}
T$_{12}$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	23.33^{abc}	26.67^{ab}	25.00^{b}	76.67	66.67^{ab}	71.67^{ab}
T$_{13}$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	1.67^{a}	16.67^{ab}	23.33^{a}	20.00^{ab}	80.00	70.00^{ab}	75.00^{b}
T$_{14}$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	20.00^{abc}	20.00^{b}	20.00^{ab}	76.67	66.67^{ab}	71.67^{ab}
T$_{15}$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	16.67^{ab}	16.67^{ab}	16.67^{ab}	66.67	63.33^{ab}	65.00^{ab}

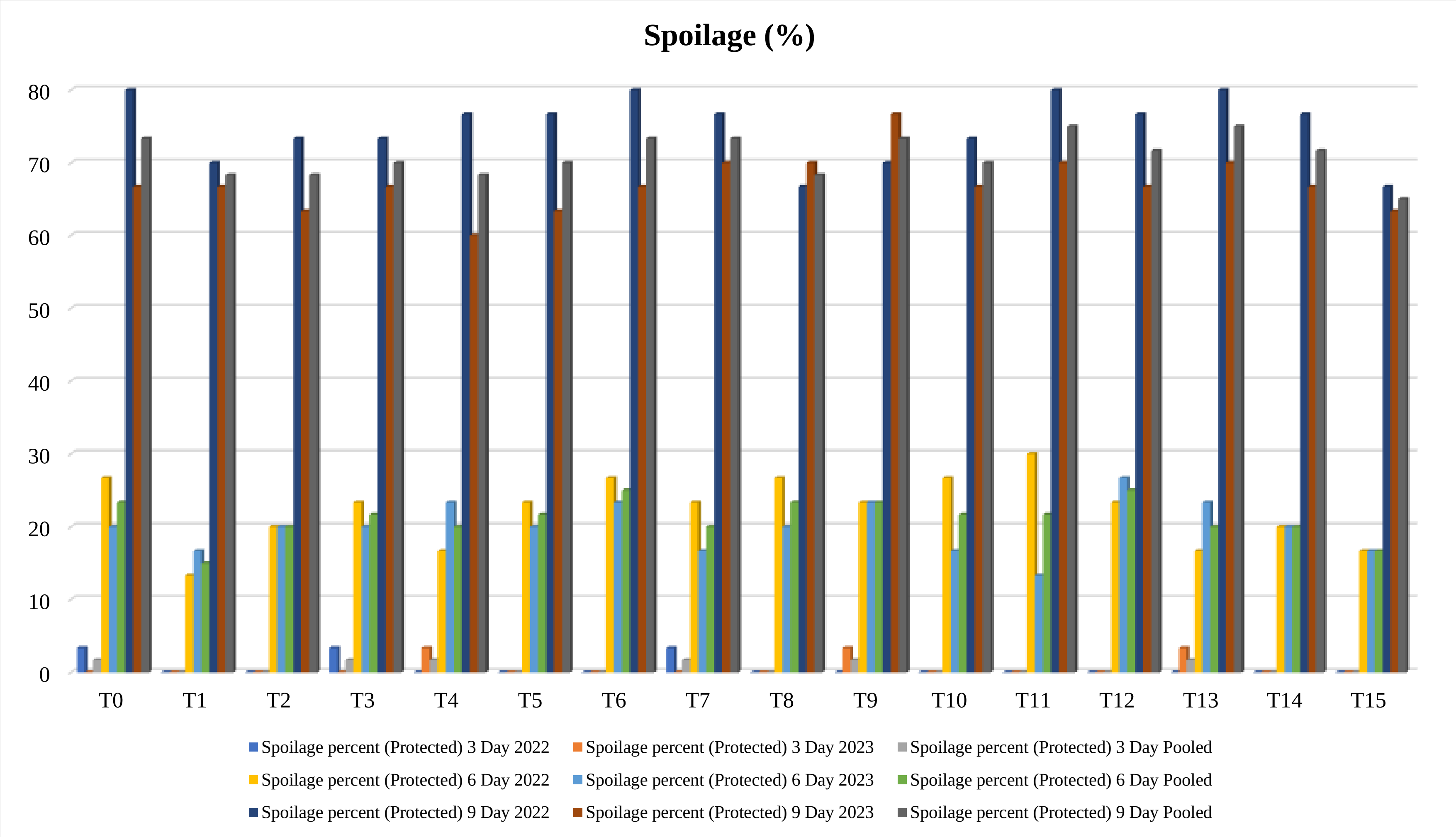

Figure 4.34a: Effect of Nano- ZnO and FeO on Spoilage (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day intervals

Table 4.34b: Effect of Nano- ZnO and FeO on Spoilage (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day intervals

Spoilage percent (Open)												
Treatments	**0 Day**			**3 Day**			**6 Day**			**9 Day**		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**
T$_0$	0.00^{a}	0.00^{a}	0.00^{a}	6.67^{a}	10.00^{a}	8.34^{a}	30.00^{b}	33.33^{a}	31.67^{b}	83.33^{a}	63.33^{a}	73.33^{a}
T$_1$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	6.67^{a}	5.00^{a}	26.67^{ab}	36.67^{a}	31.67^{b}	70.00^{a}	70.00^{a}	70.00^{a}
T$_2$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	6.67^{a}	5.00^{a}	26.67^{ab}	33.33^{a}	30.00^{b}	80.00^{a}	66.67^{a}	73.34^{a}
T$_3$	0.00^{a}	0.00^{a}	0.00^{a}	6.67^{a}	10.00^{a}	8.34^{a}	23.33^{ab}	23.33^{a}	23.33^{ab}	76.67^{a}	70.00^{a}	73.34^{a}
T$_4$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	6.67^{a}	5.00^{a}	20.00^{ab}	26.67^{a}	23.34^{ab}	80.00^{a}	70.00^{a}	75.00^{a}
T$_5$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	3.33^{a}	3.33^{a}	23.33^{ab}	33.33^{a}	28.33^{ab}	76.67^{a}	76.67^{a}	76.67^{a}
T$_6$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	6.67^{a}	5.00^{a}	23.33^{ab}	23.33^{a}	23.33^{ab}	76.67^{a}	76.67^{a}	76.67^{a}
T$_7$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	3.33^{a}	3.33^{a}	26.67^{ab}	33.33^{a}	30.00^{b}	76.67^{a}	70.00^{a}	73.34^{a}
T$_8$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	3.33^{a}	3.33^{a}	23.33^{ab}	23.33^{a}	23.33^{ab}	73.33^{a}	70.00^{a}	71.67^{a}
T$_9$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	6.67^{a}	5.00^{a}	20.00^{ab}	30.00^{a}	25.00^{ab}	70.00^{a}	66.67^{a}	68.34^{a}
T$_{10}$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	6.67^{a}	3.34^{a}	23.33^{ab}	23.33^{a}	23.33^{ab}	70.00^{a}	73.33^{a}	71.67^{a}
T$_{11}$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	6.67^{a}	5.00^{a}	26.67^{ab}	30.00^{a}	28.34^{ab}	83.33^{a}	70.00^{a}	76.67^{a}
T$_{12}$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	1.67^{a}	20.00^{ab}	23.33^{a}	21.67^{ab}	76.67^{a}	70.00^{a}	73.34^{a}
T$_{13}$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	3.33^{a}	3.33^{a}	20.00^{ab}	23.33^{a}	21.67^{ab}	83.33^{a}	70.00^{a}	76.67^{a}
T$_{14}$	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	6.67^{a}	5.00^{a}	23.33^{ab}	23.33^{a}	23.33^{ab}	83.33^{a}	70.00^{a}	76.67^{a}
T$_{15}$	0.00^{a}	0.00^{a}	0.00^{a}	0.00^{a}	3.33^{a}	1.67^{a}	13.33^{a}	23.33^{a}	18.33^{a}	70.00^{a}	70.00^{a}	70.00^{a}

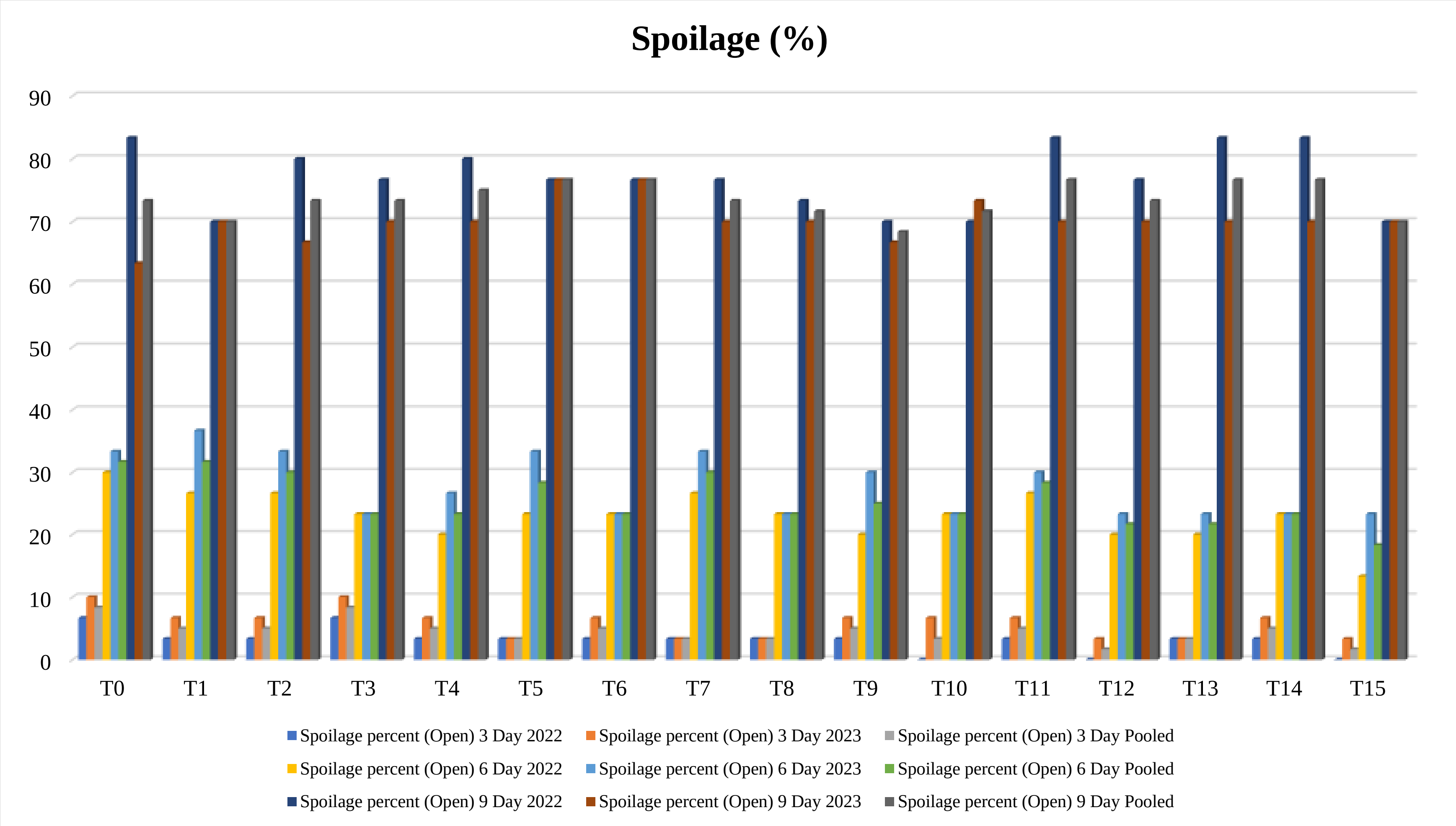

Figure 4.34: Effect of Nano- ZnO and FeO on Spoilage (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day intervals

4.2.3 Acidity (%)

The Data collected for acidity % at different days interval presented in 4.35a indicated significant variations exist among all the treatments with the application of ZnO and FeO at different levels under protected and open field conditions. During (2022-23), observation at 9th day of storage with the decreasing trend recorded the maximum (0.65%) acidity under the treatment T_9 (50 ppm ZnO + 150 ppm FeO) while the minimum (0.45 %) acidity was recorded under T_1 (50ppm ZnO). During (2023-24), recorded maximum (0.64%) acidity under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (0.38%) acidity was noticed under T_0 (control). The pooled analysis revealed the maximum (0.63%) acidity under T_{13} (150 ppm ZnO + 50 ppm FeO) while a minimum (0.43%) was recorded under T_0 (control).

It is evident from the Table 4.34b different levels of Nano-ZnO and FeO had significant variations among the treatments. During (2022-23), observation on the 9 days with decreasing trend recorded the maximum (0.63%) acidity under the treatment T_5 (100ppm FeO) while the minimum (0.44 %) acidity was recorded under T_1 (50 ppm ZnO). During (2023-24), recorded maximum (0.76%) acidity under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (0.49%) acidity was noticed under T_0 (control). The pooled analysis revealed the maximum (0.70%) acidity under T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (0.47%) was recorded under T_0 (control).

It is prominent that the optimization of acidity in strawberry fruits through the application of nano zinc and iron, observed over intervals of 0, 3, 6, and 9 days, is due to their crucial roles in maintaining fruit pH balance and metabolic stability. Nano zinc is helpful in regulating the activity of acid-metabolizing enzymes, ultimately contributing to the preservation of fruit acidity. Meanwhile, nano iron enhances overall fruit metabolism and reduces acid degraDAPion, thereby balancing acidity and extending shelf life. These findings are in conformity with the results of Khan *et al.,* (2018); Reddy *et al.,* (2021); Sajid *et al.,* (2012); Verma *et al.,* (2018); Tripathi *et al.,* (2018); Singh *et al.,* (2010) and Patel & Sharma (2021).

Table 4.35a: Effect of Nano- ZnO and FeO on acidity (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day intervals

Acidity (%) (Protected)												
Treatments	**0 Day**			**3 Day**			**6 Day**			**9 Day**		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**
T0	0.55^{ab}	0.43^{a}	0.48^{a}	0.53^{abc}	0.40^{ab}	0.47^{ab}	0.50^{abc}	0.39^{a}	0.45^{ab}	0.47^{ab}	0.38^{ab}	0.43^{a}
T1	0.51^{a}	0.46^{a}	0.49^{ab}	0.49^{a}	0.44^{a}	0.47^{ab}	0.47^{a}	0.42^{a}	0.45^{ab}	0.45^{a}	0.40^{ab}	0.43^{a}
T2	0.63^{bc}	0.63^{bcde}	0.63^{cde}	0.60^{cde}	0.59^{abc}	0.60^{cde}	0.58^{cd}	0.57^{a}	0.58^{cde}	0.56^{cd}	0.55^{abc}	0.56^{bcd}
T3	0.64^{bc}	0.64^{bcde}	0.64^{cde}	0.61^{cde}	0.60^{ab}	0.61^{cde}	0.59^{cde}	0.59^{a}	0.59^{cde}	0.58^{cd}	0.58^{a}	0.58^{bcd}
T4	0.68^{cd}	0.55^{abc}	0.62^{cde}	0.65^{def}	0.51^{abc}	0.58^{cde}	0.63^{def}	0.49^{ab}	0.56^{cde}	0.61^{cd}	0.48^{ab}	0.55^{bcd}
T5	0.71^{d}	0.63^{bcde}	0.67^{de}	0.70^{f}	0.61^{abc}	0.66^{de}	0.68^{ef}	0.59^{ab}	0.64^{de}	0.65^{d}	0.56^{ab}	0.61^{cd}
T6	0.64^{bc}	0.63^{bcde}	0.64^{cde}	0.62^{def}	0.58^{abcd}	0.60^{cde}	0.60^{ab}	0.55^{abc}	0.58^{cde}	0.57^{d}	0.53^{abcd}	0.55^{bcd}
T7	0.53^{a}	0.52^{ab}	0.53^{abc}	0.50^{a}	0.48^{abc}	0.49^{abc}	0.49^{def}	0.45^{ab}	0.47^{abc}	0.47^{ab}	0.43^{abc}	0.45^{ab}
T8	0.65^{bc}	0.54^{ab}	0.60^{bcd}	0.62^{def}	0.50^{abcd}	0.56^{bcd}	0.60^{def}	0.48^{abcd}	0.54^{bcd}	0.57^{cd}	0.46^{bcde}	0.52^{bc}
T9	0.72^{d}	0.67^{de}	0.70^{e}	0.70^{f}	0.63^{de}	0.67^{de}	0.68^{f}	0.60^{cd}	0.64^{de}	0.65^{d}	0.58^{e}	0.62^{cd}
T$_{10}$	0.60^{abc}	0.56^{abcd}	0.58^{abcd}	0.58^{bcd}	0.52^{abcd}	0.55^{bcd}	0.56^{bcd}	0.50^{abcd}	0.53^{abcd}	0.54^{bc}	0.48^{abcd}	0.51^{abc}
T$_{11}$	0.65^{bc}	0.47^{a}	0.56^{abc}	0.63^{def}	0.44^{bcde}	0.54^{abc}	0.61^{def}	0.43^{abcd}	0.52^{abc}	0.59^{cd}	0.41^{bcde}	0.50^{abc}
T$_{12}$	0.63^{bc}	0.66^{cde}	0.65^{cde}	0.61^{cde}	0.63^{cde}	0.62^{de}	0.60^{def}	0.61^{bcd}	0.61^{cde}	0.57^{cd}	0.59^{cde}	0.58^{bcd}
T$_{13}$	0.68^{cd}	0.72^{e}	0.70^{e}	0.67^{def}	0.70^{de}	0.69^{e}	0.64^{def}	0.67^{cd}	0.66^{e}	0.61^{cd}	0.64^{de}	0.63^{d}
T$_{14}$	0.63^{bc}	0.47^{a}	0.55^{abc}	0.61^{cde}	0.45^{e}	0.53^{abc}	0.58^{cd}	0.43^{cd}	0.51^{abc}	0.56^{c}	0.40^{e}	0.48^{ab}
T$_{15}$	0.71^{d}	0.57^{abcd}	0.64^{cde}	0.68^{ef}	0.54^{e}	0.61^{cde}	0.65^{def}	0.52^{cd}	0.59^{cde}	0.63^{cd}	0.50^{e}	0.57^{bcd}

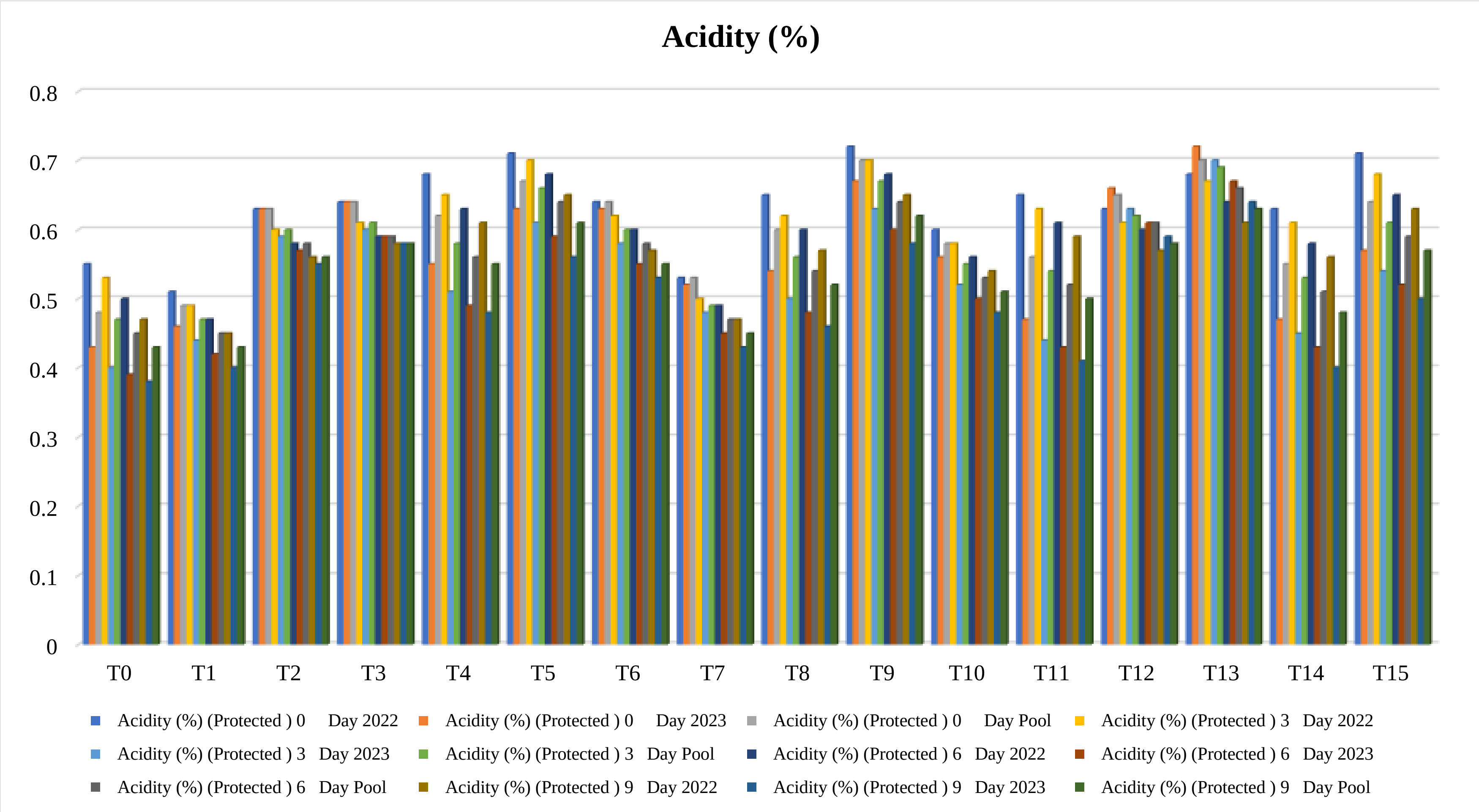

Figure 4.35a: Effect of Nano- ZnO and FeO on Acidity (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day intervals

Table 4.35b: Effect of Nano- ZnO and FeO on acidity (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day intervals

Treatments	Acidity (%) (Open)											
	0 Day			3 Day			6 Day			9 Day		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_0	0.53^{ab}	0.57^{a}	0.55^{abcde}	0.51^{ab}	0.52^{a}	0.52^{a}	0.48^{a}	0.53^{a}	0.51^{abc}	0.45^{a}	0.49^{a}	0.47^{a}
T_1	0.52^{a}	0.60^{abc}	0.56^{abcde}	0.49^{a}	0.56^{ab}	0.53^{a}	0.47^{a}	0.56^{ab}	0.52^{abc}	0.44^{a}	0.52^{ab}	0.48^{a}
T_2	0.63^{bc}	0.77^{de}	0.70^{de}	0.60^{b}	0.71^{bcde}	0.66^{abc}	0.58^{b}	0.71^{bcde}	0.65^{de}	0.55^{b}	0.67^{bcde}	0.61^{abc}
T_3	0.62^{bc}	0.78^{de}	0.70^{de}	0.60^{bc}	0.72^{bcde}	0.66^{abc}	0.57^{b}	0.74^{cde}	0.66^{de}	0.55^{b}	0.69^{cde}	0.62^{abc}
T_4	0.68^{c}	0.69^{bcd}	0.69^{de}	0.66^{b}	0.63^{abcd}	0.65^{bcd}	0.64^{b}	0.63^{abcd}	0.64^{cde}	0.62^{b}	0.59^{abcde}	0.61^{abc}
T_5	0.70^{c}	0.78^{de}	0.74^{de}	0.67^{b}	0.73^{bcde}	0.70^{d}	0.66^{b}	0.73^{cde}	0.70^{e}	0.63^{b}	0.68^{bcde}	0.66^{bcd}
T_6	0.65^{c}	0.78^{de}	0.72^{de}	0.63^{b}	0.70^{abcde}	0.67^{abc}	0.61^{b}	0.70^{abcde}	0.66^{de}	0.58^{b}	0.65^{abcde}	0.62^{abc}
T_7	0.66^{c}	0.67^{bcde}	0.67^{cde}	0.64^{b}	0.60^{abcd}	0.62^{ab}	0.61^{b}	0.59^{abcd}	0.60^{cde}	0.58^{b}	0.54^{abcd}	0.56^{ab}
T_8	0.63^{bc}	0.69^{bcde}	0.66^{cde}	0.60^{b}	0.62^{abcd}	0.61^{ab}	0.58^{b}	0.62^{abcd}	0.60^{cde}	0.56^{b}	0.57^{abcd}	0.57^{ab}
T_9	0.67^{c}	0.81^{e}	0.74^{de}	0.65^{b}	0.75^{cde}	0.70^{d}	0.63^{b}	0.75^{de}	0.69^{de}	0.60^{b}	0.69^{cde}	0.65^{abcd}
T_{10}	0.62^{bc}	0.70^{cde}	0.66^{bcde}	0.60^{bc}	0.64^{abcd}	0.62^{ab}	0.58^{b}	0.65^{abcde}	0.62^{cde}	0.55^{b}	0.59^{abcde}	0.57^{ab}
T_{11}	0.63^{bc}	0.62^{bcde}	0.63^{bcde}	0.61^{b}	0.56^{ab}	0.59^{ab}	0.59^{b}	0.57^{abc}	0.58^{bcde}	0.57^{b}	0.53^{abc}	0.55^{ab}
T_{12}	0.65^{c}	0.81^{e}	0.73^{de}	0.63^{b}	0.75^{de}	0.69^{abc}	0.61^{b}	0.76^{de}	0.69^{de}	0.59^{b}	0.71^{de}	0.65^{abcd}
T_{13}	0.69^{c}	0.87^{e}	0.78^{e}	0.67^{b}	0.82^{e}	0.75^{de}	0.65^{b}	0.81^{e}	0.73^{e}	0.63^{b}	0.76^{e}	0.70^{cd}
T_{14}	0.69^{c}	0.62^{cde}	0.66^{cde}	0.66^{b}	0.57^{abc}	0.62^{ab}	0.64^{b}	0.57^{abc}	0.61^{cde}	0.62^{b}	0.51^{ab}	0.57^{ab}
T_{15}	0.69^{c}	0.72^{cde}	0.71^{de}	0.67^{b}	0.66^{abcde}	0.67^{abc}	0.65^{b}	0.67^{abcde}	0.66^{de}	0.62^{b}	0.62^{abcde}	0.62^{abc}

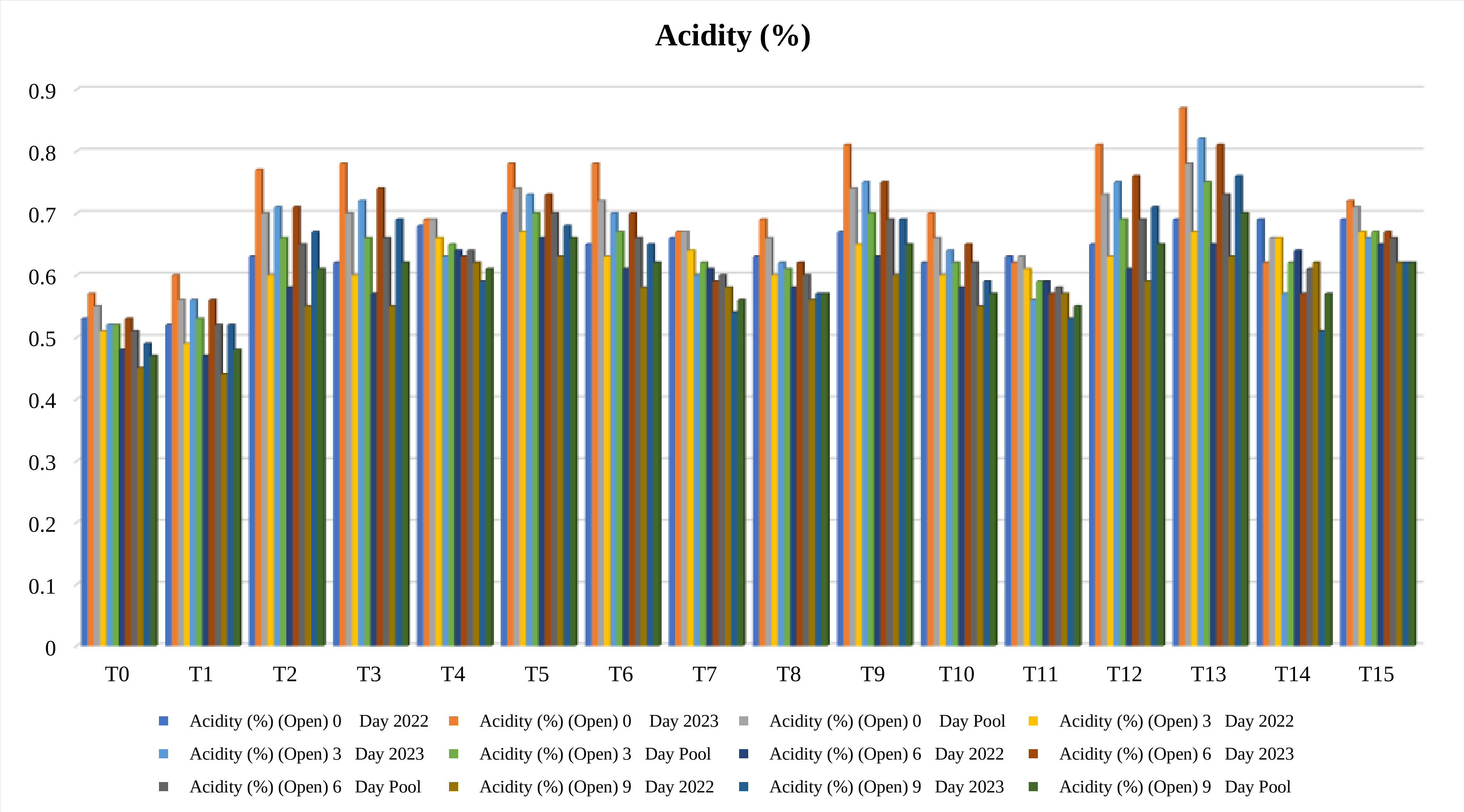

Figure 4.35b: Effect of Nano- ZnO and FeO on Acidity (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day intervals

4.2.4 Ascorbic acid (mg/100g)

The study of Table 4.36a and 4.36b indicated that Data on ascorbic acid at different days interval had significant variations among the treatments with the application of Nano-ZnO and FeO under protected and open field conditions during both the years.

During (2022-23), observation on the 9th day with decreasing trend recorded the maximum (49.66 mg/100g) ascorbic acid under the treatment T_{15} (150 ppm ZnO + 150 ppm FeO) while the minimum (46.59 mg/100g) ascorbic acid was recorded under T_7 (50 ppm ZnO + 50 ppm FeO). During (2023-24), recorded maximum (50.35 mg/100g) ascorbic acid under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (44.06 mg/100g) ascorbic acid was noticed under T_0 (control). The pooled analysis revealed the maximum (49.25 mg/100g) ascorbic acid under T_{13} (150 ppm ZnO + 50 ppm FeO) while minimum (45.35 mg/100g) ascorbic acid was recorded under T_0 (control).

The Data pertaining to effect of different levels of ZnO and FeO on ascorbic acid at different days interval under open field condition had significant variations presented in Table 4.36b. During (2022-23), observation on the 9th day with the decreasing trend recorded the maximum (49.77 mg/100g) ascorbic acid under the treatment T_{14} (150 ppm ZnO + 100 ppm FeO) while the minimum (45.15 mg/100g) ascorbic acid was noted in T_1 (50ppm ZnO). During (2023-24), recorded maximum (47.03 mg/100g) ascorbic acid under the treatment T_6 (150 ppm FeO) while the minimum (45.43 mg/100g) ascorbic acid was noticed under T_5 (100ppm FeO). The pooled analysis revealed the maximum (48.28 mg/100g) ascorbic acid under T_{14} (150 ppm ZnO + 100 ppm FeO) while minimum (45.81 mg/100g) ascorbic acid was recorded under T_0 (control).

It is obvious that the optimization of ascorbic acid (mg/100g) at intervals of 0, 3, 6, and 9 days is due to zinc and iron's role in stabilizing vitamin C content. Zinc is helpful in enhancing the activity of ascorbate peroxidase, ultimately reducing oxiDAPive stress, while iron contributes by supporting the regeneration of ascorbic acid through improved metabolic efficiency. Together, these actions preserve ascorbic acid levels and extend shelf life. These results align with the findings of Sharma *et al.,* (2021); Tripathi *et al.,* (2018); Yadav *et al.,* (2011); Zahedi *et al.,* (2020) and Sharma *et al.,* (2020).

Table 4.36a: Effect of Nano- ZnO and FeO on Ascorbic acid of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day intervals

Ascorbic acid (mg/100g) (Protected)												
Treatments	**0 Day**			**3 Day**			**6 Day**			**9 Day**		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**
T0	49.41^{a}	48.45^{a}	48.93^{ab}	49.35^{ab}	47.60^{a}	48.48^{ab}	47.93^{a}	46.23^{a}	47.08^{a}	46.63^{a}	44.06^{a}	45.35^{a}
T1	49.19^{a}	48.47^{ab}	48.83^{a}	49.14^{a}	47.72^{a}	48.43^{a}	48.65^{ab}	46.64^{ab}	47.65^{ab}	46.81^{a}	45.36^{a}	46.09^{ab}
T2	50.35^{b}	49.48^{ab}	49.92^{abc}	50.18^{abcde}	48.50^{b}	49.34^{abcde}	49.10^{abc}	47.60^{abcde}	48.35^{bcde}	47.20^{a}	46.17^{bcde}	46.69^{abc}
T3	51.10^{bc}	51.19^{bc}	51.15^{cde}	50.98^{bcde}	50.60^{bcde}	50.79^{efgh}	49.93^{bcd}	48.92^{bcdef}	49.43^{defgh}	48.61^{a}	47.49^{bcde}	48.05^{cde}
T4	51.46^{bcd}	51.56^{bcd}	51.51^{def}	51.36^{de}	50.78^{cde}	51.07^{fgh}	50.44^{cd}	49.28^{def}	49.86^{fgh}	47.59^{a}	47.86^{de}	47.73^{bcd}
T5	51.69^{cd}	50.42^{bc}	51.06^{cde}	51.61^{e}	49.60^{abcd}	50.61^{defg}	50.38^{cd}	48.35^{bcde}	49.37^{defgh}	48.13^{ab}	47.03^{bcde}	47.58^{bcd}
T6	51.15^{bc}	49.74^{abc}	50.45^{cde}	51.07^{cde}	48.29^{a}	49.68^{abcdef}	49.69^{bcd}	47.40^{abcd}	48.55^{bcde}	48.00^{ab}	46.21^{bcde}	47.11^{bcd}
T7	49.64^{a}	51.05^{bc}	50.35^{cde}	49.52^{abc}	50.54^{bcde}	50.03^{cdefg}	48.37^{ab}	49.25^{def}	48.81^{bcdef}	46.59^{ab}	48.07^{de}	47.33^{bcd}
T8	50.55^{b}	49.04^{ab}	49.80^{abcd}	50.48^{abcde}	48.05^{a}	49.27^{abcd}	49.19^{abc}	47.06^{abc}	48.13^{abcd}	47.00^{ab}	45.81^{abcd}	46.41^{abc}
T9	51.96^{cd}	51.80^{bc}	51.88^{bcde}	51.82^{e}	50.95^{cde}	51.39^{gh}	50.69^{cd}	49.92^{ef}	50.31^{gh}	47.12^{a}	47.80^{cde}	47.46^{bcd}
T$_{10}$	50.09^{b}	48.70^{ab}	49.40^{abc}	49.85^{abcd}	47.55^{a}	48.70^{abc}	49.15^{abc}	46.71^{ab}	47.93^{abc}	47.18^{a}	45.60^{abc}	46.39^{abc}
T$_{11}$	51.42^{bcd}	51.21^{bc}	51.32^{defg}	51.18^{cde}	50.48^{bcde}	50.83^{efgh}	49.96^{bcd}	49.33^{def}	49.65^{defgh}	47.89^{a}	48.32^{e}	48.11^{cde}
T$_{12}$	51.18^{bc}	49.07^{ab}	50.45^{cde}	51.71^{e}	48.64^{abc}	50.18^{defg}	50.68^{cd}	47.66^{abcde}	49.17^{cdefg}	48.75^{a}	46.36^{bcde}	47.56^{bcd}
T$_{13}$	51.18^{bc}	53.15^{e}	52.17^{f}	50.99^{bcde}	52.44^{e}	51.72^{h}	49.52^{abcd}	51.66^{ef}	50.59^{h}	48.15^{a}	50.35^{e}	49.25^{e}
T$_{14}$	50.48^{b}	49.46^{ab}	49.97^{abc}	50.36^{abcde}	49.47^{abcd}	49.92^{bcdefg}	49.13^{abc}	48.61^{bcde}	48.87^{bcdef}	46.90^{ab}	47.65^{bcde}	47.28^{bcd}
T$_{15}$	51.74^{cd}	51.66^{bc}	51.70^{def}	51.59^{e}	50.51^{bcde}	51.05^{fgh}	50.99^{d}	49.60^{def}	50.30^{gh}	49.66^{b}	48.21^{e}	48.94^{de}

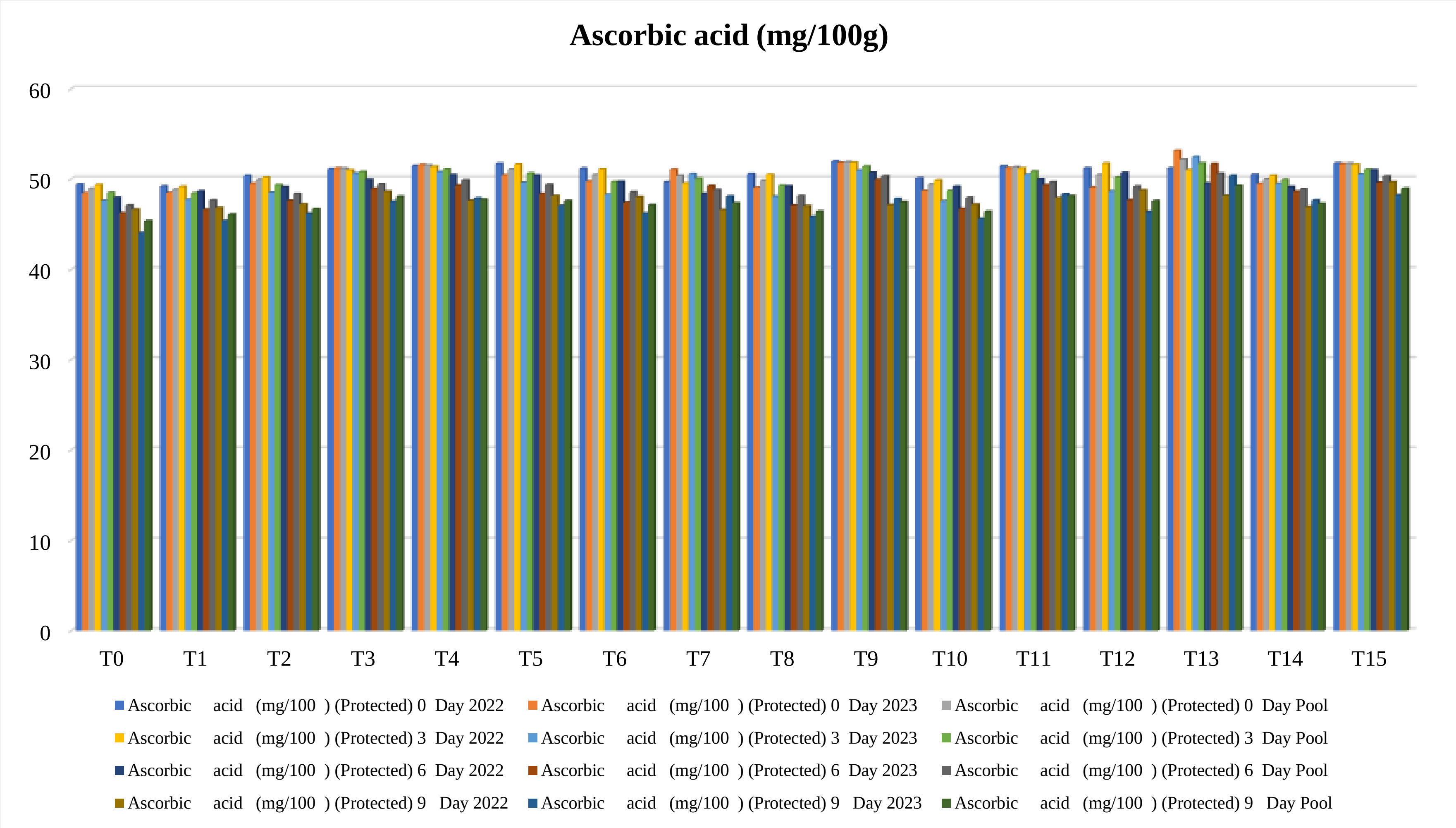

Figure 4.36a: Effect of Nano- ZnO and FeO on Ascorbic acid of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day intervals

Table 4.36b: Effect of Nano- ZnO and FeO on Ascorbic acid of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day intervals

Ascorbic acid (mg/100g) (Open)												
Treatments	0 Day			3 Day			6 Day			9 Day		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_0	48.64^{a}	47.45^{a}	48.05^{a}	48.58^{a}	47.21^{a}	47.90^{a}	47.65^{ab}	47.02^{ab}	47.34^{a}	45.85^{ab}	45.96^{ab}	45.91^{ab}
T_1	48.76^{a}	47.47^{a}	48.12^{a}	48.68^{a}	47.39^{a}	48.04^{ab}	47.55^{a}	47.24^{ab}	47.40^{ab}	45.15^{a}	46.47^{ab}	45.81^{a}
T_2	49.35^{ab}	48.61^{abcd}	48.98^{ab}	49.23^{ab}	48.48^{abcd}	48.86^{abc}	48.38^{abc}	47.74^{ab}	48.06^{abc}	46.61^{abc}	47.23^{b}	46.92^{ab}
T_3	50.52^{abc}	47.67^{ab}	49.10^{bcd}	50.45^{abc}	47.59^{ab}	49.02^{abc}	49.49^{abcd}	46.74^{a}	48.12^{abc}	47.51^{bcd}	45.88^{ab}	46.70^{abc}
T_4	50.57^{abc}	48.39^{abc}	49.48^{bc}	50.50^{abc}	48.26^{abc}	49.38^{bc}	49.82^{bcde}	47.48^{ab}	48.65^{abcd}	47.05^{abc}	46.21^{ab}	46.63^{abc}
T_5	50.94^{bcd}	47.61^{ab}	49.28^{abc}	50.83^{bcd}	47.51^{ab}	49.17^{abc}	49.59^{abcd}	46.77^{ab}	48.18^{abc}	48.18^{bcd}	45.43^{a}	46.81^{abc}
T_6	50.92^{bcd}	49.95^{d}	50.44^{cd}	50.83^{bcd}	49.79^{d}	50.31^{cd}	50.09^{cde}	48.64^{b}	49.37^{cd}	47.49^{abc}	47.03^{ab}	47.26^{abc}
T_7	51.60^{cd}	48.62^{abcd}	50.11^{bcd}	51.51^{cd}	48.43^{abcd}	49.97^{cd}	50.61^{de}	47.57^{ab}	49.09^{cd}	48.36^{bcd}	46.51^{a}b	47.44^{abc}
T_8	50.52^{abc}	48.51^{abcd}	49.52^{bc}	50.45^{abc}	48.44^{abcd}	49.45^{c}	49.59^{abcd}	47.89^{ab}	48.74^{abcd}	47.98^{bcd}	46.74^{ab}	47.36^{abc}
T_9	51.79^{cd}	48.63^{abcd}	50.21^{bcd}	51.67^{cd}	48.47^{abcd}	50.07^{cd}	50.78^{de}	47.24^{ab}	49.01^{bcd}	48.63^{cd}	45.73^{ab}	47.18^{abc}
T_{10}	51.41^{cd}	48.45^{abc}	49.93^{bcd}	51.26^{cd}	48.24^{abc}	49.75^{cd}	50.64^{de}	47.85^{ab}	49.25^{cd}	48.44^{bcd}	46.56^{ab}	47.50^{bc}
T_{11}	51.81^{cd}	48.24^{abc}	50.03^{bcd}	51.60^{cd}	48.06^{abc}	49.83^{cd}	50.52^{cde}	47.48^{ab}	49.00^{abcd}	48.81^{cd}	46.12^{ab}	47.47^{abc}
T_{12}	51.71^{cd}	47.96^{abc}	49.84^{bcd}	51.63^{cd}	47.79^{abc}	49.71^{cd}	51.07^{de}	47.09^{ab}	49.08^{cd}	49.04^{cd}	46.13^{ab}	47.59^{c}
T_{13}	51.86^{ac}	49.07^{bcd}	50.47^{cd}	51.57^{cd}	48.96^{bcd}	50.27^{cd}	49.68^{abcd}	48.22^{ab}	48.95^{abcd}	48.18^{bcd}	45.43^{a}	46.81^{c}
T_{14}	52.32^{cd}	48.62^{abcd}	50.47^{cd}	52.10^{cd}	48.52^{abcd}	50.31^{cd}	51.43^{de}	47.75^{ab}	49.59^{cd}	49.77^{d}	46.79^{ab}	48.28^{c}
T_{15}	52.84^{d}	49.32	51.08^{d}	52.64^{b}	49.19^{cd}	50.92^{d}	51.96^{e}	48.05^{ab}	50.01^{d}	49.62^{d}	46.74^{ab}	48.18^{c}

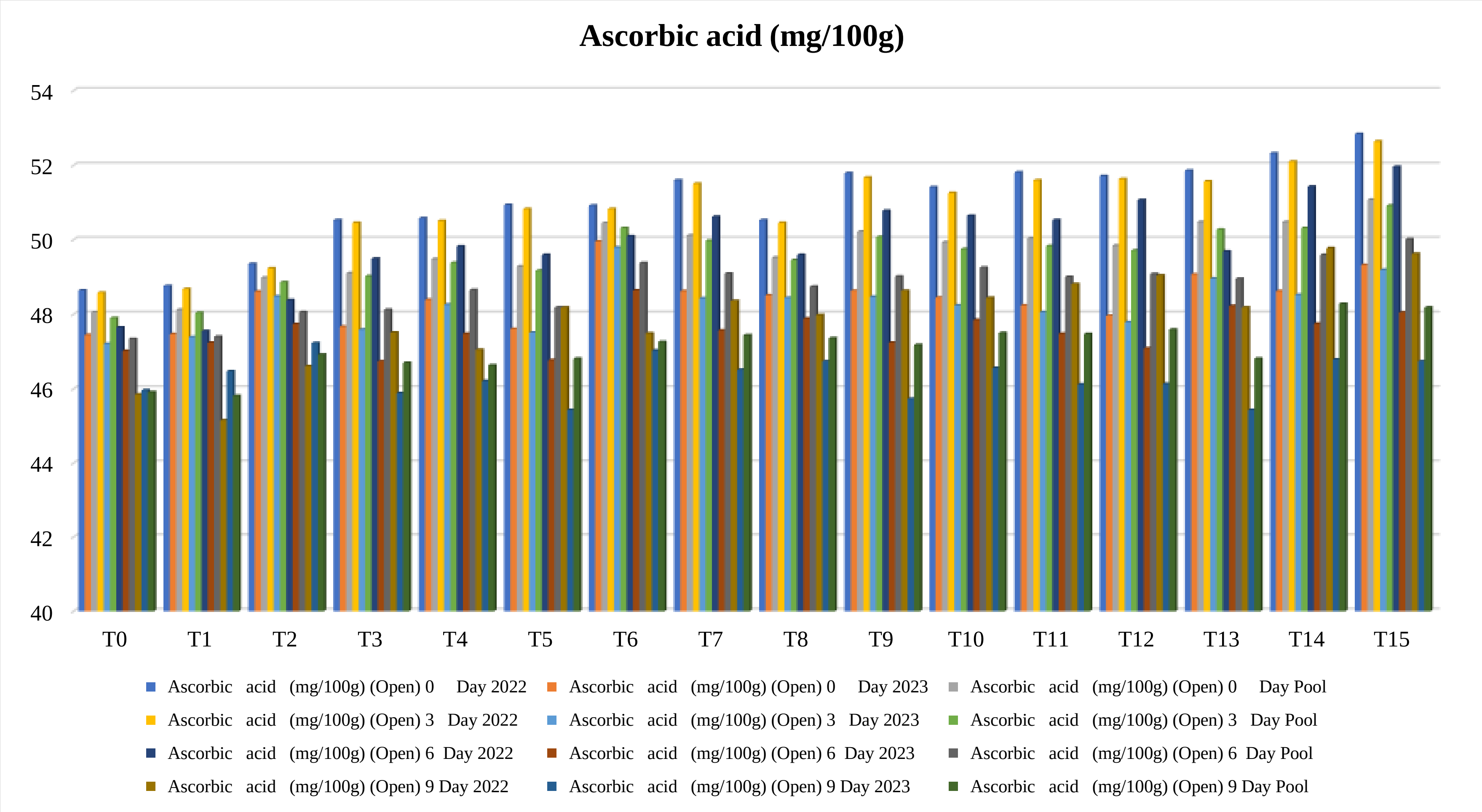

Figure 4.36b: Effect of Nano- ZnO and FeO on Ascorbic acid of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day intervals

4.2.5 Total Sugars:

The Data on reducing sugars presented in Table 4.37a revealed significant variations were found among the treatments with the application of Nano-ZnO and FeO at different levels under protected and open filed conditions. During (2022-23), showed significant Data at 9th day an increasing trend where the maximum (8.40%) total sugars was noted in the treatment T_0 (100 % RDF) while the minimum (7.08%) was noticed under T_2 (100 ppm ZnO) followed by 7.54 % under T_6 (150ppm FeO. During (2023-24), showed the same increasing pattern with the maximum (7.88%) total sugars under the treatment T_{11} (100 ppm ZnO + 100 ppm FeO), T_{12} (100 ppm ZnO + 150 ppm FeO) and T_{14} (150 ppm ZnO + 100 ppm FeO) with the value of 7.88%. while the minimum (7.24%) was noticed under the treatment T_2 (100ppm FeO) followed by 7.33 % under T_0 (100 % RDF). The pooled analysis (2022-23 and 2023-24) revealed the maximum (8.09%) reducing sugars under T_7 (50ppm ZnO+ 50ppm FeO) while the minimum (7.16%) was recorded in T_2 (100 ppm ZeO) followed by 7.53 % under T_1 (50 ppm ZnO.

It is evident from the Table4.37b different levels of ZnO and FeO had significant variations among the treatments regarding reducing sugars under open field condition. During (2022-23), showed significant Data observation. Total sugars (%) on the 9th day during the first-year trial (2022-23), observations showed an increasing trend where the maximum (8.77%) total sugars was noted under the treatment T_7 (50 ppm ZnO + 50 ppm FeO) while the minimum (7.56%) was noticed under T_2 (100 ppm ZnO). During (2023-24) showed the same increasing pattern with the maximum (8.30%) total sugars under the treatment T_{14} (150 ppm ZnO + 100 ppm FeO) while the minimum (7.78%) was noticed under the treatment T_0 (100 % RDF) followed by 7.98 % under T_3 (150ppm ZnO). The pooled analysis (2022-23 and 2023-24) revealed the maximum (8.44%) total sugars under T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (7.84%) was in T_2 (100 ppm ZeO) followed by 7.99 % under T_0 (100 % RDF).

The zinc and iron play a significant role to maintain the total sugars level at 9th day of storage by in enhancing carbohydrate metabolism and delaying senescence which ultimately helpful in improving photosynthetic efficiency by facilitating chlorophyll synthesis and ultimately enhancing enzyme activity related to photosynthesis, contributing to increased sugar production. These micronutrinets also stabilize cell membranes and reduce oxiDAPive stress, which delays the breakdown of sugars during storage. Additionally, by modulating the activity of enzymes like invertase and sucrose synthase, Zn and Fe promote the conversion of stored carbohydrates into soluble sugars. This enhanced carbohydrate conversion, coupled with reduced respiration rates, results in a higher accumulation of total sugars in strawberries by the 9th day of storage. The present results are coincide with the studies of Khan *et al.,* (2019); Taha *et al.,* (2017); Yadav *et al.,* (2011); Verma *et al.,* (2018); Raliya *et al.,* (2013); Saini *et al.,* (2021); Shukla *et al.,* (2016) and Kumar & Singh (2021).

Table 4.37a: Effect of Nano- ZnO and FeO on Total sugars (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day intervals

Total sugars (%) (Protected)												
Treatments	**0 Day**			**3 Day**			**6 Day**			**9 Day**		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**
T0	7.11^{ab}	6.59^{a}	6.85^{ab}	7.15^{bc}	6.91^{ab}	7.03^{ab}	7.53^{bcde}	7.05^{a}	7.29^{ab}	8.40^{e}	7.33^{a}	7.87^{cde}
T1	7.12^{ab}	6.61^{a}	6.87^{ab}	7.19^{bc}	6.83^{ab}	7.01^{ab}	7.42^{bcd}	6.95^{a}	7.19^{ab}	7.71^{bc}	7.34^{a}	7.53^{b}
T2	6.51^{a}	6.76^{ab}	6.64^{a}	6.54^{a}	6.84^{ab}	6.69^{a}	6.75^{bcde}	7.07^{a}	6.91^{a}	7.08^{a}	7.24^{a}	7.16^{a}
T3	7.15^{ab}	6.51^{a}	6.83^{ab}	7.21^{bc}	6.80^{a}	7.01^{ab}	7.46^{bcd}	6.99^{a}	7.23^{ab}	7.82^{bc}	7.34^{a}	7.58^{bc}
T4	7.28^{abc}	6.94^{bc}	7.11^{bc}	7.34^{bcd}	7.13^{bc}	7.24^{bc}	7.56^{a}	7.36^{b}	7.46^{bcd}	7.82^{a}	7.60^{b}	7.71^{bcd}
T5	7.59^{bc}	7.12^{c}	7.36^{cd}	7.66^{bcde}	7.33^{cd}	7.50^{cde}	7.82^{bcd}	7.54^{bc}	7.68^{de}	8.03^{bcd}	7.79^{bc}	7.91^{de}
T6	7.06^{ab}	7.23^{c}	7.15^{bc}	7.17^{bc}	7.49^{d}	7.33^{bcde}	7.32^{bcde}	7.75^{c}	7.54^{bcde}	7.54^{ab}	7.87^{bc}	7.71^{bcd}
T7	7.93^{cd}	7.20^{c}	7.57^{d}	7.98^{de}	7.38^{cd}	7.68^{e}	8.10^{bcde}	7.60^{bc}	7.85^{e}	8.34^{de}	7.83^{bc}	8.09^{e}
T8	7.28^{abc}	6.98^{bc}	7.13^{bcd}	7.38^{bcd}	7.26^{cd}	7.32^{bcde}	7.57^{bc}	7.49^{b}	7.53^{bcde}	7.80^{bc}	7.72^{bc}	7.76^{bcd}
T9	7.78^{bcd}	7.13^{c}	7.46^{cd}	7.88^{de}	7.44^{cd}	7.66^{de}	8.01^{e}	7.63^{bc}	7.82^{e}	8.17^{cde}	7.77^{bc}	7.97^{de}
T10	7.70^{bcd}	7.13^{c}	7.42^{cd}	7.78^{cde}	7.34^{cd}	7.56^{cde}	7.90^{cde}	7.54^{bc}	7.72^{de}	8.08^{bcd}	7.79^{bc}	7.94^{de}
T11	7.44^{bc}	7.01^{bc}	7.23^{bcd}	7.55^{bcde}	7.30^{cd}	7.43^{cde}	7.75^{de}	7.55^{bc}	7.65^{cde}	8.04^{cde}	7.88^{c}	7.96^{de}
T12	7.02^{ab}	7.25^{c}	7.14^{bc}	7.10^{bc}	7.47^{cd}	7.29^{bcd}	7.27^{cde}	7.66^{bc}	7.47^{bcde}	7.63^{bc}	7.88^{c}	7.76^{bcd}
T13	7.45^{bc}	7.16^{c}	7.31^{cd}	7.64^{bcde}	7.39^{cd}	7.52^{cde}	7.74^{bcde}	7.60^{bc}	7.67^{cde}	8.05^{bcde}	7.80^{c}	7.93^{de}
T14	7.13^{ab}	7.11^{c}	7.12^{bc}	7.21^{bc}	7.39^{cd}	7.30^{bcde}	7.33^{ab}	7.54^{bc}	7.44^{bcd}	7.71^{bc}	7.88^{c}	7.80^{bcde}
T15	7.46^{bc}	7.18^{c}	7.32^{cd}	7.56^{bcde}	7.30^{cd}	7.43^{cde}	7.66^{bcde}	7.41^{b}	7.54^{bcde}	7.84^{bcd}	7.64^{ab}	7.74^{bcd}

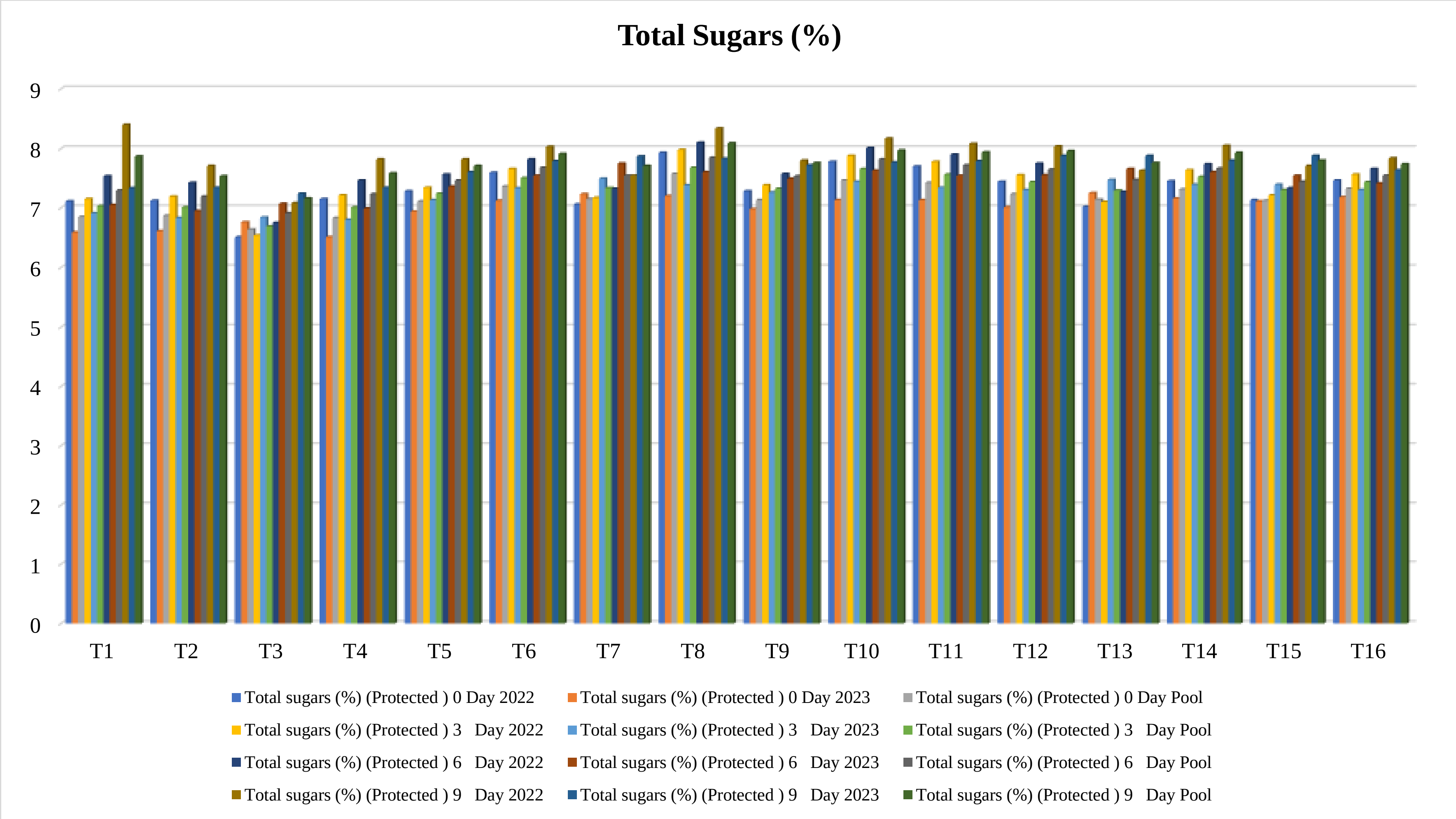

Figure 4.37a: Effect of Nano- ZnO and FeO on Total sugars (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day intervals

Table 4.37b: Effect of Nano- ZnO and FeO on Total sugars (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day intervals

Total sugars (%) (Open)												
Treatments	**0 Day**			**3 Day**			**6 Day**			**9 Day**		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**
T_0	6.74^{a}	6.92^{a}	6.83^{a}	6.78^{a}	7.11^{a}	6.95^{a}	7.25^{ab}	7.22^{a}	7.24^{ab}	8.19^{bc}	7.78^{a}	7.99^{a}
T_1	7.01^{abc}	7.26^{b}	7.14^{abc}	7.07^{abc}	7.29^{a}	7.18^{abcd}	7.33^{ab}	7.50^{abc}	7.42^{abc}	8.51^{bc}	8.18^{ab}	8.35^{bc}
T_2	6.76^{a}	7.01^{ab}	6.89^{a}	6.79^{a}	7.10^{a}	6.95^{a}	7.02^{a}	7.29^{ab}	7.16^{a}	7.56^{a}	8.12^{ab}	7.84^{a}
T_3	6.96^{ab}	6.98^{ab}	6.97^{ab}	7.02^{ab}	7.04^{a}	7.03^{ab}	7.32^{ab}	7.31^{abc}	7.32^{ab}	8.08^{ab}	7.98^{ab}	8.03^{ab}
T_4	7.15^{abcd}	6.97^{a}	7.06^{abc}	7.17^{abcd}	7.11^{a}	7.14^{abc}	7.52^{abcd}	7.36^{abc}	7.44^{abc}	8.22^{bc}	8.10^{ab}	8.16^{abc}
T_5	7.48^{abcd}	6.91^{a}	7.20^{abc}	7.51^{abcde}	7.07^{a}	7.29^{abcd}	7.74^{abcd}	7.33^{abc}	7.54^{abcd}	8.02^{ab}	8.02^{ab}	8.02^{ab}
T_6	7.39^{abcd}	6.92^{a}	7.16^{abc}	7.44^{abcde}	6.98^{a}	7.21^{abcd}	7.64^{abcd}	7.34^{abc}	7.49^{abc}	8.37^{bc}	7.98^{ab}	8.18^{bc}
T_7	7.88^{d}	7.06^{ab}	7.47^{c}	7.95^{e}	7.21^{a}	7.58^{d}	8.26^{d}	7.61^{bc}	7.94^{d}	8.77^{c}	8.09^{ab}	8.43^{bc}
T_8	7.78^{cd}	7.07^{ab}	7.43^{c}	7.80^{cde}	7.15^{a}	7.48^{cd}	8.10^{cd}	7.54^{abc}	7.82^{cd}	8.61^{bc}	8.22^{b}	8.42^{bc}
T_9	7.94^{d}	7.02^{ab}	7.48^{c}	7.96^{e}	7.06^{a}	7.51^{cd}	8.24^{d}	7.66^{bc}	7.95^{d}	8.50^{bc}	8.21^{b}	8.36^{bc}
T_{10}	7.78^{cd}	7.07^{ab}	7.43^{c}	7.81^{cde}	7.16^{a}	7.49^{cd}	8.02^{bcd}	7.60^{abc}	7.81^{cd}	8.28^{bc}	8.12^{ab}	8.20^{bc}
T_{11}	7.74^{abcd}	6.92^{a}	7.33^{bc}	7.77^{bcde}	7.04^{a}	7.41^{bcd}	7.72^{abcd}	7.59^{abc}	7.66^{bcd}	8.41^{bc}	8.26^{b}	8.34^{bc}
T_{12}	7.00^{abc}	6.94^{a}	6.97^{ab}	7.06^{abcd}	7.01^{a}	7.04^{ab}	7.39^{abc}	7.56^{abc}	7.48^{abc}	8.16^{abc}	8.16^{ab}	8.16^{abc}
T_{13}	7.94^{d}	7.02^{ab}	7.48^{c}	7.97^{e}	7.11^{a}	7.54^{cd}	8.30^{d}	7.59^{abc}	7.95^{d}	8.74^{c}	8.14^{ab}	8.44^{bc}
T_{14}	7.67^{cd}	7.04^{ab}	7.36^{bc}	7.70^{bcde}	7.14^{a}	7.42^{bcd}	7.99^{bcd}	7.67^{c}	7.83^{cd}	8.53^{bc}	8.30^{b}	8.42^{bc}
T_{15}	7.89^{d}	7.00^{a}	7.45^{c}	7.93^{de}	7.12^{a}	7.53^{cd}	8.13^{cd}	7.51^{abc}	7.82^{cd}	8.56^{bc}	8.13^{ab}	8.35^{bc}

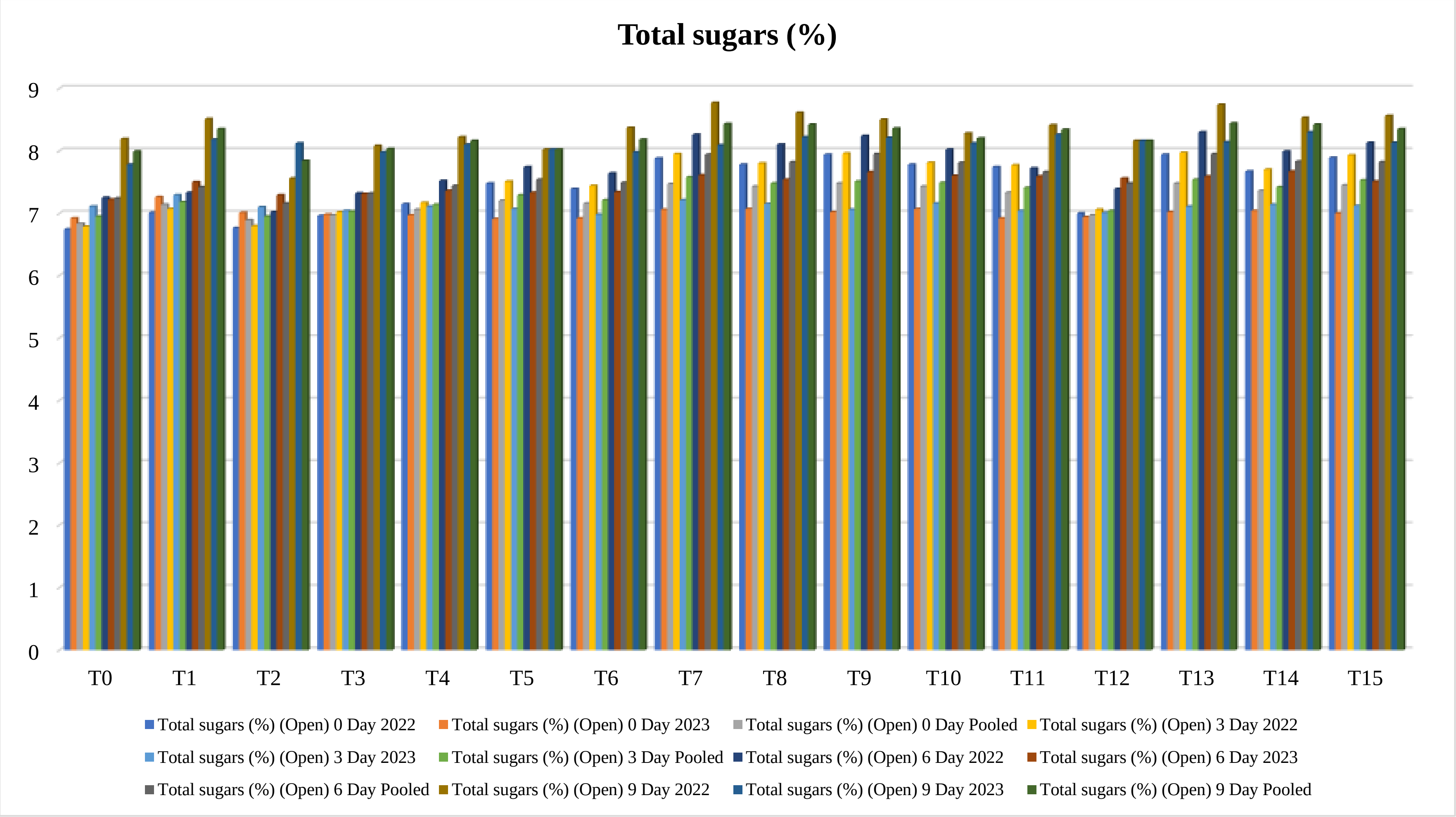

Figure 4.37b: Effect of Nano- ZnO and FeO on Total sugars (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day intervals

4.2.6 Reducing Sugars:

The study of the Table 4.38a revealed that Data on reducing sugars at different days interval had significant variations among the treatments under protected and open field conditions. In protected field conditions, during (2022-23), showed significant Data observation. The maximum (5.16%) reducing sugars on the 9th day was recorded under the treatment T_7 (50 ppm ZnO + 50 ppm FeO) while the minimum (3.83%) was noticed under T_3 (150 ppm ZnO) followed by 4.33 % under T_{12} (100 ppm ZnO + 150 ppm FeO). During (2023-24) showed the same increasing pattern with the maximum (4.94%) reducing sugars was observed under the treatment T_8 (50 ppm ZnO + 100 ppm FeO) while the minimum (4.28%) was noticed under the treatment T_1 (50 ppm FeO) followed by 4.29 % under T_2 (100ppm ZnO). The pooled analysis (2022-23 and 2023-24) revealed the maximum (4.96%) reducing sugars was recorded under T_7 (50ppm ZnO+ 50ppm FeO) while the minimum (4.06%) was noted in T_2 (100ppm ZeO) followed by 4.34 under treatment T_1 (50 ppm ZnO).

The Data on reducing sugars presented in Table 4.38b revealed significant variations exists among all the treatments with the application on ZnO and FeO under open field conditions. During (2022-23), at 9th day the maximum (5.21%) reducing sugars was recorded under the treatment T_7 (50 ppm ZnO + 50 ppm FeO) while the minimum (4.00%) was noticed under T_2 (100 ppm ZnO). During (2023-24) showed the same increasing pattern with the maximum (4.89%) reducing sugars under the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) while the minimum (4.31%) was noticed under the treatment T_0 (100 % RDF) followed by 4.33 % under T_2 (100ppm ZnO). The pooled analysis (2022-23 and 2023-24) revealed the maximum (5.02%) reducing sugars under T_7 (50ppm ZnO+ 50ppm FeO) while the minimum (4.17%) was noted in T_2 (100ppm ZeO) followed by 4.22 % under T_0 (100 % RDF).

It is obvious that the enhancement of reducing sugar content in strawberries, particularly noticeable at the 9th day interval following the application of Zn and Fe, is due to their ability to improve nutrient uptake and stimulate enzymatic activities involved in carbohydrate metabolism. Zn plays a significant role as a cofactor for enzymes like fructose-1,6-bisphosphatase, which is involved in gluconeogenesis, ultimately leading to the accumulation of sugars. Meanwhile, iron is essential for chlorophyll synthesis and electron transport in photosynthesis, is helpful in enhancing the synthesis of carbohydrates, including reducing sugars. The nanoscale of these oxides allows for better penetration and prolonged bioavailability, contributing to sustained effects on the metabolic pathways. This ultimately led to a significant increase in the reducing sugar percentage by the 9th day. The results from the present studies are in confirmation with the findings of Singh *et al.,* (2020); Verma *et al.*, (2018); Yadav *et al.,* (2011); Raliya *et al.,* (2013); Verma *et al.*, (2018); Rathore *et al.,* (2013); Tahir *et al.,* (2020); Sajid *et al.*, (2012) and Sharma and Kumar (2021).

Table 4.38a: Effect of Nano- ZnO and FeO on reducing sugars (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day intervals

Reducing sugars (%) (Protected)												
Treatments	**0 Day**			**3 Day**			**6 Day**			**9 Day**		
	2022-23	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**	**2022-23**	**2023-24**	**Pooled**
T0	4.44^{bc}	4.21^{ab}	4.33^{bcd}	4.48^{bcd}	4.23^{abc}	4.36^{bcd}	4.54^{bcd}	4.27^{ab}	4.41^{bcd}	4.77^{bcde}	4.37^{ab}	4.57^{bcd}
T1	4.12^{ab}	4.03^{a}	4.08^{ab}	4.21^{bc}	4.06^{a}	4.14^{ab}	4.31^{bc}	4.16^{a}	4.24^{b}	4.39^{abc}	4.28^{a}	4.34^{ab}
T2	3.53^{a}	4.12^{ab}	3.83^{a}	3.56^{a}	4.14^{ab}	3.85^{a}	3.61^{a}	4.16^{a}	3.89^{a}	3.83^{a}	4.29^{a}	4.06^{a}
T3	4.46^{bc}	4.13^{ab}	4.30^{bcd}	4.52^{bc}	4.16^{ab}	4.34^{bcd}	4.55^{bcd}	4.23^{a}	4.39^{bcd}	4.76^{bcde}	4.31^{a}	4.54^{bc}
T4	4.29^{bc}	4.11^{ab}	4.20^{bc}	4.33^{bcd}	4.15^{ab}	4.24^{bc}	4.40^{a}	4.21^{a}	4.31^{bc}	4.52^{bcd}	4.35^{ab}	4.44^{bc}
T5	4.57^{bcd}	4.35^{abc}	4.46^{cde}	4.62^{bcd}	4.38^{cde}	4.50^{cde}	4.68^{bcd}	4.44^{bcd}	4.56^{bcde}	4.83^{bcde}	4.53^{bcd}	4.68^{cde}
T6	4.07^{ab}	4.64^{cde}	4.36^{bcd}	4.13^{ab}	4.69^{fgh}	4.41^{bcd}	4.20^{b}	4.73^{fg}	4.47^{bcd}	4.38^{abc}	4.82^{efg}	4.60^{bcd}
T7	4.92^{cd}	4.63^{cde}	4.78^{e}	4.95^{bcd}	4.64^{fgh}	4.80^{bcde}	4.99^{cd}	4.69^{ef}	4.84^{e}	5.16^{e}	4.75^{efg}	4.96^{e}
T8	4.29^{bc}	4.75^{e}	4.52^{cde}	4.34^{bcd}	4.79^{gh}	4.57^{cde}	4.41^{bcd}	4.84^{fg}	4.63^{cde}	4.54^{bcde}	4.94^{gh}	4.74^{cde}
T9	4.77^{bcd}	4.47^{bcde}	4.62^{de}	4.83^{d}	4.51^{efg}	4.67^{de}	4.88^{cd}	4.56^{def}	4.72^{de}	5.03^{cde}	4.72^{def}	4.88^{de}
T_{10}	4.69^{bcd}	4.53^{cde}	4.61^{de}	4.76^{bcd}	4.56^{efg}	4.66^{de}	4.82^{bcd}	4.60^{def}	4.71^{de}	4.98^{cde}	4.77^{efg}	4.88^{de}
T_{11}	4.42^{bc}	4.26^{abc}	4.34^{bcd}	4.50^{bcd}	4.28^{bcd}	4.39^{bcd}	4.58^{bcd}	4.33^{ab}	4.46^{bcd}	4.76^{bcde}	4.46^{abc}	4.61^{bcd}
T_{12}	4.08^{ab}	4.44^{bcde}	4.26^{bcd}	4.13^{ab}	4.48^{ef}	4.31^{bc}	4.22^{bc}	4.53^{de}	4.38^{bcd}	4.33^{ab}	4.67^{def}	4.50^{bc}
T_{13}	4.46^{bc}	4.76^{e}	4.61^{de}	4.52^{bcd}	4.79^{f}	4.66^{de}	4.58^{bcd}	4.86^{g}	4.72^{de}	4.73^{bcde}	5.06^{g}	4.90^{de}
T_{14}	4.15^{ab}	4.56^{cde}	4.36^{bcd}	4.22^{bc}	4.60^{fg}	4.41^{bcd}	4.28^{bc}	4.64^{ef}	4.46^{bcd}	4.39^{abc}	4.73^{def}	4.56^{bcd}
T_{15}	4.44^{bc}	4.42^{bcde}	4.43^{cde}	4.50^{bcd}	4.45^{def}	4.48^{bcde}	4.60^{bcd}	4.49^{cd}	4.55^{bcde}	4.71^{bcde}	4.58^{cde}	4.65^{bcd}

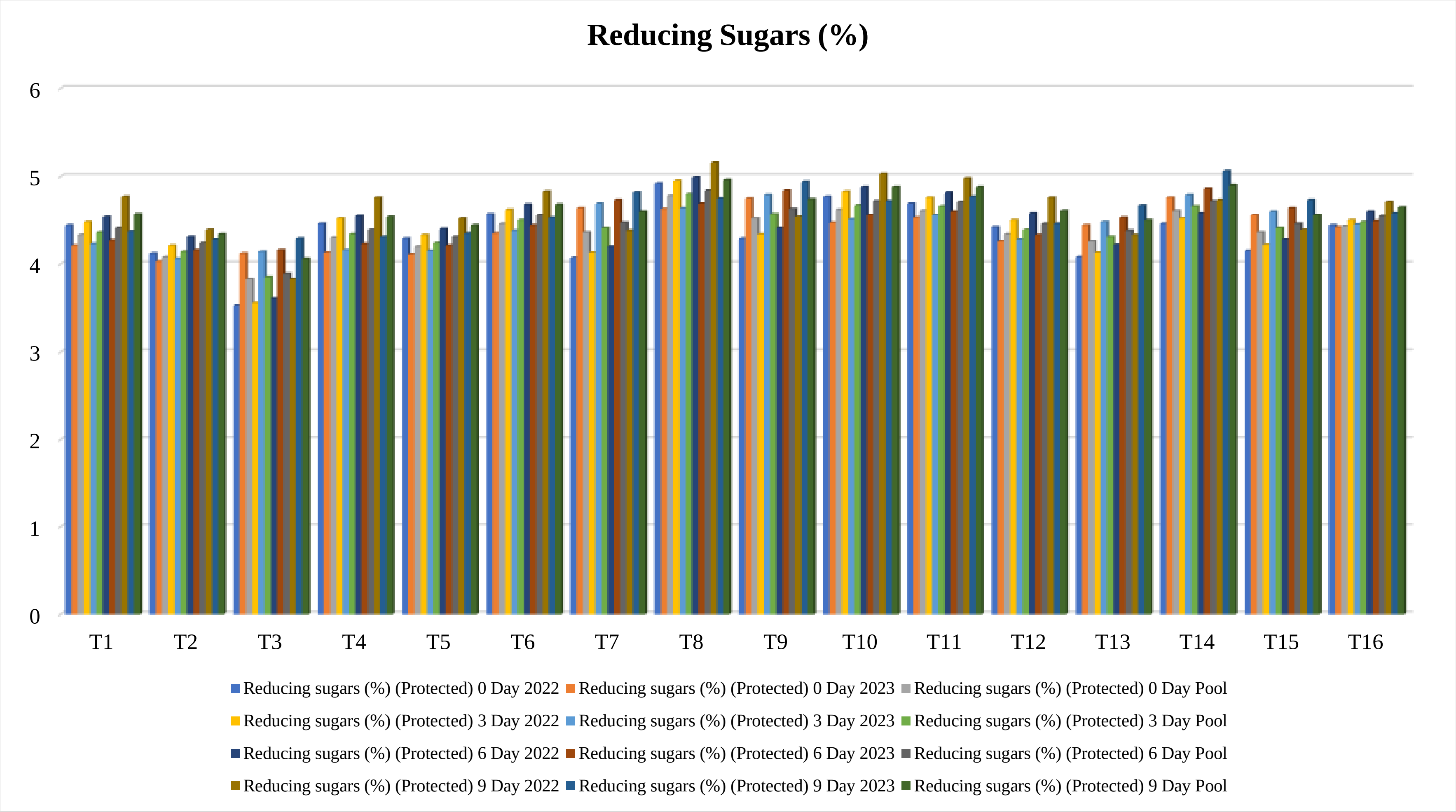

Figure 4.38a: Effect of Nano- ZnO and FeO on reducing sugars (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under protected conditions at different day intervals

Table 4.38b: Effect of Nano- ZnO and FeO on reducing sugars (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day interval.

Treatments	Reducing sugars (%) (Open)											
	0 Day			3 Day			6 Day			9 Day		
	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled	2022-23	2023-24	Pooled
T_0	3.75^{a}	4.11^{ab}	3.93^{ab}	3.79^{a}	4.20^{ab}	4.00^{a}	4.06^{ab}	4.25^{a}	4.16^{ab}	4.13^{ab}	4.31^{a}	4.22^{ab}
T_1	4.04^{ab}	4.20^{ab}	4.12^{abcd}	4.09^{ab}	4.29^{ab}	4.19^{abc}	4.21^{abc}	4.36^{ab}	4.29^{abc}	4.32^{abc}	4.41^{abc}	4.37^{abc}
T_2	3.74^{a}	4.07^{a}	3.91^{a}	3.81^{a}	4.15^{a}	3.98^{a}	3.90^{a}	4.26^{a}	4.08^{a}	4.00^{a}	4.33^{ab}	4.17^{a}
T_3	4.05^{ab}	4.08^{a}	4.07^{abc}	4.08^{ab}	4.22^{ab}	4.15^{ab}	4.16^{abc}	4.29^{ab}	4.23^{abc}	4.24^{ab}	4.35^{ab}	4.30^{ab}
T_4	4.16^{abc}	4.48^{bcde}	4.32^{abcde}	4.23^{abc}	4.55^{bcd}	4.39^{abcd}	4.36^{abcd}	4.62^{bcd}	4.49^{abcd}	4.49^{abcd}	4.69^{cde}	4.59^{abcd}
T_5	4.47^{bcd}	4.37^{abcde}	4.42^{bcde}	4.50^{abc}	4.43^{abc}	4.47^{abcd}	4.55^{abcd}	4.49^{abc}	4.52^{abcd}	4.55^{abcd}	4.58^{abcde}	4.57^{abcd}
T_6	4.33^{bcd}	4.38^{abcde}	4.36^{abcde}	4.37^{abc}	4.46^{abcd}	4.42^{abcd}	4.50^{abcd}	4.51^{abc}	4.51^{abcd}	4.62^{abcd}	4.53^{abcd}	4.58^{abcd}
T_7	4.80^{cd}	4.75^{e}	4.78^{e}	4.89^{c}	4.72^{cd}	4.81^{d}	5.04^{d}	4.76^{cd}	4.90^{d}	5.21^{d}	4.82^{de}	5.02^{d}
T_8	4.71^{bcd}	4.37^{abcde}	4.54^{cde}	4.80^{bc}	4.42^{abc}	4.61^{bcd}	4.88^{cd}	4.48^{abc}	4.68^{cd}	5.02^{cd}	4.54^{abcd}	4.78^{cd}
T_9	4.85^{cd}	4.61^{cde}	4.73^{e}	4.92^{c}	4.68^{cd}	4.80^{d}	5.00^{d}	4.72^{cd}	4.86^{d}	5.14^{d}	4.77^{de}	4.96^{d}
T_{10}	$4.69b^{cd}$	4.49^{bcde}	4.59^{de}	4.80^{bc}	4.55^{cd}	4.68^{cd}	4.99^{d}	4.62^{bcd}	4.81^{d}	5.09^{d}	4.66^{bcde}	4.88^{d}
T_{11}	$4.67b^{cd}$	4.64^{cde}	4.66^{e}	4.80^{bc}	4.71^{cd}	4.76^{d}	4.99^{d}	4.76^{cd}	4.88^{d}	5.09^{d}	4.81^{de}	4.95^{d}
T_{12}	$4.29b^{cd}$	4.31^{abc}	4.30^{abcde}	4.43^{abc}	4.40^{abc}	4.42^{abcd}	4.72^{bcd}	4.44^{abc}	4.58^{bcd}	4.80^{bcd}	4.51^{abcd}	4.66^{bcd}
T_{13}	4.85^{d}	4.74^{de}	4.80^{e}	4.91^{c}	4.82^{d}	4.87^{d}	5.03^{d}	4.87^{d}	4.95^{d}	5.08^{d}	4.89^{e}	4.99^{d}
T_{14}	4.69^{bcd}	4.66^{cde}	4.68^{e}	4.79^{bc}	4.71^{cd}	4.75^{d}	4.89^{cd}	4.76^{cd}	4.83^{d}	5.00^{cd}	4.81^{de}	4.91^{d}
T_{15}	4.68^{bcd}	4.66^{cde}	4.67^{e}	4.89^{c}	4.74^{cd}	4.82^{d}	4.98^{d}	4.78^{cd}	4.88^{d}	5.05^{cd}	4.85^{de}	4.95^{d}

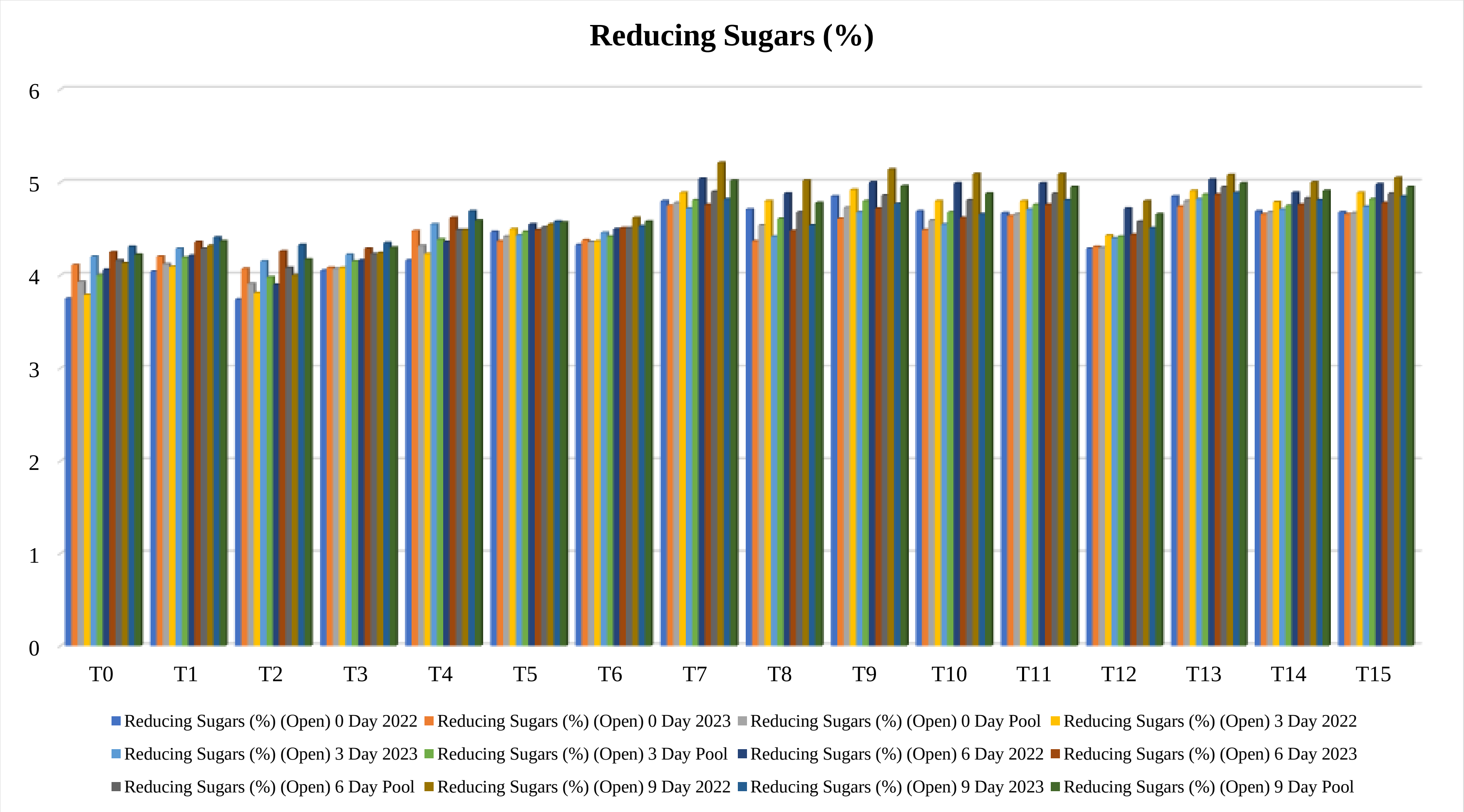

Figure 4.38b: Effect of Nano- ZnO and FeO on reducing sugars (%) of Strawberry (*Fragaria* × *ananassa* Duch.) cv. Winter Dawn under open conditions at different day intervals

Chapter V

SUMMARY AND CONCLUSION

The Investigation titled "Effect of Nano-ZnO and FeO on growth, yield, quality and shelf life of Strawberry (*Fragaria* × *ananassa* Duch.) Cv. Winter Dawn under open and protected conditions" was carried out at the experimental farm of the Department of Horticulture, School of Agriculture, Lovely professional university (Phagwara) during 2022-2024. The results of the experiment are summerized as under:

5.1 Growth Parameters (Protected and open)

- The maximum plant height (12.24 cm) during first year, 11.92 cm for second year and 12.80 cm in the pooled under protected condition, while the maximum plant height 12.30cm, 10.40cm and 11.36cm respectively, was recorded under natural condition in the treatment T_{15} (150 ppm ZnO + 150 ppm FeO).
- The maximum stem girth (26.62 mm) during first year, 24.60 mm for the second year, and 25.61 mm in the pooled Data under protected condition, wereas under open condition maximum stem girth 24.69 mm, 21.35 mm, and 23.02 mm respectively, was recorded with T_{15} (150 ppm ZnO + 150 ppm FeO).
- Under protected field condition maximum number of leaves (15.00) for the first year, 15.00 for the second year and 15.00 in the pooled Data, meanwhile under open condition maximum number of leaves 13.00, 13.00 and 13.00 respectively, was noticed under T_{15} (150 ppm ZnO + 150 ppm FeO).
- The maximum leaf length (5.71cm) during first year, 5.37cm for the second year and 5.50cm in the pooled Data under protected condition, while under open condition maximum leaf length 5.73 cm, 5.07cm and 5.40cm respectively, was observed in T_{15} (150 ppm ZnO + 150 ppm FeO).
- The maximum petiole length (9.36cm) for the pooled analysis for both the years under protected condition, wereas under open field condition maximum petiole length 9.17cm was recorded in the treatment T_{15} (150

ppm ZnO + 150 ppm FeO).

- The maximum leaf area (73.11cm^2) during first year, 71.60cm^2 for the second year and 72.36cm^2 in the pooled Data under protected condition, while under open condition maximum leaf area 74.87cm^2, 74.23cm^2 and 74.55cm^2 was observed respectively, under T_{15} (150 ppm ZnO + 150 ppm FeO).
- Under protected field condition maximum plant spread (22.99 cm) in the NS direction during first year, 22.85 cm for the second year and 22.92cm in the pooled analysis, meanwhile under open condition maximum spread 23.10 cm, 23.20 cm, and 23.15 cm respectively, was observed in the treatment T_{15} (150 ppm ZnO + 150 ppm FeO).
- The maximum chlorophyll content (55.47 mg/µmol) during first year, 54.24 mg/µmol for the second year and 54.85 mg/µmol in the pooled analysis under protected condition, wereas under open field condition maximum chlorophyll content 53.40, 52.80, and 53.10 mg/µmol respectively, was recorded under T_{15} (150 ppm ZnO + 150 ppm FeO).
- The maximum number of crowns (3.67) during first year, 3.67 in the second year and 3.67 for the pooled analysis under protected condition, while under open field condition maximum number of crowns 4.33, 3.67 and 4.15 respectively, was recorded under T_{15} (150 ppm ZnO + 150 ppm FeO).
- Under protected field condition, the maximum number of flowers (11.00) during first year, 12.33 for the second year and 11.07 in the pooled analysis, meanwhile under open field condition maximum number of flowers (12.67) for the first year, 10.33 for the second year and 11.50 for the pooled analysis respectively, was recorded in the treatment T_{15} (150 ppm ZnO + 150 ppm FeO).
- The maximum duration of flowering (55.00) per plant during first year, 54.33 in the second year and 54.40 for the pooled analysis under protected condition, while under open field condition maximum duarion of flowering 55.00, 54.07 and 54.00 respectively, was observed under T_{15} (150 ppm ZnO

+ 150 ppm FeO).

5.2 Yield Parameters

- The maximum number of fruits (9.67) per plant during first year, 7.67 for the second year and 8.67 in the pooled analysis under protected condition, meanwhile under open field condition maximum number of fruits 8.00, 7.67 and 8.00 respectively, was observed in the treatment T_{15} (150 ppm ZnO + 150 ppm FeO).
- The maximum number of days (25.00) taken from flower initiation to fruit maturity during first year, 25.67 days in the second year and in the pooled analysis 25.33 days under protected condition with T_{15} (150 ppm ZnO + 150 ppm FeO) whereas, under open condition under the same treatment, the days remained consistent at 25.33 days in the entire study.
- The maximum yield per plant (299.00 g) during first year, 272.30 g for the second year and 285.67 g in the pooled Data under protected condition, wereas, under open condition maximum yield 297.00 g, 228.00 g, and 262.50 g respectively, was recorded under T_{15} (150 ppm ZnO + 150 ppm FeO).
- Under protected field condition, the maximum number of harvestings (6.00) during first year, 4.67 in the second year, and 5.33 for the pooled analysis, wereas under open condition maximum number of harvestings (5.33) for the first year, 4.33 for the second year and 4.83 for the pooled analysis respectively, was recorded in the treatment T_{15} (150 ppm ZnO + 150 ppm FeO).
- The maximum duration of harvesting (57.15 days) during first year, 57.00 days for the second year and 57.17 days in the pooled Data under protected conditions, while under open condition maximum duration 56.00 days consistently was observed across all years with T_{15} (150 ppm ZnO + 150 ppm FeO).

Quality and Shelf Life

- The maximum fruit length (44.87 mm) during first year, 45.52 mm for the second year and 45.20 mm in the pooled Data under protected conditions, wereas under open condition maximum fruit length 45.85 mm, 44.39 mm, and 45.12 mm was recorded respectively, in the treatment T_{15} (150 ppm ZnO + 150 ppm FeO).

- The maximum fruit weight (11.91 g) during first year, 10.93 g for the second year, and 11.42 g in the pooled Data under protected conditions, wereas under open condition maximum fruit weight 11.74 g, 10.55 g, and 11.13 g was recorded respectively, under T_9 (50 ppm ZnO + 150 ppm FeO) and T_{15} (150 ppm ZnO + 150 ppm FeO).
- Under protected field condition, the maximum fruit TSS (6.72°Brix) during first year, 6.73°Brix for the second year, and 6.73°Brix in the pooled analysis, meanwhile under open condition maximum TSS values (6.85°Brix) for the first year, 6.70°Brix for the second year and 6.77°Brix for the pooled analysis was observed under treatments T_9 (50 ppm ZnO + 150 ppm FeO) and T_{15} (150 ppm ZnO + 150 ppm FeO),
- The maximum fruit acidity (0.72%) during first year, 0.68% for the second year, and 0.70% in the pooled Data under protected conditions, wereas under open condition maximum acidity 0.70%, 0.72%, and 0.71% was observed respectively, in the treatments T_9 (50 ppm ZnO + 150 ppm FeO), T_{14} (100 ppm ZnO + 150 ppm FeO) and T_{13} (50 ppm ZnO + 150 ppm FeO).
- The highest total sugars (7.93%) during first year, 7.25% for the second year and 7.46% in the pooled Data under protected conditions, while under open condition maximum total sugars 7.94%, 7.26%, and 7.48% was recorded respectively, under T_1 (50 ppm ZnO), T_7 (50 ppm ZnO + 50 ppm FeO), T_9 (50 ppm ZnO + 150 ppm FeO), T_{14} (100 ppm ZnO + 150 ppm FeO), and T_{13} (50 ppm ZnO + 150 ppm FeO).
- The maximum ascorbic acid (51.96 mg/100g) during first year, 53.15 mg/100g for the second year and 52.16 mg/100g in the pooled Data under protected conditions, while under open condition maximum ascorbic acid was 52.84 mg/100g, 49.95 mg/100g, and 51.08 mg/100g was noted respectively, in the treatments T_9 (50 ppm ZnO + 150 ppm FeO), T_{13} (150

ppm ZnO + 50 ppm FeO) and T_{15} (150 ppm ZnO + 150 ppm FeO).

- The highest total flavonoids (164.1 mg/100g) for the first year, 159.00 mg/100g for the second year and 161.83 mg/100g in the pooled Data under protected condition, while under open condition maximum total flavonoids 151.00 mg/100g, 151.05 mg/100g and 151.24 mg/100g was noted respectively, in the treatment T_{15} (150 ppm ZnO + 150 ppm FeO).
- The maximum soluble protein (2.67%) during first year, 2.75% for the second year and 2.71% in the pooled Data under protected conditions, meanwhile under open condition maximum soluble protein 2.65%, 2.73%, and 2.69% was recorded respectively, in the treatment T_{15} (150 ppm ZnO + 150 ppm FeO).
- The physiological weight was recorded minimum (1.76%) during first year, 0.91% in the second year and 2.40% in the pooled Data under protected conditions, while under open condition minimum PLW 1.11%, 0.83%, and 1.19% was recorded respectively, under T_4 (50 ppm FeO) and T_5 (100 ppm FeO) and same trend was observed in the spoilage percentage at the 9th day of storage.
- The maximum TSS (7.28°Brix) during first year, 7.20°Brix for the second year, and 7.23°Brix in the pooled Data under protected conditions, while under open field condition maximum TSS 7.67°Brix, 7.56°Brix and 7.62°Brix respectively was noted, under T_{13} (150 ppm ZnO + 50 ppm FeO) at the 9th day of storage.
- Under protected field condition, the maximum acidity (0.65%) for the first year, 0.64% for the second year and 0.63% in the pooled analysis, meanwhile under open condition maximum acidity (0.63%) for the first year, 0.76% for the second year and 0.70% in the pooled analysis was observed in the treatment T_{13} (150 ppm ZnO + 50 ppm FeO) at the 9th day of storage.
- The maximum ascorbic acid (49.66 mg/100g) for the first year, 50.35 mg/100g for the second year and 49.25 mg/100g in the pooled Data under protected condition, wereas under open condition maximum ascorbic acid

49.77 mg/100g, 47.03 mg/100g and 48.28 mg/100g was observed respectively, under T_{14} (150 ppm ZnO + 100 ppm FeO) at the 9^{th} day of storage.

- The maximum total sugars (8.34%) during first year, 7.88% for the second year and 8.09% in the pooled Data under protected conditions, while under open condition maximum total sugars 8.77%, 8.30% and 8.44% was recorded respectively, in the treatments T_7 (50 ppm ZnO + 50 ppm FeO) and T_{13} (150 ppm ZnO + 50 ppm FeO) at the 9^{th} day of storage.
- The maximum reducing sugars (5.16%) for the first year, 4.89% for the second year and 4.90% in the pooled Data under protected conditions, meanwhile under open cultivation maximum reducing sugars 5.21%, 4.89% and 5.02% was observed respectively, under T_7 (50 ppm ZnO + 50 ppm FeO) and T_{13} (150 ppm ZnO + 50 ppm FeO) at the 9^{th} day of storage.

From the present findings, it can be concluded that the application of nanofertilizers, particularly using Nano-ZnO and Nano-FeO, significantly improved the growth, yield, quality and shelf life of strawberry cv. Winter Dawn under both open and protected cultivation conditions. Among the various treatments evaluated, T_{15} (150 ppm ZnO + 150 ppm FeO) emerged as the most effective, showing remarkable improvements in key growth parameters such as plant height, leaf number, leaf area, petiole length and chlorophyll content etc. with considerable increases in fruit yield, leading to a higher number of fruits per plant, more fruit weight and overall yield along with shelf life and quality parameters i.e. total soluble solids, acidity, anthocyanin content, total proteins, vitamin C content and sugar levels. However, other micronutrients, such as copper (Cu), boron (B), manganese (Mn) etc. need to be elavuated for enhancing crop procutivity.

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Appendices

Appendix I

Table 1. Meteorological data for the experimental years

Date	Temp. (Max.)	Temp. (Min.)	RH (Max.)	RH (Min.)	Wind speed (km/hr)	RF(mm)	Evaporation (mm)
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
01-01-2023	17	7.5	87	77	10	NE	0
02-01-2023	15.8	6	97	82	7	NE	0
03-01-2023	15	5	91	81	5	NE	0
04-01-2023	15	4	98	75	5	NE	0
05-01-2023	12	6	98	86	6	NE	0
06-01-2023	11	5	97	85	5	NE	0
07-01-2023	15	5	91	87	8	NEE	0
08-01-2023	16	7	93	77	10	NE	0
09-01-2023	15	6	96	75	6	NE	0
10-01-2023	17	8	92	80	10	NE	0
11-01-2023	11	9	98	87	7	NE	0.8
12-01-2023	12	10	94	86	12	NE	1.3
13-01-2023	12.5	10	98	88	10	SW	0
14-01-2023	11	9	98	86	7	SS	0
15-01-2023	9	7	98	87	8	NE	0
16-01-2023	13	6	98	77	10	NE	0
17-01-2023	12.3	3.5	98	75	5	NNE	0
18-01-2023	13.5	5.1	87	74	4	SE	0
19-01-2023	19	9	86	77	9	NE	0
20-01-2023	14	6	87	71	3	SE	0
21-01-2023	20	5	86	75	8	E	0

22-01-2023	21	6	87	70	11	NE	0
23-01-2023	21	6	87	69	9	NE	0
24-01-2023	18	12	87	74	5	E	0
25-01-2023	16.1	8.1	87	60	9	SE	20.6
26-01-2023	17.8	7.8	87	59	6	NEE	0
27-01-2023	18.8	5.9	77	55	7	NE	14
28-01-2023	18.2	7.1	77	58	7	NE	0
29-01-2023	18.6	8.6	86	77	6	SSW	8
30-01-2023	19.2	10.1	100	100	19	SW	4.4
31-01-2023	18.3	8.5	95	71	8	NE	0
01-02-2023	18.8	6.9	96	71	14	NE	0
02-02-2023	21.5	7.7	93	70	13	NE	0
03-02-2023	21.5	8.4	96	74	10	NNE	0
04-02-2023	23	10.6	96	69	10	NE	0
05-02-2023	23.3	10.9	96	67	10	NE	0
06-02-2023	21	12	96	70	8	SE	0.01
07-02-2023	23	12	72	67	12	NE	0
08-02-2023	23.9	8.9	77	52	9	NE	0
09-02-2023	24	10.6	74	45	9	SE	0
10-02-2023	24.9	15.1	71	54	12	SW	0
11-02-2023	25.9	13	76	52	11	NE	0
12-02-2023	24.9	8.2	81	52	12	NNE	0
13-02-2023	26	5	54	33	12	NNE	0
14-02-2023	27	9	51	38	10	NE	0
15-02-2023	23.4	14	54	37	10	NE	0
16-02-2023	26.8	14.1	51	38	10	NE	0
17-02-2023	26.1	13.6	54	34	7	SSW	0
18-02-2023	27.6	11.7	96	58	6	NE	0
19-02-2023	28.7	12.6	94	54	9	SSW	0
20-02-2023	27.6	14.3	94	57	10	SW	0
21-02-2023	27.7	16.3	94	44	13	SW	0
22-02-2023	29.6	15.5	96	58	10	SW	0
23-02-2023	27.7	13.7	90	58	11	NE	0
24-02-2023	27.7	13.7	91	61	8	NE	0
25-02-2023	27.6	14	87	62	8	NE	0
26-02-2023	28.7	14.4	86	59	10	NEE	0
27-02-2023	29	13	81	52	8	NE	0

28-02-2023	25	15	76	50	10	NE	0
01-03-2023	28	14	50	48	9	NW	0.02
02-03-2023	29	15	65	43	4	SE	0
03-03-2023	24	13	58	47	14	NE	0
04-03-2023	28.4	13.5	48	36	9	NE	0
05-03-2023	28.3	13	38	31	10	NE	0
06-03-2023	28.9	11.6	30	32	10	NE	0
07-03-2023	31.3	12.8	29	31	10	SE	0
08-03-2023	28.7	14	50	40	8	SW	0
09-03-2023	30	15.1	50	42	9	SW	0
10-03-2023	29.4	16	48	46	5	NE	0
11-03-2023	29.3	15.6	80	39	9	NNE	0
12-03-2023	28.4	15.7	79	39	8	SSE	0
13-03-2023	30	17.1	75	37	10	SE	0
14-03-2023	30.6	19.5	73	34	12	E	0
15-03-2023	31	15.2	72	35	11	SW	0
16-03-2023	32.4	17.3	48	35	12	SSE	0
17-03-2023	22.8	17.1	80.8	59	2.2	SSE	0
18-03-2023	19.6	15.2	93	77	19	SSW	15
19-03-2023	25.7	14.1	92	59	1.9	SSE	0
20-03-2023	21.8	15.3	93	67	1.7	NE	1.4
21-03-2023	25	11.9	93	51	0.8	NNW	0
22-03-2023	26.7	13.8	93	59	0.7	SEE	0
23-03-2023	27	12.6	94	56	1.7	NEE	0
24-03-2023	22.7	14.1	94	65	3.1	SSE	12
25-03-2023	23.8	15.6	94	61	2.5	SSE	25
26-03-2023	26.2	12.6	93	58	12	NE	0
27-03-2023	28	15	90	40	8	NE	0
28-03-2023	27	16	92	52	10	NE	0
29-03-2023	33	17	88	39	4	SE	0
30-03-2023	32	18	90	40	8	NNW	0
31-03-2023	22	18	93	68	16	EES	2.2
01-04-2023	25.2	13.4	75	57	13	EES	0.02
02-04-2023	25.7	13.3	60	51	9	EES	0
03-04-2023	20.49	16.4	83	66	2.1	SE	2.2
04-04-2023	27.2	16.39	64	44	2.1	EES	0.2
05-04-2023	29.6	12.88	62	27	1.5	NNE	0

06-04-2023	28.7	15.38	62	33	1.9	NNE	0
07-04-2023	30.7	13	61	23	2	NNE	0
08-04-2023	31.9	11.84	64	20	1.9	NNE	0
09-04-2023	32.19	12.76	65	18	1.8	NNW	0
10-04-2023	33.56	12.8	60	22	1.9	SE	0
11-04-2023	34.41	15.5	66	22	2.4	N	0
12-04-2023	34.4	20.6	85	31	12	NNW	0
13-04-2023	36.62	17.03	85	26	2.4	NW	0
14-04-2023	37.79	16.91	85	30	1.7	NEE	0
15-04-2023	39.31	17.3	84	19	1.4	NNE	0
16-04-2023	39.51	19.16	98	22	1.9	SSE	0
17-04-2023	39.02	17.75	71	23	1.2	NNE	0
18-04-2023	37.66	21.31	72	21	2.1	NNW	0
19-04-2023	34.3	19.3	79	34	9	NNW	9.3
20-04-2023	32.7	14.9	73	41	6	NEE	0
21-04-2023	32.9	14.2	80	30	5	NEE	0
22-04-2023	30.8	13.8	84	34	9	NNE	0
23-04-2023	33.58	11.85	84	24	5	SSE	0
24-04-2023	35.8	13.5	84	25	4	NNW	0
25-04-2023	34.8	19.6	63	26	10	SWW	0
26-04-2023	34.2	20	79	33	11	SSW	0
27-04-2023	33.6	21	74	40	18	SSW	0
28-04-2023	35	21	79	34	9	SSW	0
29-04-2023	37.7	20.6	75	34	9	NEE	0
30-04-2023	32.8	18.7	77	38	9	SSE	0
01-05-2023	32	21	83		19	ES	2.3
02-05-2023	33	19	71	32	20	SE	0.5
03-05-2023	29	19	78	60	19	SE	1.2
04-05-2023	37	21	71	34	10	NWW	0.2
05-05-2023	36	21	51	43	14	NW	1.5
06-05-2023	38	23	59	48	7	SSW	0
07-05-2023	39	22	52	42	12	NS	0
08-05-2023	39	24	58	48	26	NNE	0
09-05-2023	40	23	56	44	7	NNW	0
10-05-2023	41	23	54	45	13	NNE	0
11-05-2023	42	24	53	42	4	NNE	0
12-05-2023	42	26	36	25	3	SE	0

13-05-2023	41	21	38	24	11	NE	0
14-05-2023	41	23	39	22	17	NE	0
15-05-2023	46	27	52	58	6	SE	0
16-05-2023	46	28	50	56	9	ES	0
17-05-2023	47	29	71	30	7	EES	0
18-05-2023	43	28	85	58	8	SSE	7.6
19-05-2023	37	21	82	32	9	NW	0
20-05-2023	40	22	78	24	7	NNW	0
21-05-2023	41	21	82	20	8	S	0
22-05-2023	43	22	79	18	5	WNW	0
23-05-2023	41	27	76	21	8	NNW	0
24-05-2023	36	24	71	34	9	NW	0
25-05-2023	30	20	85	63	15	SSE	12.2
26-05-2023	32	20	82	51	20	SSE	2
27-05-2023	34	22	81	42	7	SSE	0
28-05-2023	37	20	82	27	6	NEE	0
29-05-2023	31	22	81	56	9	NNW	1
30-05-2023	33	21	82	43	6	SEE	4.1
31-05-2023	26	19	91	69	7	NWW	23.3
01-06-2023	32	20	90	49	5	SSW	9.8
02-06-2023	31	21	87	49	4	NNW	1.2
03-06-2023	34	20	86	46	4	SWW	0
04-06-2023	36	23	86	40	5	NWW	0
05-06-2023	38	22	84	35	7	NNW	0
06-06-2023	38	20	58	30	8	SWW	22.8
07-06-2023	32	20	82	41	9	NW	0.4
08-06-2023	38	20	90	32	3	NNE	0
09-06-2023	40	24	80	33	2	EES	0
10-06-2023	41	26	76	31	3	NNE	0.4
11-06-2023	34	23	83	47	4	NNE	12
12-06-2023	38	24	87	41	2	WWN	0
13-06-2023	39	27	83	40	4	NNW	0
14-06-2023	38	21	78	44	4	SEE	23
15-06-2023	32	21	84	60	4	NEE	6.2
16-06-2023	35	25	87	49	3	NNW	0
17-06-2023	38	25	89	40	4	NNE	0
18-06-2023	37	27	85	50	2	SSW	0

19-06-2023	39	26	75	42	6	NNW	0
20-06-2023	39	26	82	40	2	WWS	0
21-06-2023	40	29	72	49	2	SSW	0
22-06-2023	36	27	84	66	2	SSE	16.2
23-06-2023	37	29	83	56	2	SSE	0
24-06-2023	37	29	85	58	2	SSE	0
25-06-2023	34	28	81	66	5	SSW	0
26-06-2023	33	27	81	62	3	SSW	0.2
27-06-2023	37	27	85	49	2	SSW	0
28-06-2023	35	27	81	57	3	SSW	2.2
29-06-2023	38	27	87	51	2	NNE	0
30-06-2023	37	27	83	54	2	NEE	0
01-07-2023	36	26	81	54	1	NNW	0
02-07-2023	37	27	82	52	1	SSE	0
03-07-2023	38	29	83	54	2	SSE	0
04-07-2023	34	25	84	60	2	SWW	5.4
05-07-2023	30	24	92	77	2	SEE	70
06-07-2023	32	23	89	74	2	SEE	14
07-07-2023	34	25	86	64	2	SSE	0
08-07-2023	30	24	91	78	10	SWW	63.8
09-07-2023	28	24	91	80	12	SE	8.2
10-07-2023	30	24	85	72	9	SEE	0.2
11-07-2023	36	25	92	60	2	N	0
12-07-2023	36	28	89	63	7	SSW	0
13-07-2023	34	24	88	64	8	SSW	3
14-07-2023	34	28	84	66	5	SSW	0
15-07-2023	37	28	90	58	6	SSW	0
16-07-2023	34	26	86	74	5	SSE	14.8
17-07-2023	37	26	89	60	7	SSW	8.6
18-07-2023	34	29	87	77	6	SSW	0.2
19-07-2023	32	28	84	73	7	SWW	0
20-07-2023	38	29	76	60	3	NEE	0
21-07-2023	37	29	90	63	6	SEE	0.4
22-07-2023	30	25	93	83	6	NE	26.2
23-07-2023	35	27	89	63	4	SSW	0
24-07-2023	34	26	93	74	6	SWW	40.8
25-07-2023	34	28	90	80	3	NNE	1.6

26-07-2023	32	27	90	76	6	SSW	0
27-07-2023	34	27	90	68	2	NNW	0
28-07-2023	33	27	92	77	5	S	17.6
29-07-2023	33	27	92	71	4	SWW	0
30-07-2023	34	28	92	66	6	NNW	4.2
31-07-2023	35	28	92	66	7	N	0
01-08-2023	36	28.1	92	70	4	NNW	26.4
02-08-2023	37	28	92	72	5	NNW	0
03-08-2023	36	26	86	64	5	N	9.8
04-08-2023	35	28	90	73	7	SSW	6
05-08-2023	35	27	92	70	5	NNW	14.2
06-08-2023	35	28	89	65	5	NNW	0
07-08-2023	34	26	87	75	5	SSW	0
08-08-2023	34	27	92	75	4	NNW	0
09-08-2023	33	25	89	77	4	N	5.8
10-08-2023	34	27	91	72	3	NEE	0
11-08-2023	35	27	92	77	3	NEE	0
12-08-2023	35	28	92	70	6	NWW	0
13-08-2023	34	28	89	71	6	SWW	0.2
14-08-2023	32	27	90	80	6	SSW	
15-08-2023	35	27	91	74	9	SEE	0.2
16-08-2023	36	26	90	76	5	NWW	0.2
17-08-2023	35	28	91	68	6	NNW	0.4
18-08-2023	36	28	93	66	3	NEE	0
19-08-2023	35	27	90	70	4	NWW	1.8
20-08-2023	38	28	92	58	3	NNE	0.2
21-08-2023	35	28	92	78	3	SSE	0
22-08-2023	36	28	92	70	7	N	0.8
23-08-2023	31	27	92	83	7	SSE	0.6
24-08-2023	35	26	92	71	3	SWW	0.2
25-08-2023	35	27	92	64	3	W	0.4
26-08-2023	33	24	92	66	5	NNW	0
27-08-2023	34	25	93	61	6	NEE	0
28-08-2023	29	20	92	70	5	SSW	11
29-08-2023	33	28	92	64	3	NW	0
30-08-2023	35	30	91	62	4	WS	0
31-08-2023	34	30	90	70	4	WS	0

01-09-2023	35	26	92	59	6.5	NNW	0.2
02-09-2023	35	26	92	64	7.6	N	0
03-09-2023	34	26	92	65	7.6	N	0
04-09-2023	34	25	93	61	6.8	NWW	0
05-09-2023	34	25	90	64	4.7	NEE	0
06-09-2023	35	24	92	55	4.7	NNE	0
07-09-2023	36	24	93	59	3	NEE	0
08-09-2023	36	26	93	58	3.6	NWW	0
09-09-2023	34	24	91	64	6	N	0
10-09-2023	33	25	90	69	4	NWW	0
11-09-2023	33	25	88	67	4	NWW	0
12-09-2023	34	26	92	68	3.6	NNW	0
13-09-2023	35	27	92	68	5.4	N	0
14-09-2023	37	28	91	71	3.2	NNW	0
15-09-2023	34	26	92	83	5.76	NWW	2.4
16-09-2023	34	25	92	64	4	SWW	1.6
17-09-2023	29	24	91	83	3.24	NNW	3
18-09-2023	31	24	91	73	5.04	NEE	5.7
19-09-2023	27	24	90	84	3.24	NEE	7.2
20-09-2023	35	24	93	54	3.6	NNW	0.6
21-09-2023	35	25	93	65	5.4	NNW	0.2
22-09-2023	34	25	93	68	1.44	SWW	0
23-09-2023	31	22	93	71	5.76	N	0.4
24-09-2023	33	22	93	70	4.32	SWW	1
25-09-2023	33	22	94	59	2.16	NNW	1
26-09-2023	34	22	93	61	3.24	NNW	0
27-09-2023	33	21	93	59	6.12	NEE	0
28-09-2023	34	20	93	66	3.6	N	0
29-09-2023	35	20	93	52	3.96	NEE	0
30-09-2023	34	21	92	55	7.2	NEE	0
01-10-2023	33.59	18.10	92.72	42.7	4.32	N	0.4
02-10-2023	33.31	17.22	92.39	43.53	5.4	NNW	0
03-10-2023	33.20	17.43	92.44	49.8	7.92	NNW	0
04-10-2023	34.02	17.61	92.53	48.75	6.12	NNE	0.2
05-10-2023	34.03	17.42	92.38	51.33	5.76	NWW	0.2
06-10-2023	33.58	18.23	92.89	52.6	5.76	NWW	0
07-10-2023	34.82	18.51	92.25	50.64	5.04	NWW	0.2

08-10-2023	34.66	20.49	90.39	54.09	3.96	NNW	0
09-10-2023	34.13	21.68	92.19	58.31	2.52	NNW	0
10-10-2023	30.53	19.58	91.5	56.88	6.48	NEE	6.6
11-10-2023	31.30	16.94	91.07	50	4.68	SEE	0.2
12-10-2023	32.51	16.32	92.81	45.53	4.32	NNE	0
13-10-2023	32.48	16.75	93.25	50.4	2.88	NNW	0.2
14-10-2023	30.67	19.17	92	57.28	6.48	NEE	0
15-10-2023	29.34	17.93	91.52	51.45	3.24	SWW	2
16-10-2023	25.87	18.62	92.1	58.99	7.92	SSE	0.4
17-10-2023	25.22	17.08	90.24	59.57	6.12	NEE	0.2
18-10-2023	28.13	14.74	91.24	50.47	5.76	NNW	0.4
19-10-2023	28.31	13.12	92.79	51.68	5.04	NNW	0.8
20-10-2023	30.32	13.38	93.42	48.6	2.88	N	0
21-10-2023	30.15	13.32	92.76	44.61	3.6	N	0.4
22-10-2023	29.13	16.11	92.75	55.81	5.4	NEE	0.4
23-10-2023	29.82	14.92	92.25	45.50	6.84	NNE	0
24-10-2023	30.52	13.56	92.70	49.10	4.32	NNW	0
25-10-2023	30.34	13.33	92.37	43.76	6.12	NNW	0
26-10-2023	31.16	12.36	92.95	35.87	6.12	NNW	0
27-10-2023	30.85	11.82	92.23	45.13	4.32	NNE	0
28-10-2023	30.10	13.84	92.86	54.22	4.68	NNW	0
29-10-2023	30.52	15.66	93.55	50.89	2.16	NNW	1
30-10-2023	30.96	14.16	93.61	39.86	3.24	NNE	0
31-10-2023	31.12	13.97	93.17	43.85	2.52	NWW	0
01-11-2023	30.4	14.5	92.7	48.7	2.88	NEE	0
02-11-2023	31.3	13.3	94.0	45.8	3.24	NWW	0
03-11-2023	28.6	14.0	93.7	50.0	5.04	NNW	0
04-11-2023	29.0	13.4	93.3	47.6	4.68	NNE	0
05-11-2023	29.7	11.3	94.0	40.4	6.48	NNE	0
06-11-2023	29.6	11.8	92.7	49.1	3.24	NNE	0
07-11-2023	28.2	12.9	93.3	53.1	5.04	NNE	0
08-11-2023	29.0	13.9	92.2	47.0	4.32	NNE	0
09-11-2023	29.1	13.6	93.2	47.2	4.32	NNE	0.6
10-11-2023	19.0	15.9	86.8	82.0	9	NEE	0.4
11-11-2023	23.8	11.3	92.4	59.0	6.12	NNE	0
12-11-2023	25.7	10.7	94.3	54.0	7.92	NNE	0
13-11-2023	27.6	10.0	94.6	62.2	2.52	NNW	0

14-11-2023	26.6	9.8	93.5	50.3	6.12	NNE	0
15-11-2023	27.2	10.6	93.6	48.3	6.48	NNE	0
16-11-2023	27.1	10.2	93.8	49.3	4.32	NEE	0
17-11-2023	27.9	9.9	93.6	42.3	5.4	NNE	0
18-11-2023	27.7	9.1	93.4	43.0	2.52	NEE	0
19-11-2023	28.1	8.4	93.6	44.7	1.8	SSW	0
20-11-2023	26.8	11.6	92.6	57.0	3.6	NNE	0
21-11-2023	25.77	19.15	93.23	45.07	8.64	NNE	0
22-11-2023	25.46	8.76	92.39	44.05	7.2	NNW	0.2
23-11-2023	26.7	7.38	92.48	40.96	3.24	SSW	0.2
24-11-2023	25.67	6.45	92.7	47.58	6.12	NNE	0
25-11-2023	24.84	7.55	94.78	49.2	2.88	NNE	0
26-11-2023	24.45	10.92	92.05	49.6	2.88	SSW	0
27-11-2023	21	11.65	91.6	69.72	2.52	SSE	0
28-11-2023	25.97	10.71	92.84	51.16	6.12	NNE	0
29-11-2023	26.9	11.39	92.69	50.23	3.6	SWW	0
30-11-2023	19.1	14.59	87.05	82.58	7.2	SSE	6.6
01-12-2023	22.7	10.1	91.2	59.7	6.48	NNE	0.2
02-12-2023	24.5	8.85	93.5	55.08	2.88	NNE	0
03-12-2023	24.28	8.67	93.6	61.8	1.8	SSW	0
04-12-2023	23.5	10.3	94.7	55.3	3.24	NNW	0
05-12-2023	23.04	9.52	95.15	54.7	5.76	NNE	0
06-12-2023	24.18	7.55	95.3	45.9	6.12	NEE	0
07-12-2023	23.8	8.97	94.27	42.8	6.84	NNE	0
08-12-2023	23.48	5.78	94.15	47.58	2.88	WNW	0
09-12-2023	22.57	5	95.17	59.13	5.76	N	0
10-12-2023	21.88	5.38	94.08	46.88	7.92	NNW	0
11-12-2023	23.11	5.33	93.58	52.6	2.52	WNW	0
12-12-2023	22.19	5.04	94.16	57.34	1.8	ESE	0
13-12-2023	22.26	3.47	94.15	37.47	3.6	NW	0
14-12-2023	22.16	4.1	93.48	50.03	6.48	NNW	0
15-12-2023	21.47	5.2	94.3	55.48	1.08	NNW	0
16-12-2023	21.1	2.68	93.88	51.66	2.88	NNW	0
17-12-2023	20.81	5.97	93.87	55.72	5.4	NNW	0
18-12-2023	20.63	4.03	94.57	55.87	7.2	NNE	0
19-12-2023	20.96	2.73	95.62	50	6.84	NNE	0
20-12-2023	22.81	2.46	94.45	52.83	1.08	NNW	0

21-12-2023	20.71	2.72	93.92	52.85	3.6	N	0
22-12-2023	19.45	3.54	95.03	68.31	2.52	SSW	0
23-12-2023	23.23	8.89	92.34	54.06	2.88	SW	0
24-12-2023	22.9	5.66	93.66	67.12	3.6	NEE	0
25-12-2023	19.75	5.96	95.21	65.54	5.4	NW	0
26-12-2023	18.71	6.31	96.01	79.36	1.44	SW	0.4
27-12-2023	20.2	6.56	95.87	72.15	1.56	SW	0
28-12-2023	21	7.6	94.3	68.9	2.5	SSW	0
29-12-2023	17.4	9.8	95	66	2.3	NW	0
30-12-2023	12.6	8.5	90	70	2.1	NNW	0
31-12-2023	11.4	9.2	94	76	2.5	NW	0
01-01-2024	15.0	8.0	97	82	2	NNE	0
02-01-2024	14.0	7.0	91	81	3	NNE	0
03-01-2024	14.0	7.0	95	90	2.3	N	0
04-01-2024	11.2	4.0	96	89	3.2	NNE	0.2
05-01-2024	11.0	6.8	96	88	2.8	NNE	0
06-01-2024	10.6	7.4	95	88	5	NNE	0
07-01-2024	11.0	5.9	95	83	3.24	N	0
08-01-2024	9.7	5.9	95	85	1.44	SW	0
09-01-2024	11.4	7.7	92	80	1.44	NE	0
10-01-2024	12.0	7.0	95	79	5	NW	0
11-01-2024	11.7	6.7	92	76	3.24	NNE	0
12-01-2024	12.5	5.2	95	75	3.2	NW	0
13-01-2024	13.0	7.0	95	75	2.52	SW	0
14-01-2024	12.0	5.5	96	78	3.6	SE	0
15-01-2024	10.0	4.0	96	83	3.96	NW	0
16-01-2024	15.0	5.0	96	71	1.08	NW	0
17-01-2024	17.0	3.0	96	72	1.8	SW	0
18-01-2024	16.0	4.0	97	79	4.32	NW	0
19-01-2024	10.0	7.0	97	88	3.24	SW	0
20-01-2024	13.0	9.0	89	77	2.88	NNW	0
21-01-2024	11.0	7.0	91	82	5.04	NE	0
22-01-2024	10.0	7.0	91	86	3.6	SE	0
23-01-2024	13.0	7.0	90	84	3.6	NE	0
24-01-2024	10.0	6.0	95	88	3.6	SE	0
25-01-2024	14.0	6.0	94	74	4.6	NNW	0
26-01-2024	19.0	3.0	95	62	6	NE	0

27-01-2024	14.0	4.0	96	60	7	NW	0
28-01-2024	19.0	6.0	94	71	6	SW	0
29-01-2024	22.0	8.0	95	75	2.5	NE	0
30-01-2024	19.0	7.0	96	71	4.3	NNW	0
31-01-2024	19.0	11.0	95	73	7.5	SE	2.2
01-02-2024	15.0	10.0	94	89	6.8	SSE	5
02-02-2024	18.0	8.0	94	56	8.2	NE	1.6
03-02-2024	18.0	8.0	87	63	3.6	NE	0
04-02-2024	13.0	11.0	93	83	2.5	SE	0.6
05-02-2024	18.0	8.0	95	77	2	SE	0
06-02-2024	18.7	3.4	94	50	10.08	NNE	0
07-02-2024	18.2	2.2	93	59	4.68	NEE	0
08-02-2024	19.1	2.2	94	51	8.64	NNE	0
09-02-2024	22.3	2.0	92	45	3.6	NWW	0
10-02-2024	22.0	3.6	92	54	3.6	SEE	0
11-02-2024	23.3	2.9	94	44	4.68	NEE	0
12-02-2024	22.2	3.9	94	61	1.44	SSE	0
13-02-2024	24.1	7.3	95	49	2.16	NWW	0
14-02-2024	23.8	5.2	93	42	7.2	NNE	0
15-02-2024	24.0	4.9	94	47	4.32	NNE	0
16-02-2024	24.4	4.0	94	44	5.04	NNW	0
17-02-2024	24.1	6.4	93	58	6.48	NNW	0
18-02-2024	20.6	7.2	94	78	3.96	SSE	0
19-02-2024	23.7	15.5	81	56	20.88	SSW	0
20-02-2024	23.8	14.2	85	67	17.28	SWW	1
21-02-2024	22.2	6.5	95	47	7.56	NNE	0
22-02-2024	22.3	4.5	95	47	8.29	NEE	0
23-02-2024	22.5	3.5	91	32	6.84	NNW	0
24-02-2024	22.5	4.5	89	41	4.32	NEE	0
25-02-2024	23.0	4.2	89	40	5.4	NEE	0
26-02-2024	24.2	4.3	93	34	7.2	NEE	0
27-02-2024	22.0	11.3	81	56	7.2	NEE	0
28-02-2024	23.1	5.7	93	50	9.36	NNE	0
29-02-2024	25.5	6.4	94	44	5.4	NNE	0
01-03-2024	22.6	12.45	83	59	7.56	SEE	22
02-03-2024	22.75	15.79	85	75	17.64	SWW	42
03-03-2024	19.85	7.75	89	55	10.44	SWW	0

04-03-2024	19.79	4.75	92	46	6.12	NNW	0
05-03-2024	18.33	5.76	92	61	7.2	NNE	0
06-03-2024	21.67	4.59	93	57	5.76	NNW	0
07-03-2024	23.81	7.35	92	47	4.68	NNE	0
08-03-2024	23.81	6.72	93	64	6.12	NNW	0
09-03-2024	25.34	6.86	92	43	7.92	NNW	0
10-03-2024	23.81	9	93	64	4.68	NNW	0
11-03-2024	25.76	12.34	84	52	5.4	NNW	0
12-03-2024	26.25	11.29	92	54	5.76	NW	0
13-03-2024	23.05	11.77	91	95	6.48	SWW	0
14-03-2024	26.21	9.06	94	52	9.36	NNE	0
15-03-2024	26.78	7.69	87	45	7.92	NNE	0
16-03-2024	27.97	6.59	94	36	6.48	NNW	0
17-03-2024	28.1	7.85	92	37	4.32	NNW	0
18-03-2024	29.67	8.36	93	51	4.68	NNW	0
19-03-2024	29.67	9.89	92	40	4.68	NNW	0
20-03-2024	29.81	11.56	94	57	7.56	NNW	0
21-03-2024	26.55	14.77	91	61	12.6	SWW	0
22-03-2024	30.32	17.68	84	54	6.48	SEE	0
23-03-2024	30.56	13.35	94	42	7.56	NNW	0
24-03-2024	29.85	14.57	92	48	5.04	NNW	0
25-03-2024	31.19	14.46	93	44	7.92	NNE	0
26-03-2024	29.09	13.67	92	56	3.6	NNW	0
27-03-2024	31.19	19.02	86	54	6.84	NNE	0
28-03-2024	30.78	17.13	86	48	5.4	NNW	0
29-03-2024	33.99	17	85	41	3.24	NNW	0
30-03-2024	31.36	17.52	88	60	9.72	EES	14
31-03-2024	28.99	17.06	81	70	8.64	NNW	0
01-04-2024	28.39	14.04	92.15	36.35	8	EES	0
02-04-2024	30.33	11.94	92.29	40.04	7	NEE	0
03-04-2024	32.48	13.46	90.17	37.2	6	NWW	0
04-04-2024	33.9	15.02	88.13	27.33	6	NWW	0
05-04-2024	33.22	13.19	89.41	28.54	8	NNW	0
06-04-2024	32.62	12.08	90.74	26.89	9	NNW	0
07-04-2024	33.45	11.57	92.03	34.97	9	NNW	0
08-04-2024	34.04	12.68	90.05	36.31	8	NNW	0
09-04-2024	35.3	12.85	88.42	26.73	6	NNW	0

10-04-2024	36.01	14.02	88.23	26.21	4	SSE	0
11-04-2024	34.66	18.68	57.63	26.89	7	SEE	0
12-04-2024	36.92	14.92	80.38	26.49	4	NNE	0
13-04-2024	32.24	17.54	75	40.62	5	NWW	0
14-04-2024	30.17	17.89	79.57	48.68	10	SSE	0.1
15-04-2024	33.79	19.29	83.94	44.79	3	SSW	0.5
16-04-2024	33.08	17.02	92.03	36.62	12	NNE	0
17-04-2024	34.14	13.43	89.54	27.87	10	NNW	0
18-04-2024	36.41	16.86	83.24	28.68	5	NNE	0
19-04-2024	36.7	21.5	92.5	28.9	14	SW	28.6
20-04-2024	32.7	17	88.6	27.5	7	NNW	7.2
21-04-2024	34.4	17.9	85.9	33.4	7	NE	0
22-04-2024	34.7	17.2	87.7	24.6	4	S	0
23-04-2024	33.8	17.9	71	39.2	5	NE	0
24-04-2024	35.7	16.7	78.6	30.5	2	NE	3.8
25-04-2024	37.2	17.6	81.4	23.3	2	NE	0
26-04-2024	39.8	17.5	83.9	18.3	0	S	0
27-04-2024	32.2	19.8	80	40.8	0	E	0
28-04-2024	35.6	16.8	81.2	26.3	0	EES	0
29-04-2024	26.8	15	83.9	66.6	2	E	0
30-04-2024	33.2	14.7	84.8	26.6	6	NW	5.3
23-04-2024	33.8	17.9	71	39.2	5	NE	0
24-04-2024	35.7	16.7	78.6	30.5	2	NE	3.8
25-04-2024	37.2	17.6	81.4	23.3	2	NE	0
26-04-2024	39.8	17.5	83.9	18.3	0	S	0
27-04-2024	32.2	19.8	80	40.8	0	E	0
28-04-2024	35.6	16.8	81.2	26.3	0	EES	0
29-04-2024	26.8	15	83.9	66.6	2	E	0
30-04-2024	33.2	14.7	84.8	26.6	6	NW	5.3

Research Publication Details

i) Publication in Journals

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	Russian Journal of Earth Science	Impact of Nano fertilizer and Nutrient Management on Growth and Yield of Strawberry	Vol. 23 Issue 5 Page:1-9	1681-1208 SJR: 0.244	Yes	68880
2	Scopus	Published	Research	Journal of Food Chemistry & Nanotechnology	Performance of NanoZinc Oxide and Iron Oxide on Growth, Flowering and Yield of Strawberry (*Fragaria* × *ananassa* Duch) cv. Winter Dawn	Vol. 9 Issue 1 Page: S277-S284	2471-4291 SJR: 0.217	Yes	65309
3	Scopus	Published	Research	Eurasian Journal of Soil Science	Efficacy of nano zinc oxide and iron oxide formulations on shelf life of strawberry	Vol 13 Issue 3 Page: 254-262	2147-4249 SJR: 0.314	Yes	69302

ii) IPR Details

S. No.	Type of IPR (Patent/copyright/ Design/ Trademark)	IPR Number	Title	Log Request ID on UMS
1	Copyright	-	Performance at Different Concentrations of Nano-Zinc Oxide (ZnO) and Iron Oxide (FeO) on Growth, Flowering and Yield of Strawberry (*Fragaria* × *ananassa* Duch) cv. Winter Dawn	10402
2	Copyright	-	Effect of Nano- ZnO and FeO on Growth, Flowering and Yield of Strawberry (Fragaria × ananassa Duch.)	10437