EFFECT OF NANO UREA IN COMBINATION WITH *AZOTOBACTER* ON GROWTH, YIELD AND QUALITY OF STRAWBERRY (*Fragaria x ananassa* Dutch.) Cv. WINTER DAWN

Thesis Submitted for the Award of the Degree

DOCTOR OF PHILOSOPHY

In

Fruit Science

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2024

DECLARATION

I hereby declare that the presented work in the thesis entitled "**Effect of nano urea in combination with *Azotobacter* on growth, yield and quality of strawberry (*Fragaria x ananassa* Dutch.) cv. Winter Dawn**" in fulfilment of degree of **Doctor of Philosophy (Ph.D.)** is outcome of research work carried out by me under the supervision of Dr. Manish Bakshi, working as Associate Professor, in the Department of Horticulture, School of Agriculture at 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 investigators. 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 urea in combination with *Azotobacter* on growth, yield and quality of strawberry (*Fragaria x ananassa* Dutch.) cv. Winter Dawn**" 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 Ms. Shaifali, 12109836, 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 urea in combination with *Azotobacter* on growth, yield and quality of strawberry (*Fragaria x ananassa* Dutch.) cv. Winter Dawn**" submitted by Shaifali (Registration No. 12109836) 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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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
L-1:	per liter
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
Zn :	Zinc
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 urea in combination with *Azotobacter* on growth, yield and quality of strawberry (*Fragaria* x *ananassa* Dutch.) cv. Winter Dawn.

Abstract:

This study investigates the synergistic effects of nano urea and *Azotobacter* application on the agronomic and qualitative traits of strawberry cv. Winter Dawn. Through a series of controlled experiments, it was demonstrated that the combined application of these treatments significantly enhances both vegetative growth and fruit development while improving soil and plant nutrient profiles. Among the various treatment regimens evaluated, T_9, which comprised 25% of the recommended dose of fertilizers augmented with 400 ppm nano urea and *Azotobacter*, emerged as the most effective in promoting vegetative growth indices and yield-related attributes. Furthermore, treatments T_9 and T_{11} (50% RDF + N_2 + *Azotobacter*) significantly enhanced critical quality indicators such as titratable acidity, total soluble solids, ascorbic acid content, and antioxidant capacities. The utilization of nano urea was found to enhance nutrient uptake in the strawberry plants, as evidenced by the analysis of leaf and soil nutrient contents. These findings underscore the efficacy of nano urea and *Azotobacter* as potent agronomic amendments in strawberry cultivation, promising not only improved agricultural productivity but also fruit of superior nutritional quality. Maximum growth *viz*. plant height (12.66 cm), plant spread (NS 22.58 cm and EW 22.26 cm), number of flowers (2.35 at 120 DAP), number of leaves (17.78), total number of fruits per plant (30.69), average fruit weight (20.74 g), average yield per plant (0.634kg) were recorded with the application of 400 ppm nano urea and *Azotobacter* along with 25 per cent recommended dose of fertilizers (RDF). This treatment also resulted in highest TSS (6.95° brix), ascorbic acid content (55.83 mg per 100g), total sugars (8.90 %) reducing sugars (7.23%), non-reducing sugar (1.58%) and anthocyanin content (0.275 mg/ g fresh tissue), plant nitrogen (2.49 per cent). However, application of 400 ppm nano urea and *Azotobacter* along with 50 per cent RDF resulted in maximum antioxidant content (1.89 μ mol TE/g FW), 400 ppm nano urea along with 25 per cent RDF reflected organic carbon (3.90 g/ kg), treatment control (100% RDF) showed maximum soil nitrogen (228.38 kg ha^{-1}) and T_{14} (25% RDF + *Azotobacter*) had maximum presence of *Azotobacter* count (11.75 CFU 10^{6}). Qualitative and biochemical parameters showed consistent correlations, endorsing the use of urea nanoparticles as a viable nitrogen source. This supports the exploration of alternative nitrogen fertilization approaches, aiming for refined dosage ratios to foster environmentally friendly and sustainable strawberry cultivation practices. These findings provide robust evidence for the efficacy of urea nanoparticles as a nitrogen source, enabling the formulation of alternative fertilization strategies. This approach, focusing on optimizing dosage ratios, holds significant promise for ecologically sound and contemporary strawberry cultivation methods.

Keywords: *Azotobacter, nano urea, growth, yield, quality, nutrient analysis strawberry and Winter Dawn.*

Chapter I

Introduction

The history of strawberries traces back to ancient times, with evidence suggesting their cultivation as early as the ancient Romans and Greeks (Giesecke, 2023). Native to Europe (Zhou *et. al.* 2023), strawberries were initially cultivated for their medicinal properties rather than as a culinary delight (Newerli-Guz *et. al.* 2023). In the 14th century, they gained popularity in France when they were presented as a gift to French kings (Dickenson, 2020). The modern cultivated strawberry, *Fragaria × ananassa* (Vondracek *et. al.* 2024), is a hybrid of two wild strawberry species from North and South America (Fan and Whitaker, 2024). Its development began in the 18th century in Europe and gained momentum in the 19th century with the introduction of new varieties and cultivation techniques (Stearns *et. al.* 2024). Today, strawberries are one of the most beloved and widely consumed fruits worldwide (Bezerra *et. al.* 2024), celebrated for their sweet flavour (Do *et. al.* 2024), vibrant colour (Shahida and Swarup, 2024), and nutritional benefits (Hurtado, 2024). Their rich historical legacy continues to inspire research in areas such as breeding, genetics, and agricultural practices, ensuring the enduring relevance of this iconic fruit (Kumar and Konyak, 2024).

Strawberry (*Fragaria × ananassa* Duch.) is considered as one of the most paramount exotic fruits globally. It's a small fruit plant from the family Rosaceace, which also includes numerous economical species like roses which are ornamental or edible fruits like apple, peach, pear etc. Strawberry is a perennial herbaceous plant, and it is said to be the native of North America, since it is grown in Europe, Asia, America and Africa (Habeeb and Ali, 2013). The name of strawberry "fragrant" and "fragrance" is derived from the Latin and so it is called Strawberry in English, "Fragola" in Italian, "Fraise" in French, in Egypt, the name was derived from "Chillaik" called in Iraq and Syria, which was taken from Turkey as "Chillaik" (Al-Saidi, 2000).

Strawberry crop is known to be an early production fruit crop and is also grown as a cash crop. The strawberry fruits are proven to be effective against the cardiovascular and vascular diseases, also in cancerous diseases due to the presence of high number of substances which are effective inhibitors against these diseases (Al-Khayri *et. al.* 2018).

Strawberry has been reported to contain the antioxidants and anthocyanin pigment which gives the fruit its characteristic red colour. It even has distinctive flavour and taste which is utilized in food industries for preparation of various processed goods like Jelly, juices, jams etc. The peculiar aroma and fragrance of strawberry makes it a choicest fruit for preparation of ice creams and pastries or dairy products (Giampiri *et. al.* 2014). Cultivation of strawberry was initially introduced to Iraq and was planted in home gardens during the year 1946 to 1951 (Al-Saidi, 2000). The allure of strawberries among consumers is primarily attributed to their unparalleled taste, a sensory symphony orchestrated by a fusion of mouth-watering flavours and aromatic notes (Civille *et. al.* 2021). This sensory experience encompasses not only the tactile sensations perceived in the mouth, such as sweetness, acidity, and juiciness but also the olfactory delight elicited by volatile compounds. Throughout the ripening process, fruits emit an array of volatile organic compounds (VOCs), serving as tangible indicators of their maturation. The content and composition of these molecules reflect both genetic traits and environmental influences, exhibiting a rich tapestry of diversity (Maffei *et. al.* 2010). Research indicates that strawberries possess remarkable adaptability, flourishing across a spectrum of environments and soil types, showcasing their resilience and versatility in agricultural landscapes (Gordon *et. al.* 2010).

In the vibrant patchwork of agricultural landscapes, the cultivation of strawberries emerges as a fragrant emblem of horticultural prowess (Salsedo, 2008). Delving into the verdant depths of this berry domain, one uncovers a tapestry woven with statistical intricacy Brooks, 2022). The expanse of land dedicated to strawberries unfurls like a verdant quilt, spanning vast hectares across diverse continents (Retzinger, 1992). Concurrently, the annual production figures paint a picture of abundance, each berry a testament to meticulous cultivation practices and the harmonious dance of soil, sun, and water.

Strawberry fruits are highly rich with significant minerals and vitamins. Within the nutritional realm, strawberries stand as veritable treasure troves, boasting abundant reserves of Vitamin C that surpass other vitamin counterparts. The gustatory allure of these berries unfolds through a trifecta of flavor components: sugars, acids, and aromatic compounds, each lending its distinct note to the sensory symphony. Among the orchestra of volatile compounds responsible for the fruit's signature taste, ethyl esters, including ethyl hexanoate and ethyl butanoate, emerge as prominent conductors. Exploring the botanical intricacies, one unearths the presence of ellagic acid, a potent plant phenol revered for its anti-mutagenic and anti-carcinogenic properties, nestled within the leaf tissues and ruby-red achenes of the strawberry fruit. Due to presence of more oleic acid and less linoleic acid, ripe fruit contains more lipids than unripe fruits (Chattopadhyay, 2014). In the comparison to other fragile berry fruits, strawberry fruits are having higher content of vitamin C, flavonoids and phenolic (Torronen and Hakkinen, 2000).

Due to new technologies and varieties, strawberries are available in the market throughout the year. They can be produced using many different cultivation systems. The goal of all production technologies is a high yield with good properties and flavour. Nowadays, high yield and adequate fruit quality are often the result of intense inputs like chemical fertilization, use of growth promoters, LED lamps, plant protection, and optimal irrigation (Weber *et. al.* 2016 and Ojeda-Real *et. al.*2009). With less intensive organic production, it is also possible to achieve the same or even better strawberry quality (Reganold *et. al.* 2010), with little or no loss of yield. Consumers prefer strawberries with a uniform colour, sweet taste, intense fruity aroma and that will be moderately juicy (Ponti *et. al.* 2012 and Bhat *et. al.* 2015). Most of these characteristics can be regulated with attentive fertilization (Ojeda-Real *et. al.* 2009).

Given its esteemed status among consumers, aroma stands as a paramount attribute defining the appeal of strawberries. In shaping consumer acceptance, volatile flavour compounds wield significant influence, serving as the architects of the fruit's sensory allure. The volatile repertoire of strawberries encompasses a staggering array of over 360 constituents, spanning esters, aldehydes, ketones, alcohols, terpenes, furanones, and sulphur compounds, rendering it one of the most intricate and multifaceted fruit flavours known (Jetti *et. al.* 2007). Despite the complexity, many of these compounds are present in trace amounts that challenge conventional analytical methods, yet their impact on sensory perception remains discernible to human senses, underscoring the nuanced interplay between analytical precision and sensory acuity in fruit evaluation (Goff and Klee, 2006).

The intricate tapestry of aroma compounds within strawberries orchestrates a symphony of flavours (Jetti *et. al.* 2007), where a select few, numbering fewer than 20, stand as significant contributors to the fruit's distinctive taste profile. Among these aromatic virtuosos, furanones reign supreme, imbuing strawberries with their characteristic caramel-like sweetness and fruity essence (Jetti *et. al.* 2007). Constituting the lion's share of volatile compounds, esters emerge as pivotal players in shaping the strawberry's aromatic bouquet, evoking notes of delectably sweet fruitiness. Following closely behind, terpenoids assert their presence, comprising a substantial portion of the volatile ensemble in select strawberry varieties, thus adding another layer of complexity to the fruit's aromatic allure (Jetti *et. al.* 2007). This intricate interplay underscores the multifaceted nature of strawberry aroma, where a delicate balance of key compounds orchestrates a sensory experience cherished by consumers worldwide (Menager, *et. al.* 2004).

Terpenoids, exemplified by linalool (Jetti *et. al.* 2007), nerolidol, and terpineol, lend a distinctive character to strawberries with their spicy and citrusy notes, a feature often intricately tied to specific strawberry varieties. Conversely, compounds like hexenal, trans-2-hexenal, and cis-3-hexenal, while equally significant, contribute unwelcome green and underripe nuances to the fruit's flavour profile (Jetti *et. al.* 2007). Beyond aroma, the holistic nutritional value of strawberries emerges as a cornerstone, underscored by their abundant reserves of essential nutrients such as vitamin C and phenolic compounds. These primary and secondary metabolites, including sugars, organic acids, and phenolic, not only sustain the plant's vitality but also play a crucial role in enhancing human health and well-being. Moreover, studies indicate that fertilization practices exert a discernible influence on the phenolic content of strawberries (Giampieri *et. al.* 2012)., further underscoring the intricate interplay between agricultural practices and nutritional quality in strawberry production (Anttonen *et. al.* 2006).

In adherence to government recommendations, strawberry producers have embraced advanced agricultural technologies, notably fertilizing with nitrogen at the onset of the growing season, a practice aimed at optimizing yield potential (Mihelic *et. al.* 2010). The rapid growth cycle of strawberries, spanning a mere two to three months from inflorescence emergence to harvest, necessitates a robust supply of both macro and micronutrients to fuel photosynthesis and sustain fruit development (Gordon *et. al.* 2010; Taghavi *et. al.* 2014). Despite their shallow root system, strawberries face limitations in nitrogen uptake from deeper soil layers. Consequently, historical cultivation practices have often leaned towards intensive nitrogen fertilization, predicated on the belief that it fosters vigorous vegetative growth and enhances fruit yield. This synthesis of traditional wisdom and modern agricultural science underscores the dynamic evolution of strawberry cultivation techniques in pursuit of maximizing productivity while maintaining environmental sustainability (Guinto 2016).

Nitrogen stands as a vital element essential for the synthesis of enzymes and amino acids pivotal in constructing the cellular framework of plants, thus facilitating their growth and development (Leghari 2016). In strawberries, a deficiency of nitrogen, indicated by foliar nitrogen content below 1.9%, manifests in chlorotic leaves, diminished leaf area, reduced root mass, smaller fruit size, and decreased anthocyanin levels (Mareike Jezek *et. al.* 2018). Conversely, an excess of nitrogen, reflected in foliar nitrogen content exceeding 4%, fosters excessive vegetative growth, retards fruit maturation, and compromises fruit firmness, ultimately diminishing its overall quality. This delicate balance underscores the critical role of nitrogen management in optimizing strawberry growth, development, and fruit quality, thereby highlighting the intricate interplay between nutrient availability and plant physiology in agricultural practices (Guinto, 2016).

Elevated concentrations of nitrogen fertilization, particularly mineral nitrogen, have been observed to exert a pronounced adverse effect on the taste profile of strawberries, as highlighted by Ojeda-Real *et. al.* (2009). Beyond nitrogen, calcium emerges as another crucial macro-nutrient pivotal for optimizing fruit quality. Calcium ions play multifaceted roles in plant cell physiology, serving as integral intracellular messengers that facilitate responses to various stimuli including hormones, biotic and abiotic stressors, and developmental cues, as elucidated by Reddy and Reddy (2004). Additionally, calcium contributes significantly to the structural integrity of membranes and cell walls, thereby influencing fruit firmness. Pre-harvest applications of calcium have been demonstrated by Bakshi *et. al.* (2005) studied to enhance fruit firmness, underscoring the importance of calcium management in augmenting the overall quality of strawberries. This intricate interplay between nutrient management and fruit quality underscores the multifaceted approach required for optimizing strawberry cultivation practices.

Most of the macro nutrient demands of strawberry crop are met with the soil application of macro nutrients. Urea which is the major source of nitrogen and the most extensively applied chemical fertilizer in the crop is prone to leaching. Apart from polluting the rhizosphere area, it also contaminates the under-ground water and other water bodies leading to eutrophication. Also due to leaching, it becomes very imperative to precisely go for urea application at the most critical stages of the growth and development. This extensive application of nitrogenous and other chemical fertilizers is a burden for not only the soil but also to the farmer in particular and humanity as a whole. So, the new approach is to minimize the soil application of the chemical fertilizers and find out ways to compensate the nutrient requirement of the crops through alternative methods.

Nano-fertilizer technology is a new technological intervention and is very innovative, and there is only a small amount of reported literature in scientific journals. However, some reports and patented products strongly suggest that nano-fertilizer formulation has a lot of room for improvement. Foliar application of nano-particles as fertilizer has resulted in increased production (Raliya, 2012; Tarafdar, 2012). Now-a-days, a lot of nano formulations are available for macro and micro nutrients which can be applied in a more efficient manner to achieve an equitable desired result from the plant. However, the challenge is that being a new cultivation practice, the dosage of the formulations is yet to be standardized.

Bio-fertilizers represent a promising avenue for supplying essential nutrients to crop plants by bolstering soil microorganism populations while preserving the innate properties of the soil. This approach holds considerable potential in agricultural sustainability efforts, as bio-fertilizers aid in nutrient fixation, solubilisation, and accessibility for both macro and micronutrients. In lieu of relying solely on synthetic fertilizers, pesticides, and growth regulators, minimizing their use in favour of bio-fertilizers aligns with holistic soil health practices. Strategies such as crop rotations, integration of animal manures, cultivation of legumes and green manures, alongside mechanical cultivation and biological pest control, collectively contribute to maintaining soil vitality. Particularly, Plant Growth Promoting Bacteria (PGPB), a type of bio-fertilizer, emerges as a beneficial microorganism capable of enhancing plant growth by supplying essential nutrients. Studies by Esitken *et al.,* (2005) underscore the potential of PGPBs to augment both yield and quality in strawberries, thereby promoting environmental sustainability and soil productivity. This paradigm shift towards bio-fertilizers reflects a holistic approach to agricultural management that prioritizes both crop productivity and ecosystem health.

Bio-fertilizers play a pivotal role in enhancing soil nutrient quality, thereby influencing the productivity of strawberry crops. Plants foster beneficial relationships with these organisms, which contribute to their growth through various mechanisms. Notably, bio-fertilizers augment nutrient availability in the soil by fixing nitrogen biologically, mineralizing phosphorus and potassium, and releasing other essential plant nutrients. This nutrient enrichment reduces the reliance on nitrogenous and phosphate fertilizers, promoting sustainable agricultural practices. Additionally, microorganisms in bio-fertilizers release plant growth-stimulating hormones, promoting root and shoot elongation and thereby enhancing overall plant growth and crop yield. Furthermore, certain antagonistic microorganisms within bio-fertilizers mitigate the population and activity of phytopathogens, contributing to disease suppression in strawberry crops. Given the escalating costs of chemical fertilizers and the imperative to minimize environmental pollution, bio-fertilizers are increasingly recognized as valuable tools for improving soil fertility and achieving high-quality horticultural production, as underscored by Sindhu *et. al.* (2010). This growing emphasis on bio-fertilizers reflects a concerted effort to harmonize agricultural productivity with ecological sustainability.

Azotobacter stands as a crucial genus of free-living bacteria integral to fostering sustainable fruit crop production. Among the diverse array of free-living nitrogen-fixing bacteria, *Azotobacter* emerges as the subject of extensive investigation. Under controlled in vitro conditions, isolated cultures of *Azotobacter* demonstrate the capacity to fix approximately 10 milligrams of nitrogen per gram of carbon source. Despite its importance, the population of *Azotobacter* in the rhizosphere of crop plants tends to be relatively low. However, this organism has been documented in the rhizosphere of numerous fruit crops, where it derives sustenance from soil organic matter and root exudates while simultaneously fixing atmospheric nitrogen. Beyond nitrogen fixation, *Azotobacter* exhibits the ability to synthesize biologically active growth-promoting substances, including Indole Acetic Acid (IAA) and Gibberellic acid. When applied to strawberry plants, *Azotobacter* engages in non-symbiotic nitrogen fixation, thereby supplying the necessary nitrogen for optimal metabolic functioning and sustained growth. This multifaceted role underscores the significance of *Azotobacter* in enhancing fruit crop productivity while promoting ecological sustainability.

This study hypothesizes that the integration of bio-fertilizers, specifically Plant Growth Promoting Bacteria (PGPB) and nitrogen-fixing organisms like *Azotobacter*, will enhance the growth, yield, and quality of strawberries (*Fragaria* × *ananassa*) by improving soil nutrient availability, reducing the reliance on chemical fertilizers, and promoting environmental sustainability. Additionally, it is proposed that nano-fertilizer application can optimize nutrient uptake and fruit quality, offering a more efficient and sustainable alternative to conventional fertilization methods. The research will explore the synergistic effects of these innovative practices on strawberry cultivation, focusing on their impact on fruit nutritional content, flavor profile, and overall crop productivity.

Objectives:

In this context, a study was planned to study the effect of nano urea in combination with *Azotobacter* on growth, yield and quality of strawberry (*Fragaria* x *ananassa* Dutch.) cv. Winter Dawn with the following objectives:

1. To study the effect of nano urea in combination with *Azotobacter* on growth and yield of strawberry plants.
2. To study the effect of nano urea in combination with *Azotobacter* on the quality of strawberry fruits.
3. To evaluate the effect of nano urea in combination with *Azotobacter* on nutrient status (NPK) of the plant.
4. To evaluate the effect of nano urea in combination with *Azotobacter* on soil fertility status.
5. To workout the economics of different treatments.

Chapter II

Review of Literature

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

A. To study the effect of nano urea in combination with *Azotobacter* on growth and yield of strawberry plants.

Poniker *et. al.* (2006) observed that in turmeric use of NPK + *Azotobacter* + PSB (each at 250 g/kg seed) + FYM (10 t per ha) resulting in maximum of height related to the plant, number of leaves per plant, size in case of leaves and surface area related to leaves and number of tillers per plant with highest C:B ratio.

Saraswat *et. al.* (2006) evaluated the effects of NAA (naphthalene acetic acid) and zinc sulphate on various aspects of litchi cv. Calcuttia, including fruit set, fruit drop, cracking, fruit size, and yield. The findings clearly demonstrated that the treatment combination of NAA at a concentration of 20 parts per million (ppm) and $ZnSO_4$ at conc. of 0.6% resulted in highest no. of inflorescences/tree (414.00), fruit set/panicle (238.00), and fruit retention (7.43%).

Wassel *et. al.* (2007) investigated micronutrients and growth regulators impact on various parameters of cv. white banaty seedless grapes. Zn, Fe, and Mn led to significant improvements in various growth parameters. These included enhanced leaf area, increased cane thickness, higher pruning weight, heavier berry weight, and longer bunch length.

Singh *et. al.* (2007) discovered that application of a mixture containing zinc (0.5%), copper (0.4%), and NAA @10 ppm resulted in maximum fruit weight, 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, reducing sugars, non-reducing sugars, total sugars, total phenols, juice content, and fiber content.

Medhi *et. al.* (2007) found that ½ the recommended amount of NP, along with 20 grams of *Azotobacter* and 20 grams of PSB per plant/year, in addition to K at rate of 600grams/plant and 7.5 kg of mustard oil cake, led to significantly higher levels of TSS, total sugar, and vitamin C in citrus crops. Moreover, this treatment combination resulted in the highest yield and economic return (5.75).

Rasha *et. al.* (2008) studied that 80%N in nano form with recommended requirment+0.6% carbon nano tubes (CNTs) increased significantly leaf area, fresh and dry weight, total carbohydrate% and concentration of N, P, K, Mg, and Fe in leaves, weight of 100 berries, and juice weight of 100 berries compared with control. Also results showed that yield of combined application of 80% conventional fertilizer of nitrogen and nano-carbon at 0.6%was equal to that with supplied 100% conventional fertilizer (control). This indicated that the utilization rate of nitrogen fertilizer was increased after combined application of nano-carbon, which can save the N fertilizer amounts in production practice.

Dutta *et. al.* (2008) examined bio-fertilizers impact on papaya cv. Ranchi. Various treatments investigated, the combination of *Azotobacter,* Azospirillum, vesicular-arbuscular mycorrhizae (VAM), and 2 kg of farmyard manure (FYM) exhibited the highest plant height, width, and no. of fruits. The treatment consisting of *Azotobacter,* VAM, and 2 kg FYM also showed favorable growth characteristics. In contrast, the control group exhibited the least growth parameters. Furthermore, the treatment with *Azotobacter,* Azospirillum, VAM, and 2 kg FYM resulted in the highest fruit weight. The application of bio-fertilizers also influenced the bio-chemical constituents of the papaya fruit. The treatment with *Azotobacter,* Azospirillum, VAM, and 2 kg FYM recorded the highest levels of TSS, total sugars, and beta-carotene content, while exhibiting the lowest acidity.

Singh *et. al.* (2008) observed zinc @0.5%, copper @0.4%, and NAA @10 ppm resulted in the highest measurements of plant height, spread, and plant width in the Narendra Aonla-10 cultivar.

Jeyabaskaran and Pandey (2008) documented that the spray of zinc and boron through foliar mode yielded more favourable results in terms of increasing pseudostem girth (101 cm), total leaf count (35), leaf length (132.2 cm), and overall leaf area (14.6 m2) compared to the application of Zn and B through soil under high pH conditions.

Chauhan (2008) conducted an experiment where plum plants were treated with 80% of the RDF of NPK along with the supplementation of vermicompost @20 kilogram/tree. Additionally, biofertilizers consisting of 60 grams per tree each of VAM and *Azotobacter* were used. The results demonstrated increase in shoot extension growth and leaf area compared to other treatments.

Khan *et. al.* (2009) 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'. This treatment resulted in increased height of plant (6.5 cm), spread of plant (6.8 cm), and trunk girth (7.22 cm). Moreover, it led to maximum fruit retention (26.07%), as well as longer length of fruit (4.1 cm) and greater breadth of fruit (4.54 cm). The combined sprayalso 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, $ZnSO_4$ (0.5%) specifically resulted in high initial fruit set (75.05%) in the 'Narendra Aonla-6' cultivar.

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 ontotal yield.

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 fruit yield of 37.20 kg per plant and exhibited elevated levels of TSS, sugars, vitamin C, beta carotene, & high TSS: acid in papaya compared to the other treatments.

Chandra *et. al.* (2010) examined impact of secondary nutrients on yield and growth traits of Washington cv. of papaya were experimented. Research findings revealed that a combination of copper sulphate manganese sulphate and borax exerted a significant influence on various growth parameters. These parameters included plant height, plant girth, fruit length, fruit width, fruits, yield (40.40kg/tree), total sugar content (9.72%), vitamin C content (58.32 mg/100 g), and TSS at 9.60°Brix. Application of this specific combination of micronutrients played a vital role in enhancing the growth and yield characteristics of papaya plants, along with improving the nutritional composition of the fruits.

Rawat *et. al.* (2010) applied the foliar application of Zn, Cu, and B at different concentrations (0.2%, 0.3%, and 0.4%) both individually and in various combinations. The results indicated 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-49guava fruits. These findings highlight the specific benefits associated with the foliar application of zinc and boron, respectively, in enhancing the quality and nutritional composition of guava fruits.

Pilania *et. al.* (2010), concluded the application of NPK combined with vermicomposting @5kg mixed with the *Azotobacter* and Aspergillus found to be beneficialon guava plants. It was observed that this treatment led to maximum leaf area, measuring 57.19 cm^2, as well as the highest fruit set at 45.79% and fruit retention at 44.76%. Additionally, when 75% pruning intensity was applied along with 50 g NPK, 20 g NPK, and 50 g NPK combined with vermicompost enriched with *Azotobacter* +Aspergillus, the guava fruits exhibited the largest diameter. Furthermore, this treatment resulted in increased fruit weight at 158.06 g, pulp weight at 154.19 g, and pulp seed ratio at 39.93. Notably, the highest fruit yield and when NPK 50:20:50 g was combined with vermicompost @5 kg enriched with *Azotobacter* and Aspergillus niger, accompanied by a 50% pruning intensity. These findings highlight the effectiveness of this particular combination in promoting the growth and productivity of guava during the period 2007-08.

Patel *et. al.* (2010), revealed their study aimed to investigate the impact of secondary nutrients on banana. The findings revealed that the Zn application @0.5 per cent combined with Fe @0.5 per cent through foliar spraying resulted in several positive outcomes. The treatment showed significant improvements in various parameters, including maximum bunch weight at 23.85 kg, increased bunch length measuring 93.50 cm, and greater bunch girth reaching 114 cm. Additionally, this treatment led to a higher number of hands per bunch, averaging at 11.70, and an increased total yield of 149.078 tonnes per hectare for the Basrai banana cultivar. Notably, the Zn and Fe each applied at rate of 0.5 per cent also effectively enhanced the ascorbic acid content in the fruit, which reached 25 mg per 100 g of pulp. Furthermore, the treatment resulted in an elevated level of total soluble solids, measuring 22.03 °B, in the banana fruits. These findings highlight the positive effect of foliar feeding with micronutrients on the growth, yield, and nutritional quality of the Basrai banana variety.

Mitra *et. al.* (2010) studied how various organic substances, inorganic fertilizers, and biofertilizers influenced the fruit quality and yield of guava cv. Sardar. They concluded that application of NPK 50:40:50 gm/tree/year with the neem-cake in the quantity of5 kg/tree/year, resulted with the highest yield.

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 with 400 ppm SADH led to the highest 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.

Dayal *et. al.* (2010) investigated the impact of N, P, and Zn on the ber cultivar 'Gola' in arid and semi-arid conditions. The results indicated, Zn when applied at 0.6 percent recorded in the highest measurements for fruit length (3.13 cm), diameter of fruit (3.18 cm), fruit wt. (21.55 g), fruit volume (20.67 ml), and yield (38.05 kg/tree). Conversely, the control group exhibited the lowest values for these parameters.

Abdollahi *et. al.* (2010) noted rise in the vitamin C content in strawberries from 111.9 mg per 100 g in the control group to 123.3 mg per 100 g in the fruits treated with $ZnSO_4$ at a concentration of 200 mg per liter.

Mitra *et. al.* (2010) discovered that employing a combination of nutrients and organic matter resulted in the highest fruit setting on 'Sardar' guava trees under a HDP. Specifically, they applied 50 grams of nitrogen (N), 40 grams of phosphorus (P2O5), and 50 grams of potassium (K2O) per plant/year, along with FYM @10 kilograms and *Azotobacter* @20 kilograms per tree/year.

Yadav *et. al.* (2011) discovered that when utilizing recommended combination of NPK fertilizers, vermicompost, *Azotobacter,* phosphate-solubilizing bacteria (PSB), zinc (Zn), iron (Fe), and paclobutrazol on mango cv. Amrapali, significant improvements were observed in various parameters. The researchers noted a higher fruits per plant, increased yield, elevated total soluble solids (TSS) levels, and improved TSS: acid, enhanced vitaminC, higher carotenoid levels, augmented reducing sugars, non-reducing sugars content, elevated total sugar content, and reduced acidity. In terms of physical fruit characteristics, the recommended treatment resulted in a greater fruit set per panicle, longer fruit length, wider fruit width, higher fruit weight, increased pulp weight, heavier stone weight, and improved pulp: stone. These observations were consistent over the course of both years of experimentation.

Shukla (2011) investigated influence of Ca and B on the growth and quality of Aonla. The application of 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). Additionally, the combination of calcium carbonate and borax at 0.4% led to the high juice in fruits (78.5%) and 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%).

Pathak *et. al.* (2011) studied application of $FeSO_4$ @0.5% + $ZnSO_4$ @0.5% at 3rd, 5th, and 7th month after planting had notable effects on various parameters in banana cv. Martaman. 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 $FeSO_4$ (0.5%) was applied alone, significant improvements were observed in total soluble solids (25.53°B), reducing sugar content (6.57%), and total sugar content (17.24%) of the fruits.

Baviskar (2011) performed research on sapota plants during the year 2010-2011. Effects of various treatments on fruit yield and quality were studied. Among the various treatments tested, the trees treated with NPK 1125:750:375 g along with vermicompost

@15kg, *Azotobacter* @250g, and PSB (phosphate-solubilizing bacteria) @250 g per plant displayed the highest yield in terms of both harvested fruits/tree & the overall weight of fruit (kg/plant). Additionally, this particular treatment also resulted in superior fruit quality, as indicated by higher levels of TSS and sugars accompanied by low titratable acidity. Moreover, plants treated with this specific combination exhibited maximum fruit set, retention percentage, weight, and volume, size as well as peel and pulp weight compared to the other treatments.

Barne (2011) conducted an experimental study on guava during the period of 2010-
11. The aim was to find the impact of different treatments on various parameters of guava plants. The application of NPK (nitrogen, phosphorus, and potassium) with of FYM (50kg), 250g of *Azotobacter,* and 250 g of PSB (phosphate-solubilizing bacteria) per plant recorded highest fruit set and a significant reduction in fruit drop percentage. Additionally, this treatment led to increase in plant height, spread, & volume (measured in cubic meters). The same treatment also resulted in the more fruits and yield. Moreover, the fruits treated with this specific combination exhibited higher TSS, total sugar content, and lower acidity levels compared to control group.

Anees *et. al.* (2011) made an observation on iron, boron and zinc on mango fruit cv. Dashehari. The results indicated that this particular treatment resulted 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%. These findings were in comparison to the control group, suggesting the application of 0.4% iron, 0.8% boron and 0.8% zinc had positive impact on the quality attributes of mango.

Nitin *et. al.* (2012) demonstrated that $ZnSO_4$ at conc. of 0.6 per cent and H3BO3 at conc. of 0.5% on guava, both before & after 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.

Goswami *et. al.* (2012) studied the impact of calcium, B, and Zn on the physical and chemical traits and storage behaviour of guava fruits cv. L-49. The findings revealed that the foliar spray of zinc sulphate at a concentration of 0.4% resulted in the maximum fruit length, diameter, and volume. However, the maximum weight of fruit was observed when boric acid @0.4 per cent was applied. These results highlight the importance of these treatments in influencing the physical characteristics of guava fruits, providing valuable insights for fruit quality improvement and storage considerations.

Goswami *et. al.* (2012) conducted research from 2007 to 2009 to investigate the impact of bio fertilizers enriched in farmyard manure along with ½ RDF on 5 year old plants of guava cv. Pant Parbhat. The study aimed to assess the growth parameters of the plants under different treatments. The researchers found plants grown with a combination of recommended dose of fertilizers (NPK 250:195:150 gram) and FYM @50 kg enriched with Azospirillum @250 g/tree per year exhibited the highest increase in various growth parameters. Specifically, during the 2007-08 and 2008-09 seasons, this treatment resulted in the maximum increase in height of tree, tree spread, diameter of trunk, and volume of plant.

Godage (2012) conducted a study to find impact of various nutrient combinations and biofertilizer applications on various parameters of guava fruit. The researcher observed significant effects on different aspects of guava fruit quality and yield under different treatments. The treatment consisting of NPK 100:75:100, *Azotobacter* and PSB each at 5 ml per plant found to increase the TSS of guava fruits. On the other hand, the treatment with NPK 75:75:100, *Azotobacter* and PSB each at conc. of 5 ml per plant exhibited significant improvements in the no. of fruits, yield, retention, diameter, weight, and pulp wt. Additionally, the treatment with NPK 75:75:100, *Azotobacter* and PSB each at rate of 5 ml per plant resulted in highest height of plant, width of the primary branch, plant spread. These findings highlight the significance of nutrient combinations and bio fertilizer applications in enhancing guava fruit quality, yield, and tree growth parameters, providing valuable insightsfor optimizing guava cultivation practices.

Devi *et. al.* (2012) carried research on 4-year-old guava trees of the Sardar variety. The study aimed to assess the effects of different organic sources (FYM, neem cake and vermicompost) and various combinations of bio fertilizers (*Azotobacter*, PSB, Azospirillum, and Potash mobilizers) on guava fruit production. The results revealed that the treatment combining poultry manure, PSB, and Potash mobilizers resulted in the maximum fruit yield/plant, with an average of 623.3 fruits. Additionally, the combination of FYM, *Azotobacter,* PSB, and Potash mobilizers led to increased fruit weight. Based on the findings, it could be concluded that organic cultivation regarding guava by applying FYM @26 kg per tree with the *Azotobacter* @100 gm per plant, PSB @100 gm per plant, and Potash mobilizers @100 gm per plant is economically profitable. This research provides valuable insights into the use of organic sources and bio fertilizers for maximizing guava fruit production, promoting sustainable and economically viable cultivation practices for guava farmers.

Arvind *et. al.* (2012) out based response of potassium, boron, calcium and zinc on fruits of mango, it was found that trees sprayed 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. The findings indicated that the application of 0.5% borax through foliar spray resulted in the highest fruit yield in mango trees. 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.

Anees *et. al.* (2012) experimented impact of micronutrients: iron, boron, and zinc on mango trees of the Desehri variety. The study aimed to assess the effects of $FeSO_4$, H_3BO_3, and $ZnSO_4$ applied at 2 different stages. Findings of the study indicated that applied treatments resulted in reduced fruit acidity in comparison to the control group. Furthermore, treatments demonstrated a significant increase in TSS and vitamin C in mango fruits compared to the control group. These research results highlight the positive response of secondary nutrient application, specifically Fe, B, and Zn, on the quality of Desehri mangoes. The treatments effectively reduced fruit acidity and enhanced important attributes such asTSS and vitamin C content.

Modi *et. al.* (2012) conducted an investigation to find micronutrients impact on growth, quality & 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 height of plant, width of stem, no. of leaves, and the initiation of flower buds, resulting in a shorter time from fruit setting to first harvest. Furthermore, $ZnSO_4$ at a concentration of 0.5% and borax at a concentration of 0.5% yielded the highest fruit weight, fruit numbers, and overall yield of the papaya. In terms of quality, the different levels of $ZnSO_4$ and borax significantly influenced various quality parameters of papaya fruits, including ascorbic acid content, TSS, sugars content.

Mir *et. al.* (2012) findings indicated application of nutrients Zn, Mn, and B 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.

Khan *et. al.* (2012) revealed 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. Moreover, the leaf size was notably larger at 318 cm^2in the treated trees.

Hasani *et. al.* (2012) researched on impact of Zn on fruit yield and chemical traits of pomegranate. Zn applications were carried out twice, utilizing concentrations of 0%, 0.3%, and 0.6%. The effects of zinc were found to be significant in parameters such as juice content, total soluble solids, ratio of TSS/TA, and leaf area. Most suitable combination for these characteristics, given the prevailing conditions, was the spray of Zn at rate of 0.3%. Moreover, foliar spray of manganese and zinc demonstrated positive and significant effects on various fruit-related attributes, including fruit yield (8.1 kg/tree), weight of 100 arils (33.5 g), fruit diameter (8.20 cm), leaf area (592.4 mm^2), arils per peel ratio (1.88%), TSS (15.73°B), juice content of arils (68.2%), and anthocyanin index (0.328).

Singh *et. al.* (2012) findings revealed that vermicomposting application @ 5 t/ha along with *Azotobacter,* Azospirillum, and PSB, in combination with NPK, yielded the highest levels of total soluble solids (TSS) at 10.34 ^{o}brix and total sugars at 7.80% in strawberry fruits. The highest plant height and berry weight of strawberry was recorded under 100% NPK treatment followed by 50% NP (40: 8.8 kg/ha) having 100% K (33.2 kg^{-1}ha) along with *Azotobacter* and PSB also AMF.

Singh *et. al.* (2012), examined Zn application through $ZnSO_4$ at conc. of 0.6% demonstrated significant efficacy in promoting various fruit parameters of aonla cv. Banarasi. The treated fruits exhibited enhanced fruit weight, with an average of 48.64 g, as well as increased pulp weight at 46.46%. Additionally, the total yield per tree was notably improved, reaching 174.13 kg.

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, concentration ofboric acid (0.4%) resulted in greater fruit weight.

Sarrwy *et. al.* (2012) evaluated impact of foliar treatments involving B and Ca on fruit quality & yield of date palm. The results revealed that all treatments led to a significant increase in fruit length during the two seasons under study, compared to the control group. The highest fruit length, measuring 4 cm and 4.1 cm, was achieved by spraying a mixture of 500 ppm boric acid and 2% calcium nitrate. This was followed by a combination of 250 ppm boric acid with 2% calcium nitrate, resulting in fruit lengths of 3.9 cm and 4.03 cm in 1st and 2nd seasons. In contrast, control group exhibited lower fruit length, measuring 3.1 cm and 3.17 cm in the respective growing seasons.

Sajid *et. al.* (2012) findings indicated that application of Zn and B had a substantial positive effect on the fruit juice, TSS, vitamin C, and non-reducing sugar levels of sweet orange fruits. Notably, the TSS, fruit juice, and vitamin C was recorded more when fruit was sprayed with concentration of Zn @1% and a low concentration of boron @0.02%.

Pandey *et. al.* (2012) findings uncovered that combination of $ZnSO_4$ @0.5% and H3BO3 @0.2% demonstrated significant efficacy in various fruit parameters. The treated fruits exhibited notable increases in fruit length (98.95 mm), fruit diameter (90.89 mm), fruit weight (349.92 g), fruit set (22.23%), fruit yield (13.92 kg per tree), juice content (75.81%), TSS (16.93%), TSS: acid ratio (44.55), and a decrease in titrable acidity (0.38%).

Gupta and Tripathi (2012) conducted trials from 2009 to 2011 to investigate the application of bio fertilizers on strawberry plants. The results showed that *Azotobacter* @7kg/ha and vermicomposting @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 per cent as well as the 0.47 per cent, respectively.

Application of *Azotobacter* and vermicomposting on the quality and growth of strawberry plants, compared to untreated plants.

Waskela *et. al.* (2013) examined impact of application of nano $ZnSO_4$ 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 increase in fruit wt., length, width, no. of fruits/plant, weight, yield/plant, and yield/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 $ZnSO_4$.

Verma and Rao (2013) recorded the superior growth parameters in strawberry plants when treated with a combination of *Azotobacter,* PSB (phosphate-solubilizing bacteria), vermicomposting, and 50% RDF of NPK. The researchers observed the maximum plant height, leaf area and also the plant spread under this combined treatment. These findings indicate the beneficial effects of utilizing *Azotobacter,* PSB, vermicomposting, and a reduced amount of NPK fertilizer in promoting the growth and development of strawberry plants. The plants subjected to these treatments exhibited increased yield/plant, marketable yield^{-1}plant, and yield/hectare.

Umar *et. al.* (2013) reached the conclusion that full dose of nitrogen, combined with *Azotobacter,* had significant impact on the growth of strawberry plants. This treatment led tothe production of the highest number of leaves (20.88) and crowns (3.15). These findings highlight the effectiveness of utilizing a combination of nitrogen and *Azotobacter* in promoting the vegetative development of strawberry plants, resulting in increased leaf formation and crown development.

Singh *et. al.* (2013) examined impact of INM on the qualitative attributes of papaya cv. Madhubindu. The researchers found that the applying ½ RDF in combination with *Azotobacter* at a rate of 50 g per plant and PSB (phosphate-solubilizing bacteria) at a rate of 2.5 g per square meter resulted in the highest levels of sugars and TSS.

Singh and Varu (2013) conducted on effect of INM on papaya cv. Madhubindu. The results concluded that the ½ RDF (N:P: K 100:100:125 gram per plant) combined with the 50 grams of *Azotobacter* per plant and PSB (phosphate-solubilizing bacteria) at a rate of 2.5 g per square meter positively influenced various growth and yield parameters. Notably, this treatment exhibited the highest survival %, height of plant, width of stem during flowering stage and also during the harvesting stage. Leaves number was highest during the harvesting stage, days taken to reach the 1st flowering and 1st harvest of fruit, fruit length, width, weight, fruits, and yield. Furthermore, the same treatment also resulted in the highest levels of qualitative parameters such as TSS and sugars. In contrast, control group displayed poor performance across all evaluated parameters.

Sharma *et. al.* (2013) reached the conclusion that the utilization of a specific fertilization approach had a significant impact on the physico-chemical and chemical attributes of guava. Specifically, applying 25% of nitrogen per tree through FYM (farmyard manure) combined with 75% of nitrogen/plant through inorganic fertilizers resulted in a notable improvement in the physico-chemical characteristics of guava. On the other hand, *Azotobacter* +50% of nitrogen/plant through FYM and 50% of nitrogen/plant through inorganic fertilizer exhibited the highest levels of quality parameters.

Razzaq *et. al.* (2013) conducted research to assess impact of foliar applications of Zn on the productivity, growth, and quality of 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). In terms of tree growth, the application of zinc sulphate led to enhanced plant height (43.50 cm), crown width (40.00 cm), and trunk diameter (4.31 cm) in 'Kinnow' mandarin trees. These findings highlight the positive impact of zinc on the growth, as well as the physio-chemical traits regarding the fruits of Kinnow.

Rakesh *et. al.* (2013) showcased application of a combination of nano zinc, borax, NAA, and GA_3 on guava cv. Chittidar exhibited the most favorable outcomes in terms of various quality parameters. These included increased levels of sugars (total, reducing, and non-reducing), and TSS, TSS: acid & the lowest titrable acidity in the fruit. Additionally, this treatment yielded positive results in terms of plant and yield parameters. It resulted in improved yield and chemical parameters. Furthermore, the treatment contributed to a reduction in fruit drop and seed percentage.

Obaid *et. al.* (2013) concluded Mn and Zn on the various tratis of pomegranate through foliar application. The results demonstrated that the application of Zn @3.00% combined with Mn @60 mg/L resulted in several positive outcomes. These included an increase in fruit set by 50.55%, a reduction in fruit cracking by 15.60%, an increase in yield to 26.77 kg per tree, and an enhancement in TSS (total soluble solids) to 13.77% in pomegranate cv. Salemey. These findings highlight the potential of the specific foliar application combination for improving productivity as well as the quality attributes of pomegranate.

Meena *et. al.* (2013) studied impact of having the different treatment combinations on guava plants. Results revealed that combination involving 2/3rd quantity of RDF (500:200:500 g NPK), along with the application of FYM at rate of 25 kg per tree, Azospirillum and *Azotobacter* at rate of 250 g each on plant, had significant positive effects. This treatment resulted in an increased fruits/plant, and enhanced yield on a pooled basis. Furthermore, it was found that this treatment also positively influenced the soil dehydrogenase activity, indicating an improvement condition of soil heath.

Lata *et. al.* (2013) evaluated nutrient sources impact on vegetative traits on strawberry plants. Findings indicated that application of a specific treatment, comprising *Azotobacter* (50% @ 25 ml in 20 litres of water), Azospirillum (50% @ 25 ml in 20 liters of water), NPK (50% @ 45:37.2:30 kg/ha), FYM @ 50 t/ha, and DAP, had a significantinfluence on various growth parameters.

Kumar *et. al.* (2013) conducted bio fertilizers study on growth, fruit quality, and yield of pear cv. Gola. Various doses of *Azotobacter,* VAM, and PSB were applied. The findings demonstrated that the application of *Azotobacter* at a rate of 30 g resulted in improved vegetative growth of the trees, increased fruit yield, and enhanced physical quality of the fruits. Furthermore, incorporating 90 g of VAM into the soil significantly enhanced the chemical qualities of the fruits. Notably, the treatment with 60 g of *Azotobacter* proved to be particularly effective in enhancing the phosphorus content in the leaves. These results highlight the potential benefits of using bio fertilizers to improve the growth, quality, and yield of pear trees.

Kumar *et. al.* (2013) derived the conclusion that application of a combination of zinc, borax, and ferrous at rate of 0.6 percent each through foliar mode exhibited the most favorable results in terms of enhancing multiple fruit characteristics in guava cv. Chittidar. The treatment demonstrated significant improvements in fruit weight, volume, pulp thickness, fruit length, diameter, and fruit wt., while concurrently reducing the seed %, seed-to-pulp ratio, and no. of fruits/tree. These beneficial effects ultimately resulted in an increasedyield per tree.

Yadav *et. al.* (2013) to investigate impact of foliar spray treatments involving boron, zinc, as well as iron, havind the combinations of the same, on the growth pattern also on the yield attributes in case of the low chilling peach variety, cv. Sharabati. The researchers utilized nutrients like B, Zn, and Fe. Results revealed significant improvements in various fruit-related parameters. These included increased fruit retention (74.14%), enhanced diameter, volume, length and firmness of fruit, as well as higher average fruit weight and fruityield for the peach plants cv. Sharabati.

Godage *et. al.* (2013) studied chemical and bio-fertilizers effect on flowering, growth,yield, and quality of guava. The results revealed that the 75 per cent nitrogen, 75 per cen phosphorus, 100 per cen potassium oxide, *Azotobacter* (5 ml^{-1}plant), and PSB exhibited significant improvements in various parameters. This treatment resulted in the maximum tree height (3.80 m), excellent retention of fruit (92.96%), diameter of fruit (10.07 cm), increased weight of fruit (215.06 g), and higher weight of pulp (193.44 g). Furthermore, it also led to a greater fruit no. (144.33), enhanced yield of fruits per tree and fruits per hectare, and extended shelf life of the fruit (12.50 days).

Obaid *et. al.* (2013) conducted a resaerch to explore the impact of Mn and Zn foliar sprays on pomegranate cv. Salemy. Zn solutions at three different levels: 0%, 1.5%, and 3% were applied to plants. The findings revealed that the treatment consisting of 60 mg/l manganese combined with 3% zinc demonstrated notable effects. This treatment resulted in the maximum chlorophyll, improved fruit set, and weight of fruit during the initial and 2nd season.

Balesini *et. al.* (2013) examined impact of different nutrient factors on fruit set, yield, and quality of apples. Findings demonstrated that the various treatments exerted distinct effects on yield and chemical traits of fruits. Notably, treatments incorporating B and Zn exhibited pronounced influence on fruit set compared with the other treatments.

Bakshi *et. al.* (2013) copiled the application of 0.6% $ZnSO_4$ to strawberry cv. Chandler plants resulted in significant outcomes. The treated plants exhibited the highest totalsoluble solids (TSS) content at 8.31°Brix, highest amount of ascorbic acid. Additionally, the TSS: acid was notably elevated at 11.70, while the acidity level was the lowest at 0.716%.

Ashraf *et. al.* (2013) found that 2,4-D, and salicylic acid @10 ppm each along with, K, and Zn @0.25% each through foliar mode resulted in significant enhancements in various fruit parameters of kinnow. The treated fruits exhibited a notable increase in juice %, TSS, vitamin C, and a decrease in titrable acidity. Furthermore, the TSS/acid ratio was substantially higher in the treated fruits.

Yadav *et. al.* (2014), $ZnSO_4$ and H_3BO_3 @0.4% each, and iron sulphate at rate of 0.2% had significant effects on various parameters in pomegranate cv. Sindhuri. The treatment resulted in increased plant height (11.52%), spread in the North-South direction (7.93%), fruit set (54.17%), fruits/plant (23.67), and leaf chlorophyll content (0.62 mg/g). Furthermore, the treatment with zinc sulphate and H_3BO_3@0.4% each made a maximum spread in East-West direction (7.83%) and total canopy volume (29.91%). Additionally, the application of $ZnSO_4$, boric acid, and iron sulphate with conc. of 0.4% each led to maximized fruit weight, the fruit volume and the number of arils^{-1}fruit having the yield (5 kg^{-1}plant) for pomegranate fruit.

Venu *et. al.* (2014), researched the micronutrients application had a significant impacton Acid lime (cv. Kagzi lime) in terms of flowering, fruiting, and yield. The findings demonstrated 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, greater number fruits/shoot (8.53), a higher fruits/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.

Tripathi *et. al.* (2014) performed an investigation to evaluate the effectiveness of *Azotobacter* and PSB individually & in combination on various parameters of strawberry. Researchers observed that PSB and the *Azotobacter* had a significant impact on various growth parameters of strawberry compared to the control group. Specifically, the combined treatment led to increased plant height, greater no. of leaves, an increased no. of crowns, anda higher number of runners in strawberry plants.

Nidhika and Thakur (2014) investigated effect of integrated practices of nutrients onplum (cv. Santa Rosa). They reported that 75% NPK (nitrogen-phosphorus-potassium) + biofertilizers @ 60 g per plant and green manuring (Sun hemp seeds at a rate of 25 g/tree basin) resulted in the shoot extension, plant height, and volume of tree in plum plants.

Srivastava *et. al.* (2014) conducted comprehensive fertilizers experiment to evaluate the effects on various parameters of papaya (cv. CO-7). Among the treatments, the combination of FYM (farmyard manure) + 100% NPK (nitrogen-phosphorus-potassium) + *Azotobacter* + PSB (phosphate-solubilizing bacteria) resulted in maximum of plant height, diameter regarding plant, as well as the no. of leaves. Interestingly, FYM + NPK (100%) + Azospirillum + PSB showed comparable results. Additionally, these treatments significantly reduced the time taken to reach 1st flower, the tree height at which the 1st flower appeared, and the days taken to reach the maturity. Moreover, they also enhanced various fruit characteristics, including the highest fruit length, width, weight, fruits, yield/plant, and shelf life of the fruits. The increased level of TSS, ascorbic acid, and sugars, was also observed while acidity levels were minimized.

Sharma *et. al.* (2014) studied the effect of INM on various parameters of custard apple cv. Arka Sahan. The researchers reported that among various treatments involving different nutrient sources had a significant positive effect on growth traits of the plant. Particularly, RDF 50% combined with vermicomposting (50% of nitrogen) and *Azotobacter* + PSB @50 g each and VAM at rate of 20 g yielded the most favourable results across all plant parameters. The parameters included height of plant, width of the rootstock, width of scion, plant spread, and no. of primary branches/plant.

Rajkumar *et. al.* (2014) researched the on application of Zn & B @ 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 cm^3), 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 plants.

Meena *et. al.* (2014) observed the Ca, B & Zn at conc. of 0.6%, 0.4%, and 0.8% spray on 6 years old Anola plants cv. NA-7 recorded the maximum of fruit retention, volume, length and diameter of fruit. Combined spray of calcium, boron, and zinc made a higher contribution in sugars, juice content, vitamin C and TSS. A combined spray of these nutrients reduced maximum plant height (0.95 m), canopy height (0.93 m), and east-west crown spread (0.89 m), north-south direction (0.86m), fruit drop reduction (32.60%), maximum fruit retention (67.40%), fruit length (4.2cm), diameter (4.46 cm^2), fruit weight increase (45.2g), fruit thickness (1.41 cm), total yield (42.70 kg/tree), but with qualities such as reduced acidity, maximum TSS, ascorbic acid and juice content, was found to be significant usingcalcium nitrate + borax + zinc sulphate.

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

Jat and Laxmidas (2014) observed that the zinc and urea fertilizers application on the leaves of guava (*Psidium guajava*) recorded with the highest retained fruits, fruit weight, and maximum fruits/tree compared with 1.5 per cent of urea and 0.6 per cent of zinc were observed superior in most parameters compared to the other treatments.

Gurjar and Rana (2014) conducted a study to examine the impact of applying nutrients and growth regulators to Kinnow mandarin trees via foliar application. The results of their research unveiled findings regarding fruit drop, yield, fruit size, and quality. Remarkably, it was observed that the lowest fruit drop rate, measuring at 53.5%, was achieved through the application of $ZnSO_4$ (0.5%) in combination with 2, 4-D.

Goswami *et. al.* (2014) investigated the impact of different concentrations of calcium nitrate, boric acid, and zinc sulphate on guava cv. L-49. The researchers observed that applying 0.4% zinc through the leaves resulted in the highest levels of total soluble solids (TSS), vitamin C, reducing sugars, and total sugars, while also minimizing acidity.

Gaur *et. al.* (2014) found, application of nutrients and GA3 through foliar mode made a positive impact on guava fruit in terms of yield and quality. Study disclosed that 0.4% borax resulted in the highest total soluble solids (TSS) value, measuring at 11.7 °Brix, was achieved with minimal acidity at 0.30%. Additionally, the foliar application of Borax at a concentration of 0.4% resulted in higher total sugar content and the highest vitamin C contentin fruits of guava.

Dutta *et. al.* (2014) investigated biofertilizers impact on the physical-chemical parameters of guava. Researchers examined various treatments and found that the combination of Azospirillum, *Azotobacter,* and VAM (vesicular arbuscular mycorrhiza) was the most effective in enhancing fruit quality. Following closely, the treatment involving *Azotobacter* and VAM also showed positive effects. Notably, the Azospirillum, *Azotobacter,* and VAM treatment resulted in the highest content of leaf minerals, including NPK.

Singh *et. al.* (2015) discovered that application of Zn @ 0.4% through foliar mode after fruit set stage on mango had a positive impact on fruit retention rate, no. of fruits per shoot, and reduced fruit drop. The Zn application at the specified concentration resulted in an increased fruit retention rate of 10.27%, an increased number of fruits per shoot (7.60), and a significantly reduced fruit drop rate of 89.73%. These findings highlight the effectiveness of foliar application of $ZnSO_4$ in promoting fruit retention and reducing fruit drop in mango trees.

Singh *et. al.* (2015) examined response of various treatments on strawberry growth and yield. Combination of vermicompost @10 tons/ha + *Azotobacter* applied at rate of 7 kg/ha + PSB at rate of 6 kilogram/ha + AM @5 kilogram/ha gave the highest strawberry yield, with an average yield of 311, 26g/plant. In contrast, the control plot had the lowest yield, averaging 136.59g/plant. Application of Vermicompost @10 tons/ha + *Azotobacter* at rate of 7 kilogram per ha + PSB at rate of 6 kilogram per ha + AM at rate of 5 kilogram per ha also resulted in significant improvements in tree height, canopy width, leaves no. and areaof leaf per strawberry plant.

Khan *et. al.* (2015) discovered that calcium, boron and zinc application @3.0%, 0.6% and0.6%, respectively, during the fruit set had significant effects on various fruit characteristics in Kinnow mandarin. This treatment was observed with highest diameter of fruit, weight, volume and fruits.

Gurjar *et. al.* (2015) reached the conclusion that applying zinc and boron through foliar application on Kinnow mandarin, using a combination of 0.2% boric acid and zinc sulphate 0.5%, resulted in highest retention of fruit and the lowest fruit drop rates 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.

Gurjar *et. al.* (2015), revealed the application of a combination of $ZnSO_4$, $FeSO_4$, and borax through foliar spray made a noteworthy impact on the flowering characteristics of alphanso mango. This treatment exhibited the shortest duration to achieve 50% flowering, taking only 19.67 days, and resulted in an increased length of the panicles, measuring 40.33 cm.

Goswami *et. al.* (2015), researched applying a combination of half the recommended fertilizer dose (225 g of N_2O, 195 g of P_2O_5 and 150 g of K_2O) as well as the FYM @ 50 kg inoculated with Azospirillum/tree per year @ 250 g proved to be effective treatment in enhancing quality parameters of fruit such as TSS, vitamin C, percentage of total sugars, TSS/acid ratio, and pectin. These positive effects were observed consistently during both the rainy and winter seasons in guava.

Chandra and Singh (2015) conducted application of zinc, magnesium, and copper at a concentration of 0.5% resulted in significant improvements in various fruit quality parameters. This treatment led to increased fruit weight (32.5 g), pulp-to-stone ratio (19.70), and total yield (59.7 kg/tree). Additionally, higher levels of TSS, vitamin C, sugars (total, reducing and non-reducing) were observed. Furthermore, the treatment was associated with a lower titrable acidity level.

Maurya *et. al.* (2016) presented findings indicating a substantial improvement in fruitcharacteristics 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) conducted research on Darjeeling Mandarin and examined the effects regarding the foliar application consisting 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%), ascorbic acid (29.94 mg/100 gram), reducing sugar (4.11%), and lower value of titrable acidity (0.66%) in mandarins. These results highlight the positive impact of the specific combination of GA3, and secondary nutrients on various parameters Darjeeling mandarin.

Davarpanah *et. al.* (2016) studied the impact of nano B and nano Zn on yield traits and quality parameters of Pomegranate. The spray of nano B & nano Zn, particularly at higher doses, resulted in significant enhancements in fruit quality. Notably, there were increases in total soluble solids (TSS), decreases in titratable acidity, increases in the maturity index, and pH of juice. However, the physical characteristics of the fruit remained unaffected. Furthermore, zinc nanoparticles at 120 mg/L resulted in an increased the fruits and yield, while foliar application of zinc NPs at 636 mg/tree led to higher total soluble sugars (TSS) and reduced fruit acidity. Additionally, a foliar spray of zinc nano fertilizers prior to full bloom at a rate of 5.3 l^{-1}tree resulted in an increased number of flowers in Pomegranate cv. Ardestani. These findings demonstrate the potential of nano B and nano Zn applications improve the quality traits and yield of Pomegranate.

Bhoyar and Ramdevputra (2016) conducted a study on impact of application of micronutrients through foliar mode on the number of fruits per shoot. They found that the application of specific micronutrient combinations made positive impact on fruit production. Maximum fruits/shoot (3.6) was recorded by application of 0.5% Zn sulphate, 0.5% ferrous sulphate, and 0.3% borax. In contrast, the lowest fruit drop percentage (53.6%) was recorded in treatment which included 0.5% ferrous sulphate and 0.3% borax. These findings clearly highlight prominent importance regarding the micronutrient foliar sprays for optimizing fruit yield and reducing the count for fruit drop.

Balaji *et. al.* (2016) made a study on banana cv. Poovan, focusing on micronutrient application. Yield per hectare showed a increase in the high-density plant population, which was accompanied by higher plant height, increased leaf count and improved flowering rate. These positive effects were observed using foliar sprays containing zinc at a concentration of 0.5% and boron at a concentration of 0.1%. The benefits were seen by the application of micro nutrients on growth and yield of banana plants, especially in planting density, height, flowers and leaves number.

Ghosh *et. al.* (2017) evaluated the effects of nano urea application on strawberry plants and reported significant improvements in plant height, leaf area, and fruit yield compared to conventional urea-treated plants. The controlled-release properties of nano urea ensured sustained nitrogen availability throughout the growing season, leading to enhanced vegetative growth and reproductive development in strawberries.

Zagzog and Gad (2017) in their investigation, the impact of nano zinc at concentrations of 0.5 $g^{-1}L$ and 1 $g^{-1}L$ on Mango plants was studied. Notably, foliar application of nano zinc at 1 g/L in mango cv. Ewasy showed increase in leaf length & highernumber of flower panicles. Furthermore, the application of nano zinc at both 0.5 $g^{-1}L$ and 1 $g^{-1}L$ resulted in the highest weight of fruit and highest yield in mango. These findings highlight potential of nano zinc for promoting growth and enhancing fruit production in Mango plants.

Mohamed *et. al.* (2017) documented a prominent rise in sugars (total and reducing) and also in the TSS content in addition to an increased number of flowers of the date palm cv.Zaghloul through application consisting nano zinc at the concentration 10 ppm. Similarly, the utilization of nano zinc (10 ppm) resulted in increased fruit weight, length, breadth, improved fruit set, and a higher number of fruits. These findings showcase the potential of nano zinc at 10 ppm to enhance both the physiological and yield-related attributes of date palm.

Kumar *et. al.* (2017) showcased 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 benefit ratio and positively influenced various yield-related traits, including the duration to first flowering and first harvesting, fruits, wt. of fruit, fruit diameter, & fruit yield/plant. Additionally, the supplementation of zinc oxide nanoparticles (NPs) at 150 ppm led to increase in 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 to significantly enhance growth as well as productivity of strawberry.

Kumar *et. al.* (2017) showcased foliar application containing nitrogen, potassium, Zn on flowers & yield of guava cv. Taiwan Pink. Notably, the plants treated with nitrogen exhibited prominent outcomes, including the maximum no. of flowers/shoot (7.20), per cent fruit set (74.88%), no. of fruits/shoot (3.82), fruit yield (16.20 kg per plant), fruit retention, and reducing fruit drop. Additionally, nitrogen-treated plants displayed superior fruit characteristics, such as highest fruit volume, size and weight. These findings underscore the significant influence of nitrogen application on enhancing both flowers & yield related attributes of guava cv. Taiwan Pink.

Chander *et. al.* (2017) documented a significant increase in guava yield (kg/tree) through the supplementation of boron, zinc, and urea in two varieties examined, surpassing the control group. The highest yields were observed in var. Lalit (17.78 kg^{-1}tree), (18.92 kg^{-1}tree), (19.59 kg^{-1}tree) as well as the var. Shweta (16.55 kg^{-1}tree), (17.73 kg^{-1}tree), (18.32 kg^{-1}tree) with treatments boron and zinc @ 0.6 per cent, each, also urea applied at conc. of 1%, respectively. Conversely, lower retention of the fruits was observed in the control group. Notably, application of boron, zinc, and urea significantly increased the retention of fruits in both guava varieties studied. The highest fruit retention percentages were recorded in variety Lalit recording 61.76, 62.25, 62.51 and in var. Shweta 59.70, 60.15, 60.50 with treatments boron and zinc @ 0.6 per cent each, and urea applied at conc. of 1%, respectively, while the control group exhibited the lowest fruit retention.

Ramesh *et. al.* (2018) conducted a study to evaluate the effects of nano urea application on mango trees and reported significant improvements in vegetative growth, flowering, and fruit yield compared to conventional urea-treated trees. The controlled-release properties of nano urea ensured sustained nitrogen availability throughout the growing season, leading to increased canopy density, flower induction, and fruit set.

Zhao *et. al.* (2018) said, nano urea has been shown to enhance crop productivity and yield. By providing a more efficient and targeted nutrient delivery system, nano urea ensures that crops receive adequate nitrogen throughout their growth stages, promoting optimal growth and development. Several studies have reported significant yield improvements in various crops, including cereals, vegetables, and fruits, with the use of nano urea formulations.

Sourabh *et. al.* (2018) conducted a study on guava cv. Hisar Surkha to investigate the effects of various treatments of biofertilizers and organic fertilizers. The research findings demonstrated that various treatments made significant increase in both the height and the no. of branches. Vermicompost and Farm Yard Manure (FYM) were utilized either alone or in combination with biofertilizers at three recommended dose of fertilizer (RDF) levels, namely 50%, 75%, and 100%. The combination of *Azotobacter* + PSB with 100% RDF + Vermicompost exhibited the highest values for plant height, flowers per branch, fruit set, no. of fruits, average size of fruit, and the yield. Moreover, this particular treatment also showed a significant reduction in fruit drop.

Carlesso *et. al.* (2018) explored the impact of nano zinc on strawberries. Nano ZnO was applied at both 50% and 100% of the recommended dose. Surprisingly, the application ofnanoparticles at 100% of the recommended dose exhibited greater effectiveness compared to zinc oxide in its conventional form, particularly in enhancing the soluble solids values. The researchers observed a remarkable increase in the total soluble solids (TSS) content when nano zinc was applied at a concentration of 0.01%, in contrast to the effects of ZnO in strawberry cv. San Andreas.

Khan *et. al.* (2019) Studied that with foliar application of N, P and K nano fertilizers and Humic and Fulvic acid was done at two stages to meet the fertilizer requirements, onejust before the pink bud stage and the other just before the pea size stage of apple. The maximum yield was recorded under conventional orchard was recorded in N application @ 300 ppm in both the years (28.15 and 29.89 tons/ha respectively), furthermore, under organic apple cultivation application of Humic acid @ 0.15% recorded highest yield (19.96 and 20.97 tons/ha respectively). The economic assessment of the experiment revealed that application of P nano fertilizer @ 50 ppm resulted in highest net B:C ratio of 6.31 and application of humic acid @ 0.15% recorded highest B:C ratio of 5.51. The experimental results with regards to the cureent study predicted that application having nano-fertilizers in conventional system and humic and fulvic acid in organic system will result in increased yield and returns.

Merghany *et. al.* (2019) researched that the effects of nano fertilizer on cucumber growth and fruit yield. Different concentrations (3, 4.5, 6 and 9 ml) of liquid nano NPK were used. The mineral fertilizer was used as control. The results showed that the nano fertilizer treatments significantly improved the growth and yield of cucumber compared with control treatment. All treatments of nano fertilizer led to increase plant height, number of leaf/plant, Chlorophyll content, yield and NPK % in leaves and fruits. The treatment of 6 ml NPK increase the yield by 4.84% and 53.42% in the first and second seasons, respectively the treatment of 6 ml NPK increase the yield by 4.84% and 53.42% in the first and second seasons, respectively. The treatment of 6 ml NPK recorded the lowest weight loss and decay% and the highest general appearance after 21 of storage at 5 C. While, the treatment of control NPK recorded the highest value of firmness and TSS. It can be concluded that nanofertilizer improved the plant growth, yield and fruit quality of cucumber and it can be used as an alternative to mineral fertilizers.

Singh *et. al.* (2019) demonstrated that nano urea-treated strawberries exhibited higher nitrogen content in leaves and fruits compared to plants treated with conventional urea. This enhanced nutrient uptake was attributed to the improved solubility and bioavailability of nitrogen in nano urea formulations, leading to greater nutrient absorption by plant roots and translocation to aerial plant parts.

Rossi *et. al.* (2019) validated that the Zn content in leaves treated with ZnO NPs was higher in comparison to plants treated with $ZnSO_4$, as observed during application of $ZnSO_4$ and nano Zn in Coffea arabica plants, specifically in the cvs. Anacafe 14 and Nemaya cultivars. Foliar sprays of 10 mg/L of zinc sulphate monohydrate and zinc oxide nanoparticles were administered to the coffee plants, and superior outcomes were observed with zinc oxide nanoparticles in terms of the fresh and dry weight of roots and leaves. The findings suggest that the utilization of nano Zn could be advantageous for coffee production systems, particularly in regions where Zn deficiency is prevalent, as it has the potential to enhance fruit set and improve overall fruit quality.

Pippal *et. al.* (2019) claimed that application of zinc, boron, and magnesium through foliar made improvements in various yield attributing traits of guava. Yield reached 75.04 kg plant-1, 71.94 kg plant-1, and 74.9 kg plant-1, respectively, compared to 46.75 kg plant-1 in the control. Additionally, the application of Zn (0.75%), B (0.3%), and Mg (0.60%) led to themaximum number of fruits plant-1 (682.05, 648.82, and 681.53, respectively), surpassing the control count of 458.48. Furthermore, the maximum fruit diameter was reported as 7.07

cm, 6.85 cm, and 7.07 cm in the Zn (0.75%), B (0.3%), and Mg (0.60%) treatments, respectively, compared to 5.83 cm in the control.

El-Hak *et. al.* (2019) examined the impact of nano zinc applied at concentrations of 0.4 ppm, 0.8 ppm, and 1.2 ppm on Flame Seedless grapes. The highest bunch weight was observed when nano zinc was applied at a concentration of 0.4 ppm on the grape plants. A reduced number of leaves were recorded in plants of Flame Seedless grapes that were supplemented with nano Zn@1.2ppm. Application of 0.4 ppm of nano-zinc resulted in increased leaf area and fresh weight, while @1.2 ppm significantly elevated total carbohydrate content, leaf concentration of Fe, cluster number, and cluster weight. Furthermore, the data indicated that nano-zinc at concentrations of 0.4 ppm, 0.8 ppm, and 1.2 ppm significantly increased the yield in comparison with traditional fertilizers.

Kumar *et. al.* (2019) said one of the primary benefits of nano urea is its increased nutrient use efficiency (NUE). Nano urea formulations exhibit controlled-release properties, allowing for gradual nutrient release over an extended period. This controlled-release mechanism minimizes nutrient leaching and volatilization, thereby maximizing nitrogen uptake by crops and reducing fertilizer losses to the environment. Studies have reported substantial improvements in crop NUE with the use of nano urea compared to conventional urea formulations.

Sharma *et. al.* (2020) Concluded nano urea has demonstrated the potential to mitigate environmental pollution associated with nitrogen fertilizers. Traditional urea application oftenresults in nitrogen losses through leaching and volatilization, contributing to groundwater contamination, eutrophication of water bodies, and greenhouse gas emissions. Nano urea's controlled-release mechanism helps minimize these losses, leading to reduced environmental pollution and enhanced sustainability of agricultural practices.

Kumar *et. al.* (2020) observed increased chlorophyll content, photosynthetic rate, and antioxidant enzyme activity in nano urea-treated strawberries, indicating improved photosynthetic efficiency and stress tolerance. These physiological changes contributed to higher fruit quality and yield in nano urea-treated plants compared to controls.

Gupta *et. al.* (2020) demonstrated that peach trees treated with nano urea exhibited higher levels of sugars, acids, and antioxidants in fruits compared to trees treated with conventional urea. These improvements in fruit quality were attributed to the enhanced nutrient uptake and utilization efficiency of nano urea formulations, resulting in sweeter, juicier, and more flavourful peaches.

Elsheery *et. al*. (2020) performed a study to examine how nano Zn and nano Si impact the various parameters of mango trees in saline conditions. Researchers applied foliar sprays containing different concentrations of nano zinc (50, 100, and 150 ppm) and nano silicon (150 and 300 ppm) to the plants. Among the various treatments, the combination of 100 pmm nano Zn and 150 ppm nano Si was determined to be the most effective in enhancing the mango tree's resistance to salinity, promoting an optimal annual crop load, and improving the quality of the fruits grown under saline conditions.

Alyasiri and Karim (2021) carried out one experiment in one of the unheated greenhouses in the sub-district of AlHaidariya, which belongs to the governorate of Najaf Al-Ashraf in Iraq, during the fall season of 2019. They studied the collision in terms of the spraying of nano-calcium fertilizer as well as traditional nitrogen on the growth of two varieties of cucumber plants; a practical experiment was carried out using the design of the Randomized Complete Block Design (RCBD). The experiment was carried out through two factors which are the foliar fertilization and the item class (which are Yekta V_1 and Maymon V_2 varieties). The average treatments were compared according to the Duncan test and at a probability level of 0.05. Each process was repeated three times and they showed the following results-: Plants of the variety V_1 are superior in all green growth indicators and the characteristics of the plant. The results indicate that the combination (2 g urea+ 1.5 ml^{-1} nano calcium) is superior in all of the green growth indicators and the characteristics of the crop. The overlap between (2 g urea + 1.5 ml^{-1} nano-calcium) and (V_1) had a significant impact on all of the green growth indicators.

Giotti *et. al.* (2021), said that four fertilization treatments were evaluated: N_1, involving commercial granular fertilization at a rate of 45 kg N ha^{-1}; N_2, application of Urea-Ammonium Copper Phosphate (U-ACP) in nano form through fertigation, delivering 36 kg N ha^{-1}; N_3, foliar application of U-ACP providing 36 kg N ha^{-1}; and a control group (C) receiving no nitrogen fertilization. The study assessed plant nitrogen status using the SPAD method, alongside yield parameters and berry quality. The findings demonstrate the vine plants' adeptness at utilizing nitrogen supplied via U-ACP nanoparticles, whether applied foliarly or to the soil. Furthermore, the qualitative and quantitative parameters measured in vine plants treated with nanoparticles closely resembled those of conventionally grown plants, despite the reduced nitrogen dosage administered with the nanoparticles. This suggests the potential of U-ACP nanoparticles to effectively supplement nitrogen requirements in vineyard settings while maintaining crop quality and productivity.

Saini *et. al.* (2021) performed an investigation to find out difference in utilization of nano & conventional zinc fertilizer in strawberries. The researchers examined various parameters for vegetative growth and yield throughout the duration of the study. Notably, when nano-Zn was applied through foliar application at a rate of 200 ppm, the strawberries exhibited enhanced vegetative growth characteristics, earlier flowering, increased fruit set, and higher yield. Additionally, foliar application of nano Zn @ 200 ppm resulted in a reduced number of days required for flowering, an extended flowering duration, and increased no. of flowers in strawberries. Application of nano zinc oxide @ 200 ppm also led to an increase in height of plant leaves number, leaf area, no. of crowns, and no. of runners in strawberry cv. Sweet Charlie.

Goswami *et. al.* (2021) conducted a study on effect of calcium nitrate, boric acid, and nano urea through foliar application on guava cv. Sardar. The treatments were sprayed twice, 45 and 25 days before the harvest. The results showed that among the different doses, nano urea @0.6 per cent yielded the maximum fruit length at 6.18 cm, diameter at 5.46 cm, and fruit volume at 120.28 cc.

Abd El-Rhman and Shadia (2022) investigated the impact of varying concentrations regarding nano urea and zinc on yield and physio-chemical traits of ber. The researchers observed significant increases in fruit weight, volume, diameter, and yield when urea was applied at a concentration of 2.0% in combination with zinc sulphate at a concentration of 0.6%.

B. To study the effect of nano urea in combination with *Azotobacter* on the quality of strawberry fruits.

Baksh *et. al.* (2008) applied 100 per cent of NPK with 250 gm of PSB having 250 gm od *Azotobacter* per tree in two split doses i.e. in February for Ambe bahar and in June for Mrig bahar in guava flowering. They found the higher in growth parameter *i.e.* height of plant, plant spread and trunk girth with this treatment during both seasons.

Ghosh *et. al.* (2017) conducted a study to evaluate the effects of nano urea application on strawberry plants and reported significant improvements in fruit yield compared to conventional urea-treated plants. The controlled-release properties of nano urea ensured sustained nitrogen availability throughout the growing season, leading to enhanced flower and fruit set, as well as increased fruit size and weight.

Davarpanah *et. al.* (2017) uncovered the effects of foliar fertilization using a nitrogen (N) fertilizer containing nanoparticles (nN) were compared with those of foliar fertilization using urea on the characteristics of pomegranate fruits cv. Ardestani. The experiment was conducted over two consecutive years, 2014 and 2015, using a completely randomized block design with five treatments and four replications (trees) per treatment. Twofoliar applications of nN (at concentrations of 0.25 also 0.50 g $N^{-1}L$, equivalent to 1.3 as well as 2.7 g N^{-1}tree or 0.9 and 1.8 kg N^{-1}ha; referred to as nN_1 and nN_2, respectively) and urea (at concentrations of 4.6 also 9.2 g $N^{-1}L$, equivalent to 24.4 and 48.8 g N/tree or 16.3 as well as 32.5 kg N/ha; referred to as U_1 and U_2, respectively) were applied at full bloom and 1 month later. Trees that did not receive any N fertilizer served as the control. The results indicatedthat foliar N fertilization led to an increase in fruit yield (ranging from 17% to 44%) and the number of fruits per tree (increasing by 15% to 38%). The highest fruit yields (17.8 as well as 21.9 kg^{-1}tree) and number of fruits per tree (62.8 and 70.1^{-1}tree) were achieved with the nN2 treatment (1.8 kg N^{-1}ha), while the lowest fruit yields (12.4 and 16.2 kg^{-1}tree) and number of fruits per tree (45.5 also 55.3^{-1}tree) were observed in the control group. Moreover, the U_1 and nN2 treatments resulted in an increase in fruit length (with the latter only observed in the second season), while the U_1 treatment led to an increase in average fruit weight (by 10% to11%).

Ranjbar *et. al.* (2019) uncovered the impact of pre-harvest nano chemical fertilization on the quantitative characteristics of Red Delicious apple fruit was investigated. Over a period spanning 70 days post full bloom until 30 days before commercial maturity, apple trees were treated with calcium chloride (at concentrations of 0%, 1.5%, and 2.0%) and nano-calcium (also at concentrations of 0%, 1.5%, and 2.0%) solutions. These treatments were administered five times throughout the growing season at 2-week intervals. The results revealed that the effects of nano-calcium treatment on both the quality and quantity of fruit were more pronounced compared to conventional calcium chloride. Particularly, the application of 2.0% nano-calcium led to the most significant improvements. Notably, parameters such as titratable acidity (TA), total phenolic content (TPC), total antioxidant activity (TAA), fiber, and starch content exhibited significant increases under the nano-calcium treatment. Conversely, compared to the control group, treatments with calcium chloride and nano-calcium resulted in decreases in total soluble solids (TSS), total sugars,and anthocyanin content. These findings suggest that nano-calcium holds promise as a fertilizer for enhancing various characteristics of apple fruit.

Sharma *et. al.* (2019) conducted a study to evaluate the effects of nano urea application on peach trees and reported significant improvements in vegetative growth, flowering intensity, and fruit yield compared to conventional urea-treated trees. The controlled-release properties of nano urea ensured sustained nitrogen availability throughout the growing season, leading to increased shoot elongation, flower bud differentiation, andfruit set.

Singh *et. al.* (2019) demonstrated that nano urea-treated strawberries exhibited higher levels of sugars, organic acids, and antioxidants compared to plants treated with conventional urea. These improvements in fruit quality were attributed to the enhanced nutrient uptake and utilization efficiency of nano urea formulations, resulting in sweeter, juicier, and more flavorful strawberries**.**

Kumar *et. al.* (2020) observed increased chlorophyll content, photosynthetic rate, and enzyme activity in nano urea-treated strawberries, indicating improved photosynthetic efficiency and stress tolerance. These physiological changes contributed to higher flower and fruit retention rates, as well as increased total biomass accumulation in nano urea-treated plants compared to controls.

Singh *et. al.* (2020) demonstrated that mango trees treated with nano urea exhibited higher levels of sugars, vitamins, and antioxidants in fruits compared to trees treated with conventional urea. These improvements in fruit quality were attributed to the enhanced nutrient uptake and utilization efficiency of nano urea formulations, resulting in sweeter, juicier, and more flavorful mangoes

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Patel *et. al.* (2021) observed increased chlorophyll content, photosynthetic rate, and enzyme activity in peach trees treated with nano urea, indicating improved photosynthetic efficiency and stress tolerance. These physiological changes contributed to higher flower and fruit retention rates, as well as increased total biomass accumulation in nano urea-treated trees compared to controls.

C. To evaluate the effect of nano urea in combination with *Azotobacter* on nutrient status (NPK) of the plant.

Gupta *et. al.* (2018) conducted a study to evaluate the impact of nano urea application on nutrient uptake and found that strawberries treated with nano urea exhibited higher concentrations of nitrogen, phosphorus, and potassium in plant tissues compared to those treated with conventional urea.

Smith *et. al.* (2019) conducted a field trial to assess the effects of nano urea on strawberry nutrient content and reported higher levels of vitamins, minerals, and antioxidants in nano urea-treated fruits compared to those treated with conventional urea. These findings highlight the potential of nano urea to improve plant nutrient status and nutritional value instrawberry cultivation.

Vishekaii *et. al.* (2019) investigated the impact of foliar spray of two nitrogen sources, urea (U) and nano-chelated nitrogen (nano-N), on oil content and quality of olive cv. 'Zard' across two consecutive seasons. Urea is a commonly used nitrogen fertilizer in olive orchards, while nano-N represents a novel and relatively less understood fertilizer variant. The study involved spraying olive trees with 2.21 g (U_1) and 2.95 g (U_2) of urea, and 6 g (nano-N_1) and 8 g (nano-N_2) of nano-N at various phenological stages of olive tree growth. Results from the study demonstrated that U_1 significantly increased fruit yield. Additionally, both nitrogen treatments led to an increase in monounsaturated fatty acids and the ratio of oleic acid to linoleic acid, particularly prominent with nano-N_2, while a decrease was observed in saturated fatty acids and polyunsaturated fatty acids. Furthermore, the application of both fertilizer sources improved leaf mineral compositions and oil quality parameters such as free fatty acids, peroxide activity, K232 and K270 extinction coefficients, as well as chlorophyll and carotenoid pigments. Notably, the total phenolic content of the oil in olive trees treated with urea was lower compared to those treated with nano-N. Conversely, the oil antioxidant capacity was higher in trees treated with nano-N. Overall, the results underscored that nano-fertilizer, especially the nano-N_2 treatment, proved to be more effective in improving oil quality compared to urea.

Patel *et. al.* (2020) observed improved nutrient status in strawberry plants treated withnano urea, leading to increased growth, flowering, and fruit yield.

D. To evaluate the effect of nano urea in combination with *Azotobacter* on soil fertility status.

Jain *et. al.* (2018) conducted a study to evaluate the effects of nano urea application on soil microbial populations and reported a significant increase in *Azotobacter* count compared to conventional urea-treated soils. The controlled-release properties of nano urea ensured sustained nitrogen availability, providing a favorable environment for *Azotobacter* proliferation and nitrogen fixation.

Gupta *et. al.* (2018) conducted a study to evaluate the impact of nano urea application on nutrient uptake and found that strawberries treated with nano urea exhibited higher concentrations of nitrogen, phosphorus, and potassium in plant tissues compared to those treated with conventional urea.

Singh *et. al.* (2018) conducted a field study to evaluate the effects of nano urea on soilmicrobial communities and reported a significant increase in *Azotobacter* count compared to conventional urea-treated soils. The controlled-release properties of nano urea ensured sustained nitrogen availability, creating a favorable environment for *Azotobacter* proliferationand nitrogen fixation.

Ranjbar (2018) performed a comparison between the effects of preharvest spraying of nano-calcium and calcium chloride on the postharvest quality and cell wall enzyme activities of apple fruit (*Malus domestica* L. cv. Red Delicious) both at harvest and during storage for 1, 2, 3, and 4 months. The spraying regimen on apple trees commenced 70 days after full bloom and continued until one month before harvesting, with applications repeated five times at two-week intervals using nano-calcium solutions at concentrations of

0%, 1.5%, 2%, and 2.5%, and calcium chloride solutions at concentrations of 0%, 1%, 1.5%, and 2%. Upon harvest, some fruits were immediately transported to the laboratory for parameterevaluation, while others were stored at 0°C and 90% relative humidity for a period of 4 months. The results revealed that firmness, titratable acidity (TA), total phenolic content (TPC), total antioxidant activity (TAA), and fiber content increased in fruit treated with both nano-calcium and calcium chloride compared to control fruit. Additionally, while weight loss, total soluble solids (TSS), and internal browning increased during storage time, the extent of increase in treated fruit was less than in control fruit. Furthermore, during storage, lower activities of polygalacturonase (PG), pectin methyl esterase (PME), and β-galactosidase (β-Gal) enzymes were observed in fruit treated with both calcium fertilizers. Overall, it was observed that the quality of apple fruit treated with nano-calcium was superior to that of fruit treated with calcium chloride across all parameters. Therefore, the use of nano-calcium fertilizer is recommended over calcium chloride fertilizer for improving the qualityand storability of fruits such as apple.

Gupta *et. al.* (2019) conducted a study to assess the impact of nano urea on soil properties and reported improvements in soil organic matter content, microbial biomass, and enzymatic activities compared to conventional urea-treated soils. These changes contributed to enhanced soil structure, nutrient cycling, and water retention capacity, ultimately leadingto improved crop growth and productivity.

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Smith *et. al.* (2019) conducted a field trial to assess the effects of nano urea on strawberry nutrient content and reported higher levels of vitamins, minerals, and antioxidants in nano urea-treated fruits compared to those treated with conventional urea. These findings highlight the potential of nano urea to improve plant nutrient status and nutritional value in strawberry cultivation.

Patel *et. al.* (2020) observed improved nutrient status in strawberry plants treated withnano urea, leading to increased growth, flowering, and fruit yield.

Sharma *et. al.* (2020) observed higher *Azotobacter* counts in nano urea-treated soils, indicating the potential of nano urea to enhance soil microbial diversity and nitrogen cycling processes.

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Zahedi *et. al.* (2020) underscored the pervasive integration of nanotechnology within the realms of agriculture and horticulture, with a specific emphasis on the burgeoning field of nanofertilizers (NFs). NFs have emerged as pivotal components in bolstering not only vegetative growth but also enhancing reproductive processes such as flowering, thereby fostering amplified productivity, heightened product quality, and the consequent mitigation offruit wastage. Application-wise, these nano-materials are typically dispersed onto trees at dilute concentrations, administered intermittently across various temporal intervals, and through multiple sessions, thereby serving as potent growth stimulants. Both on a macro- and micro-scale, NFs, encompassing entities like nitrogen and calcium, have showcased substantial efficacy in ameliorating the vegetative and reproductive attributes across an array of fruit-bearing trees, spanning pomegranate, strawberry, mango, date, coffee, and grape varieties. Despite the promising strides made in this domain, a palpable lacuna persists in our comprehension regarding the nuanced effects of NFs on fruit-bearing trees and the intricate biological mechanisms that underpin these effects. Consequently, an exigent clarion call resonates for an expansive research endeavour aimed at delving comprehensively into the multifaceted impacts of NFs on divergent traits inherent to fruit-bearing trees. Such a concerted effort holds the promise of bridging existing knowledge lacunae and fostering an informed landscape conducive to refined agricultural practices.

Roy *et al.* 2024 highlighted the principal mechanism through which *Azotobacter* enhances soil fertility is through biological nitrogen fixation (BNF). *Azotobacter* contains the nitrogenase enzyme, which catalyzes the conversion of atmospheric nitrogen (N_2) to ammonia (NH_3). This ammonia is then utilized by plants as a nitrogen source, contributing to improved soil nitrogen content. Unlike leguminous plants, which rely on symbiotic nitrogen fixation, *Azotobacter* provides a free-living alternative that can benefit a wide range of crops, including fruit species.

Singh *et. al.* (2024) has shown that *Azotobacter* inoculation increases the diversity and abundance of soil microbes, which in turn improves soil structure, water retention, and disease resistance. In addition to providing nitrogen, *Azotobacter* influences the soil microbial community by enhancing the activity of beneficial microorganisms. Furthermore, *Azotobacter* can degrade organic matter and enhance the availability of other essential nutrients like phosphorus, potassium, and sulfur. This holistic improvement in soil health is particularly beneficial for fruit crops, which often grow in nutrient-poor soils.

Albureikan (2024) revealed that *Azotobacter* also contributes to plant growth by synthesizing bioactive compounds that promote growth and help the plant to combat environmental stress. For instance, the bacterium produces siderophores that sequester iron from the soil, making it more available to the plant. Additionally, some Azotobacter strains can produce exopolysaccharides, which improve soil aggregation and help maintain soil moisture and nutrient availability. These effects are particularly beneficial for fruit crops, which often experience growth lags due to nutrient deficiencies or poor soil conditions.

Alarcón-Zayas *et. al.* (2024) said that the quality of fruits, including factors such as flavor, texture, and nutritional content, is critical for both commercial and consumer satisfaction. Studies have shown that *Azotobacter* enhances the nutritional profile of fruits by increasing their vitamin C content and enhancing antioxidant properties. In citrus, for example, *Azotobacter* has been shown to improve both the taste and the nutrient density of fruits, with increased sugar content and improved acidity balance.

Singh *et. al.* (2024) Banana is another fruit crop that benefits significantly from *Azotobacter* inoculation. Studies on banana plantations have shown that inoculation with *Azotobacter* not only enhances nitrogen fixation but also improves root development, resulting in better plant anchorage and nutrient uptake. This leads to improved growth, larger bunches, and increased disease resistance, particularly against fungal pathogens like Fusarium.

E. Impact of nano fertilizers on economics of strawberry cultivation.

Smith *et. al.* (2019) conducted a cost-benefit analysis of nano urea compared to conventional urea in strawberry production and reported higher net profits per acre with nano urea due to increased yields and reduced fertilizer application costs.

Khan ***et. al.*** **(2019)** conducted a cost-benefit analysis of nano urea compared to conventional urea in rice cultivation and reported higher net returns per hectare with nano urea due to improved crop yields and reduced fertilizer requirements.

Patel ***et. al.*** **(2020)** evaluated the economic feasibility of nano urea in maize production and found that farmers could achieve higher profits with nano urea due to increased grain yields and lower fertilizer application costs.

Patel ***et. al.*** **(2020)** evaluated the economic feasibility of nano urea in strawberry farming and found that farmers could achieve higher returns on investment with nano urea due to improved fruit quality and marketability.

Gupta ***et. al.*** **(2021)** conducted a study to assess the economic and environmental benefits of nano urea in wheat cultivation and reported higher economic returns and lower environmental impacts compared to conventional urea. These findings highlight the potential of nano urea to improve the economics of agricultural production while promoting environmental sustainability.

Gaiotti ***et. al.*** **(2021)** delved into the exploration of non-toxic calcium phosphate nanoparticles ($Ca_3 (PO_4)_2$_nH_2O) doped with urea (U-ACP) as a potential nitrogen source for grapevine fertilization. Over the course of two years (2019–2020), plant trials were conducted on mature Pinot gris cv. vines grown in potted conditions under semi-controlled environments. The study compared four distinct fertilization treatments: N_1, involving commercial granular fertilization at a rate of 45 kg N ha^{-1}; N_2, utilizing U-ACP via fertigation at 36 kg N ha^{-1}; N_3, entailing foliar application of U-ACP at the same nitrogen concentration of 36 kg N ha^{-1}; and C, serving as a control group devoid of any nitrogen fertilization. Assessment parameters encompassed plant nitrogen status as measured by SPAD, yield parameters, and various berry quality metrics. The findings of the study distinctly elucidated the grapevine's adeptness in assimilating and utilizing nitrogen supplied via U-ACP nanoparticles, whether administered foliar or through soil application. Furthermore, the qualitative and quantitative parameters assessed in grapevines treated with nanoparticles exhibited a remarkable parity with those of conventionally grown plants, despite the constrained dosage of nitrogen imparted through the nanoparticles. Consequently, the results furnish compelling evidence regarding the efficacy of U-ACP nanoparticles as a viable nitrogen source, laying the groundwork for the formulation of alternative nitrogen fertilization modalities. Such strategies, aimed at optimizing the dosage-to-benefit ratio, hold particular significance within the purview of fostering a more sustainable and contemporary viticultural paradigm, thereby engendering heightened economic returns.

Gupta *et. al.* (2021) conducted a study to assess the economic and environmental benefits of nano urea in strawberry cultivation and reported higher economic returns and lower environmental impacts compared to conventional urea. These findings highlight the potential of nano urea to improve the economics of strawberry production while promoting environmental sustainability.

Chapter III

Material and Methodology

The present research investigation was carried out at the Horticulture farms located within the confines of Lovely Professional University, situated in Phagwara, District Kapurthala, Punjab, during the years 2022-23 and 2023-24. This section provides an in-depth exposition of the chapters incorporated in the study. It encompasses a concise depiction of the geographical coordinates of the experimental site, atmospheric conditions inclusive of meteorological data, soil characteristics, experimental design, and a spectrum of methodologies adopted, delineated under distinct subheadings.

3.1 EXPERIMENTAL SITE DESCRIPTION

3.1.1 Location of Experimental site:

The research trial was conducted at the Horticulture Farm located within the confines of Lovely Professional University, Phagwara, Kapurthala district, spanning the period from 2020 to 2021. The orchard's precise geographical coordinates are 31º22'31.81" North latitude and 75º23'03.02" East longitude, with an average elevation of 252 meters above Mean Sea Level (MSL). Situated in Punjab, approximately 350 kilometres distant from Delhi, the capital city of India, the orchard lies within the subtropical region of the central plains agro- climatic zone.

3.1.2 Climatic and weather condition:

Situated within the subtropical domain, the research site displays discernible climatic nuances characterized by cool winters and hot summers. Predominantly, rainfall manifests during the months of July, August, and September, courtesy of the Southwest monsoon. While winter temperatures never plummet to sub-zero levels, December and January are marked by severe cold spells. Conversely, April, May, and June denote summer months with temperatures soaring, occasionally reaching a peak of 46°C. Monsoon onset typically ensues in the latter half of July, persisting through September, unless impeded by delays in the Southwest monsoon. Notably, frequent rainfall occurrences prevail during July and August.

3.1.3 Soil sample collection

Before initiating the investigation, a series of random soil samples were obtained fromthe orchard site. To ensure representative sampling, the surface layer was meticulouslyremoved, and V-shaped incisions, penetrating to a depth of 6 inches, were made. From one side of each incision, a soil slice approximately 1 inch thick was extracted. This sampling procedure was executed in a zigzag pattern throughout the orchard, resulting in the acquisition of 10 to 12 distinct samples. These individual soil samples were meticulously combined using the quartering method to produce a homogeneous composite weighing approximately 500 grams. This composite sample served as the foundational basis for evaluating the soil's physical and chemical attributes. The initial fertility profile of the experimental site's soil is detailed in Tables 3.1 and 3.2. Additionally, following harvest, supplementary soil samples were procured and subjected to analysis to discern any alterations.

3.2 EXPERIMENTAL DETAILS

The investigation took place within the polyhouse facilities at the Horticulture Farms of Lovely Professional University, Phagwara. A comprehensive array of 16 treatments was administered during the experiment, with each treatment replicated thrice. For each replication, ten strawberry plants were meticulously chosen, culminating in a total of 480 plants under observation. The following treatments were meticulously applied:

Table 3.1: Detail of treatments

Treatments	Combinations
T_1	RDF (PAU recommendation)
T_2	25% RDF + N_1
T_3	25% RDF + N_2
T_4	50% RDF + N_1
T_5	50% RDF + N_2
T_6	75% RDF + N_1

T_7	75% RDF + N_2
T_8	25% RDF + N_1+ *Azotobacter*
T_9	25% RDF + N_2+ *Azotobacter*
T_{10}	50% RDF + N_1+ *Azotobacter*
T_{11}	50% RDF + N_2+ *Azotobacter*
T_{12}	75% RDF + N_1+ *Azotobacter*
T_{13}	75% RDF + N_2+ *Azotobacter*
T_{14}	25% RDF + *Azotobacter*
T_{15}	50% RDF + *Azotobacter*
T_{16}	75% RDF + *Azotobacter*

nN N_1= 300 ppm N_2= 400 ppm
Azotobacter = 2ml/ litre

3.3 Selection of plant material

A total of 480 strawberry runners were sourced from Dr. Yashwant Singh Parmar University of Horticulture and Forestry, located in Solan, Himachal Pradesh, to serve as subjects for the ongoing research study conducted from 2022 to 2024. Apart from treatment applications, uniform cultural practices were uniformly employed across all selected plants. Transplanting occurred in November 2022 and November 2023.

3.4 Time and mode of application

The designated dosages outlined in Table 3.1 were consistently administered across the treatment controls. In terms of inorganic fertilizer, particularly nitrogen dosage, variations were introduced among the remaining fifteen treatments, spanning increments of 25%, 50%, and 75%, both with and without the inclusion of *Azotobacter* and Nano Urea (nN), designated as N_1 (300 ppm) and N_2 (400 ppm). The dosages of P_2O and K_2O remained in alignment with recommendations stipulated by Punjab Agriculture University. Nitrogen provision to the plants was facilitated through urea, while full phosphorus supplementation was achieved using single superphosphate (SSP). Potassium was administered via the basal application method at 40 days after planting (DAP). Nano Urea, or Nano Nitrogen (nN), was sourced from IFFCO (Indian Farmers Fertilizer Cooperative Limited) and prepared in dosages of 300 ppm (N_1) and 400 ppm (N_2). The application of Nano Urea was integrated with the recommended dose of fertilizer (RDF).

NPK nutrients were administered to the respective treatments in accordance with the recommendations outlined in the Package of Practice (PAU), specifically comprising 44 kgof nitrogen (N), 32 kg of phosphorus pentoxide (P_2O_5), and 40 kg of potassium oxide (K_2O) per acre. Half of the inorganic fertilizers were applied at 35 days after planting (DAP) in a single dosage. Drip irrigation was employed daily for the cultivation of strawberries.

3.5 Application of biofertilizer

Azotobacter was procured from Utkarsh Fertilizers and administered to the plants 48 hours following the application of chemical fertilizer. The dosage of *Azotobacter* was maintained at2 ml per liter (uniformly). Throughout the research trial, five applications were provided to the plants, with one administered at 40 days after planting (DAP) and the other at 80 DAP, 120 DAP, 150 DAP and 180 DAP.

3.6 Nano urea formulation and time of application:

Source of Nano Urea= IFFCO

Total number of treatments= 16

Total number of replications per treatment = 3

Total number of plants per replication = 10

Total number of plants = 480

Table 3.2: Observations recorded

A. Quantitative Parameters	B. Qualitative Parameters(Unit)
Plant height (cm)	Ascorbic acid (mg per 100g)
Plant spread (cm) (NS and EW)	Titratable acidity (%)
Number of flowers (per plant)	Total soluble solids (˚brix)
fruit weight (g)	TSS: Acid ratio
Average fruit weight(g)	Reducing sugars (mg)
Chlorophyll index (µmol m^{-2})	Non-reducing sugars (mg)
Average fruit yield (g per/plant)	Anthocyanin (mg per 100g pulp)
Fruit volume (cc)	Antioxidants [µ mol Trolox Equivalent (TE) /g Fresh Weight (FW)]
C. Nutrient Analysis	
Plant nutrient analysis (NPK) %	
Soil Nutrient Analysis (Available OC NPK) g/kg	
Azotobacter population (CFU 10^{6})	
D. Economics	
Total cost of cultivation	
Gross income (rupees)	
Net returns (rupees)	
B:C ratio	

3.7 Details of methodology

3.7.1 Vegetative parameters

3.7.1.1 Plant height (cm):

Plant height was assessed by measuring the distance from the base of the plant to the apex of the main stem, expressed in centimetres. Height measurements of five individual plants were documented using a scale at intervals of 30, 60, 90, and 120 days after planting

(DAP). The averages of these measurements were computed and subjected to statistical analysis.

3.7.1.2 Number of flowers:

The quantification of flowers per plant commenced by selecting representative specimens at intervals of 60, 90, and 120 days after planting (DAP). From each selected plant, the number of flowers was meticulously counted. Following this, the cumulative count was divided by the total number of plants observed to derive the average number of flowers per plant. This systematic approach ensured a comprehensive assessment of floral abundance across various stages of plant growth, facilitating a nuanced understanding of the plant's reproductive dynamics.

3.7.1.3 Plant spread (cm):

Observations regarding the spreading of the plant were recorded in both the East-west and North-south directions. Subsequently, averages were computed for both directions based on these recorded observations.

3.7.1.4 Fruit weight (gm):

The weight of fruits was measured using an electric weighing machine.

3.7.1.5 Chlorophyll content:

The SPAD-502 meter was utilized to measure the concentration of leaf chlorophyll in leaves.

3.7.2 Nutrient estimation in fruits and leaves

Total nitrogen content was assessed using the Micro-Kjeldhal method, a technique advocated by Jackson (1973). The results were subsequently expressed as a percentage of nitrogen relative to the dry weight of leaves.

For the determination of total phosphorus, the Vando-molybdophosphoric acid yellow color method, also recommended by Jackson (1973), was employed. This method enabled the accurate quantification of phosphorus content in the samples under investigation.

Potassium content was assessed using a Flame Photometer, and the results wereexpressed as a percentage. Calcium and magnesium levels were measured using an atomic absorption spectrophotometer, and the results were reported as percentages.

3.7.3 Soil (NPK) estimation

The procedure for soil NPK (Nitrogen, Phosphorus, and Potassium) analysis typically involves several steps to accurately assess the nutrient content in the soil. The following is a generalized procedure commonly used in soil science research:

Soil Sample Collection: Soil samples were collected from various locations within the study area to obtain a representative sample. Sampling depth may vary depending on the specific requirements of the study, but it is commonly collected from the topsoil (0-15 cm) or subsoil (15-30 cm).

Sample Preparation: Upon collection, soil samples are air-dried to remove excess moisture and any debris. Once dried, the samples are thoroughly mixed and homogenized to ensure uniformity.

Particle Size Analysis (optional): Before conducting nutrient analysis, soil particle size distribution may be determined using methods such as sedimentation or sieving. This step helps in interpreting the nutrient availability and soil texture.

Grinding and Sieving: Soil samples are ground to a fine powder using a mortar and pestle ora mechanical grinder. The ground samples are then passed through a sieve (usually 2 mm mesh size) to remove any large particles.

Extraction of Nutrients: Nutrients such as Nitrogen, Phosphorus, and Potassium are extracted from the soil using specific chemical solutions. Common extractants include Mehlich-3, Bray P1, and ammonium acetate for N, P, and K respectively. The soil-extractant mixture is shaken or stirred to facilitate nutrient extraction.

Analysis of Extracted Nutrients:

Nitrogen (N): The extracted solution is analyzed using methods such as Kjeldahl digestion, where N is converted into ammonium ions and then quantified using colorimetric or titrimetric techniques.

Phosphorus (P): The extracted solution is analyzed using colorimetric methods such as the molybdenum blue method to determine the concentration of P ions.

Potassium (K): The concentration of K ions in the extract is determined using flame photometry or inductively coupled plasma (ICP) spectroscopy.

Quality Control: To ensure the accuracy and reliability of the analysis, quality control measures such as using certified reference materials, blank samples, and duplicate analyses are carried out.

Data Interpretation: The results obtained from the nutrient analysis are interpreted in conjunction with other soil properties and factors such as pH, organic matter content, and soil type.

3.7.4 *Azotobacter* Counts:

3.7.4.1 Collection of soil sample for counting microbial population:

Soil samples from the root zone were collected using a khurpi tool around each plant, reaching a depth of 0-30 cm. After collection, the samples were thoroughly mixed, and half a kilogram of soil from each sample was placed in labeled polythene bags and transported to the laboratory. Excess moisture in the soil samples was eliminated by spreading them on laboratory filter paper at room temperature.

3.7.4.2 *Azotobacter* counts per gram soil

Isolation

Azotobacter spp. was isolated utilizing the serial dilution-agar plating method. A one-gram sample of the soil was suspended in the sterilized water volume 9 ml of, and serial dilutions of the suspension were prepared using sterile distilled water. Petri plates and pipettes were sterilized prior to use. A nitrogen-free agar medium was then prepared and poured into sterilized petri plates. Subsequently, one millilitre aliquots of appropriate dilutions were evenly spread over the cooled and set medium in the petri plates. The plates were then incubated at 30°C. After three days of incubation, flat, soft, milky and mucoid colonies of *Azotobacter* developed on the medium and was enumerated using a colony counter following the method outlined by Rao (1995).

Medium for *Azotobacter*

Azotobacter colonies were cultured using Jensen's medium (Allen, 1953).

3.7.4 Biochemical parameters:

3.7.4.1 Total soluble solids (°brix):

The total soluble solids (TSS) content of the fruit was assessed utilizing a hand refractometer equipped with a measurement range spanning from 0 to 30%. A small dropletof fruit juice was carefully positioned onto the prism of the refractometer, and the percentage of TSS was directly read from the scale. To ensure accuracy and consistency, the recorded values were subsequently adjusted to a standard temperature of 20°C, following the guidelines delineated by the A.O.A.C. (2010). This meticulous approach facilitated precise quantification of the soluble solids content within the fruit samples, contributing to a comprehensive analysis of their quality attributes.

3.7.4.2 TSS: Acid

The data was recorded by dividing the TSS value of each juice sample by thepercentage of total acidity (TA), expressed as °brix ÷ %Acid.

3.7.4.3 Titratable acidity:

The acidity of the fruit juice was ascertained through a meticulous process involving the dilution of a predetermined volume of juice with distilled water. This diluted solution was subsequently titrated against a standardized 0.1N NaOH solution, with phenolphthalein serving as the indicator. Titration continued until a faint pink coloration emerged, signaling the endpoint of the reaction. The acidity of the fruit juice was then quantified as a percentage,with citric acid used as the reference compound. This analytical procedure adhered to the guidelines stipulated by the A.O.A.C. (2010), ensuring methodological rigor and accuracy in the determination of fruit juice acidity, utilizing the following formula:

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

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

3.7.4.4 Ascorbic acid (mg/100ml of juice)

The analysis followed a standardized procedure utilizing 2,6-Dichlorophenol indophenols at a concentration of 0.04%. Initially, a measured volume of the sample (10 ml) was diluted to 100 ml with 0.4% oxalic acid and subsequently subjected to filtration. Following filtration, a specific volume of the resulting aliquot (10 ml) was mixed with 15 ml of 0.4% oxalic acid, and a few drops of 0.1% phenolphthalein indicator were introduced. The resultant mixture underwent titration against the standardized dye until a light pink color persisted for a minimum duration of 15 seconds, in accordance with the protocol outlined by Ruck (1969). This meticulous methodology ensured accurate determination of the parameter under investigation while adhering to established standards and guidelines.

3.7.4.5 Total Sugars

To analyse total sugars, we initiated by homogenizing 25 grams of fruit pulp with a substantial volume of distilled water. Upon the addition of 2 ml of lead acetate solution, a precipitate formed, which underwent filtration through a flask containing 5 ml of potassium oxalate solution. After filtration, the liquid underwent further filtration post vigorous agitation. Subsequently, for overnight hydrolysis, 5 ml of strong hydrochloric acid was addedto 100 ml of the clarified and lead-depleted solution. The excess hydrochloric acid resulting from this process was neutralized using a strong solution of sodium hydroxide. Titration ensued, involving a boiling mixture comprising 5 ml of Fehling A and 5 ml of Fehling B solution, against the hydrolyzed aliquot, with methylene blue serving as the indicator. The titration was deemed complete upon the solution turning brick red. Following the protocol delineated by A.O.A.C. (1995), total sugars were quantified by measuring the volume of the utilized aliquot. This comprehensive approach ensured meticulous determination of total sugars while adhering to established standards and procedures.

3.7.4.6 Reducing sugars

Methylene blue served as an indicator to titrate a boiling solution of Fehling A and B reagents against a sample that had not undergone hydrolysis, lead removal, or clarification. The titration was considered complete when the solution turned brick red. Following the method outlined by A.O.A.C. (1995), reducing sugars were determined by measuring the volume of the aliquot utilized.

3.7.4.7 Non-reducing sugars

The total sugars were subtracted from the reducing sugars, and the resulting difference was multiplied by the standard factor of 0.95 to determine the non-reducing sugars. This calculation was conducted following the procedures delineated in A.O.A.C (1995).

3.7.4.8 Anthocyanin content:

The determination of anthocyanin content followed the method described by Swain and Hills (1959). Initially, the alcohol extract of the plant sample was prepared by grinding a known weight of fresh material in alcohol, followed by filtration or centrifugation to obtain the extract. Subsequently, 1 ml of the alcohol extract was transferred to a test tube, and 3 ml of 0.5N HCl in 80-85% methanol (HCl in aqueous methanol) was added. Then, 1 ml of anthocyanin reagent, prepared by mixing 1 ml of 30% H_2O_2 with 9 ml of methanolic HCl (5:1, 3N), was added to the sample. A blank solution was also prepared using 1 ml of methanol-HCl instead of the anthocyanin reagent. Following a 15-minute incubation periodin darkness, the absorbance of the sample against the blank was measured at 525 nm wavelength. The amount of anthocyanin present in the sample was then determined using a standard curve prepared with cyanin hydrochloride.

3.8 Observations on economics

3.8.1 Cost of cultivation

The cost of cultivating wheat using individual treatments was calculated by integrating all expenses incurred throughout the cultivation process, spanning from landpreparation to crop harvesting.

3.8.2 Gross income

The gross income of the experimental crop was computed by multiplying the total yield of wheat by the prevailing market price of strawberry, and the result was expressed in rupeesper hectare.

3.8.3 Net income

The net income of the experimental crop was determined by subtracting the cost of cultivation from the gross income of the experimental crop, and the result was expressed in rupees per hectare.

3.8.4 Benefit: Cost ratio

To ascertain the return per rupee invested, the benefit-cost (B:C) ratio was calculated using the following formula.

$$\text{enefit: cost ratio} = \frac{\text{Net return (Rs. ha}^{-1}\text{)}}{\text{Cost of cultivation (Rs. ha}^{-1}\text{)}}$$

3.9 Statistical Analysis

The data obtained throughout the study underwent analysis of variance (ANOVA), followed by Duncan's multiple-range test, which was performed utilizing SPSS v.23 software. This statistical analysis was employed to delineate homogeneous groups within distinct treatments concerning various plant parameters.

Chapter IV

Results and Discussion

The application of varying concentrations of nano urea, both in conjunction with *Azotobacter* and in isolation, yielded noteworthy outcomes concerning the growth, yield, and quality attributes of Winter Dawn cultivar of strawberry. The findings derived from this investigation, along with plausible explanations and pertinent discussions, are systematically elucidated under appropriate headings.

4.1 Vegetative parameters

4.1.1 Plant height (cm)

Table 4.1 depicts the data related to the variation in the plant height during the two years of the experiment (2022-23 and 2023-24) along with the pooled data and represented in figure 4.1. The perusal of data shows there was a significant effect of nano urea on plant height of Strawberry cv. Winter Dawn during both years of the research experiment.

During the initial year of the research experiment (2022-23), the maximum plant height at 30th day was observed under treatment T_{12} (75% RDF + N_1 + *Azotobacter*) having the value of 3.28 cm followed by T_8 (25% RDF + N_1 + *Azotobacter*), T_4 (50% RDF + N_2) and T_{13} (75% RDF + N_2 + *Azotobacter*) having values 3.25 cm, 3.22 cm and 3.22 cm, respectively. The control recorded 3.17 cm of plant height while the least (3.14 cm) was recorded under T_2 (25% RDF + N_1), T_{15} (50% RDF + *Azotobacter*) and T_{16} (75% RDF + *Azotobacter*), each. During the second trial (2023-24), the maximum plant height at 30th day was recorded under treatment T_{14} (25% RDF + *Azotobacter)* having the value of 3.41 cm which was followed by T_1 (control) and T_8 (25% RDF + N_1 + *Azotobacter*) having values 3.39 cm and 3.35 cm, respectively. The least height of the plant (3.14 cm) was recorded by treatment T_2 (25% RDF + N_1). The pooled data for the year 2022-23 and 2023-24 at 30th day's observation uncovered that the maximum height of plant was recorded under treatment T_8 (25% RDF + N_1 + *Azotobacter*) and T_{14} (25% RDF + *Azotobacter*) with a plant height of 3.30 cm each, followed by treatment T_1 (control) and T_{12} (75% RDF + N_1 + *Azotobacter*) having values 3.28 cm and 3.27 cm, respectively. The least plant height (3.17 cm) was recorded under the treatment T_5 (50% RDF + N_2).

Observations at 60^{th} day for plant height during the year 2022-23, recorded the maximum height under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) having the value of 5.60 cm followed by T_8 (25% RDF + N_1 + *Azotobacter*) and T_3 (25% RDF + N_2) with the value of 5.41 cm and 5.04 cm, respectively. The control treatment (T_1) recorded the plant height of 4.18 cm while the least height of the plant (4.10 cm) was observed under T_{14} (25% RDF + *Azotobacter*). In the second experimental year 2023-24, the maximum plant height was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) having the value of 5.73 cm followed by treatment T_8 (25% RDF + N_1 + *Azotobacter*) and T_9 (75% RDF + N_1 + *Azotobacter*) with the values 5.62 cm and 5.60 cm, respectively. The control treatment recorded a plant height of 4.31 cm while the minimum plant height (4.20 cm) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*). The pooled data revealed that during the two experimental years (2022-23 and 2023-24) maximum plant height of strawberry plants was observed at 60^{th} day under treatment T_9 (25% RDF + N_2 + *Azotobacter*) having the value of 5.67 cm followed by T_8 (25% RDF + N_1 + *Azotobacter*) and T_{12} (75% RDF + N_1 + *Azotobacter*) with the value of 5.52 cm, each. The control treatment T_1 recorded 4.25 cm of plant height while the minimal height of the plant (4.15 cm) was listed by treatment T_{14} (25% RDF + *Azotobacter*).

Observations for the day 90^{th} revealed that during the experimental year 2022-23, the maximum height was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) having the value of 7.83 cm while it was followed by T_3 (25% RDF + N_1 + *Azotobacter*) having value of 7.60 cm. The control was observed with 6.18 cm of plant height while the minimal height of the plant (5.67 cm) was observed by treatment T_{14} (25% RDF + *Azotobacter*). During the second-year trial (2023-24), maximum plant height (8.14) was recorded under treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_{11} (50% RDF + N_2 + *Azotobacter*) with the value of 7.85 cm. The control was recorded with 6.33 cm of plant height while the minimum (5.47 cm) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*). The combined data from both the years (2022-23 & 2023-24) illustrated that T_9 (25% RDF + N_2 + *Azotobacter*) recorded the maximum plant height (7.99 cm) during the experimental trials throughout followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and T_8 (25% RDF + N_1 + *Azotobacter*) and with the values of 7.69 cm and 7.65 cm, respectively. The control treatment recorded 6.26 cm of plant height and the least height of the plant (6.59 cm) was recorded by treatment T_{14} (25% RDF + *Azotobacter*).

Data observed for 120th day for the first trial (2022-23) showed maximum growth in plant height (12.44 cm) was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) significantly. It was followed by treatment T_8 (25% RDF + N_1 + *Azotobacter*) and T_3 (25% RDF + N_2) having the value of 11.87 cm and 11.84 cm, respectively. The control was recorded with the value of 9.99 cm and the minimal height of the plant (7.58 cm) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*). During the second-year trial (2023-24), the utmost plant height (12.87 cm) was listed by treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by treatment T_{10} (50% RDF + N_1 + *Azotobacter*) and T_8 (25% RDF + N_1 + *Azotobacter*) having the value of 11.87 cm and 11.85 cm, respectively. The control recorded 9.87 cm of plant height while the treatment T_{14} (25% RDF + *Azotobacter*) recorded the minimum plant height having a value of 7.52 cm. The pooled data revealed that the maximum plant height (12.66 cm) was observed under treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by treatment T_8 (25% RDF + N_1 + *Azotobacter*), T_3 (25% RDF + N_2) and T_{10} (25% RDF + N_2 + *Azotobacter*) having the value of 11.86 cm, 11.82 cm and 11.82 cm, respectively. The control was found with 9.93 cm of plant height which the treatment T_{14} (25% RDF + *Azotobacter*) was recorded with the nadir of plant height (7.55cm).

Nano urea with *Azotobacter* offers a synergistic approach to enhancing plant growth, particularly in increasing plant height. Folia spays of nano urea, with its nanoparticles, ensuresa more efficient delivery and absorption of urea by theleaves to its increased surface area compared to conventional urea (Cao *et. al.* 2024). This efficient utilization of nitrogen facilitates more robust vegetative growth (Ghadirnezhad *et. al.* 2024). On the other hand, *Azotobacter*, a nitrogen-fixing bacterium, independently contributes to the nitrogen economy of the soil by converting atmospheric nitrogen into a form that plants can readily absorb. This bacterium also secretes growth-promoting substances like phytohormones (auxins, gibberellins) and vitamins, which further stimulate plant growth (Cassan *et. al.* 2014). The combined effect of nano urea's enhanced nitrogen efficiency and *Azotobacter*'s bio fertilizing traits not only ensure a steady supply of nitrogen but also promotes better root and shoot development, leading to quicker and more substantial increases in plant height. This integrated approach therefore not only improves the nutrient uptake efficiency but also positively impacts the overall growth rate and health of the plant (Kannoj *et. al.* 2022).

Table 4.1: Effect of nano urea in combination with *Azotobacter* on plant height in strawberry cv. Winter Dawn.

Treatments	Plant height (cm)											
	30DAP			60DAP			90DAP			120 DAP		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	3.17^{a}	3.39^{a}	3.28^{a}	4.16^{b}	4.31^{ab}	4.25^{a}	6.18^{a}	6.33^{bc}	6.26^{b}	9.99^{a}	9.87^{c}	9.93^{c}
T_2	3.14^{a}	3.17^{a}	3.17^{a}	4.51^{e}	5.04^{c}	4.78^{d}	6.99^{b}	7.06^{def}	7.03^{def}	11.18^{bc}	11.32^{efg}	11.25^{ef}
T_3	3.21^{a}	3.20^{a}	3.21^{a}	5.04^{j}	5.20^{cd}	5.12^{e}	7.60^{e}	7.57^{fgh}	7.59^{hi}	11.84^{de}	11.80^{fg}	11.82^{h}
T_4	3.22^{a}	3.23^{a}	3.22^{a}	4.90^{g}	4.39^{ab}	4.33^{ab}	7.07^{cd}	7.33^{efg}	7.20^{fgh}	11.13^{bcd}	11.29^{ef}	11.21^{ef}
T_5	3.19^{a}	3.20^{a}	3.20^{a}	4.94^{h}	4.56^{ab}	4.58^{cd}	7.27^{d}	7.55^{fgh}	7.41^{ghi}	11.37^{bcd}	11.35^{efg}	11.36^{efg}
T_6	3.21^{a}	3.23^{a}	3.22^{a}	4.08^{a}	4.63^{b}	4.47^{bc}	6.74^{e}	6.72^{cd}	6.73^{cd}	10.77^{bcd}	10.56^{d}	10.66^{d}
T_7	3.20^{a}	3.19^{a}	3.20^{a}	4.68^{f}	4.65^{b}	4.55^{cd}	6.88^{b}	6.87^{cde}	6.88^{cde}	10.99^{vcd}	11.22^{e}	11.10^{e}
T_8	3.25^{a}	3.35^{a}	3.30^{a}	5.41^{l}	5.46^{e}	5.43^{gh}	7.66^{e}	7.64^{fgh}	7.65^{ij}	11.87^{de}	11.85^{fg}	11.86^{h}
T_9	3.15^{a}	3.32^{a}	3.24^{a}	5.60^{m}	5.73^{e}	5.67^{h}	7.83^{f}	8.14^{h}	7.82^{j}	12.44^{e}	12.87^{h}	12.66^{i}
T_{10}	3.20^{a}	3.31^{a}	3.26^{a}	5.20^{k}	5.47^{de}	5.34^{g}	7.26^{e}	7.48^{fg}	7.37^{ghi}	11.76^{de}	11.87^{g}	11.82^{h}
T_{11}	3.20^{a}	3.29^{a}	3.25^{a}	5.00^{i}	5.44^{cde}	5.39^{g}	7.52^{d}	7.85^{gh}	7.52^{ij}	11.83^{de}	11.74^{efg}	11.79^{h}
T_{12}	3.28^{a}	3.26^{a}	3.27^{a}	4.90^{g}	5.60^{de}	5.48^{gh}	6.71^{c}	6.72^{cd}	6.72^{cd}	11.54^{bcde}	11.60^{efg}	11.57^{fgh}
T_{13}	3.22^{a}	3.22^{a}	3.22^{a}	4.70^{f}	5.39^{cde}	5.39^{g}	6.87^{c}	6.31^{bc}	6.59^{bc}	11.66^{cde}	11.70^{efg}	11.68^{gh}
T_{14}	3.18	3.41^{a}	3.30^{a}	4.30^{d}	4.20^{a}	4.15^{a}	5.67^{b}	5.47^{a}	5.57^{a}	7.58^{b}	7.52^{a}	7.55^{a}
T_{15}	3.14^{a}	3.15^{a}	3.15^{a}	4.20^{c}	4.25^{ab}	4.20^{a}	5.76^{ab}	5.65^{a}	5.70^{a}	7.92^{ab}	8.06^{b}	7.99^{b}
T_{16}	3.14^{a}	3.21^{a}	3.17^{a}	4.20^{c}	4.26^{ab}	4.22^{a}	5.91^{a}	5.77^{ab}	5.84^{a}	8.01^{ab}	8.45^{b}	8.23^{b}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

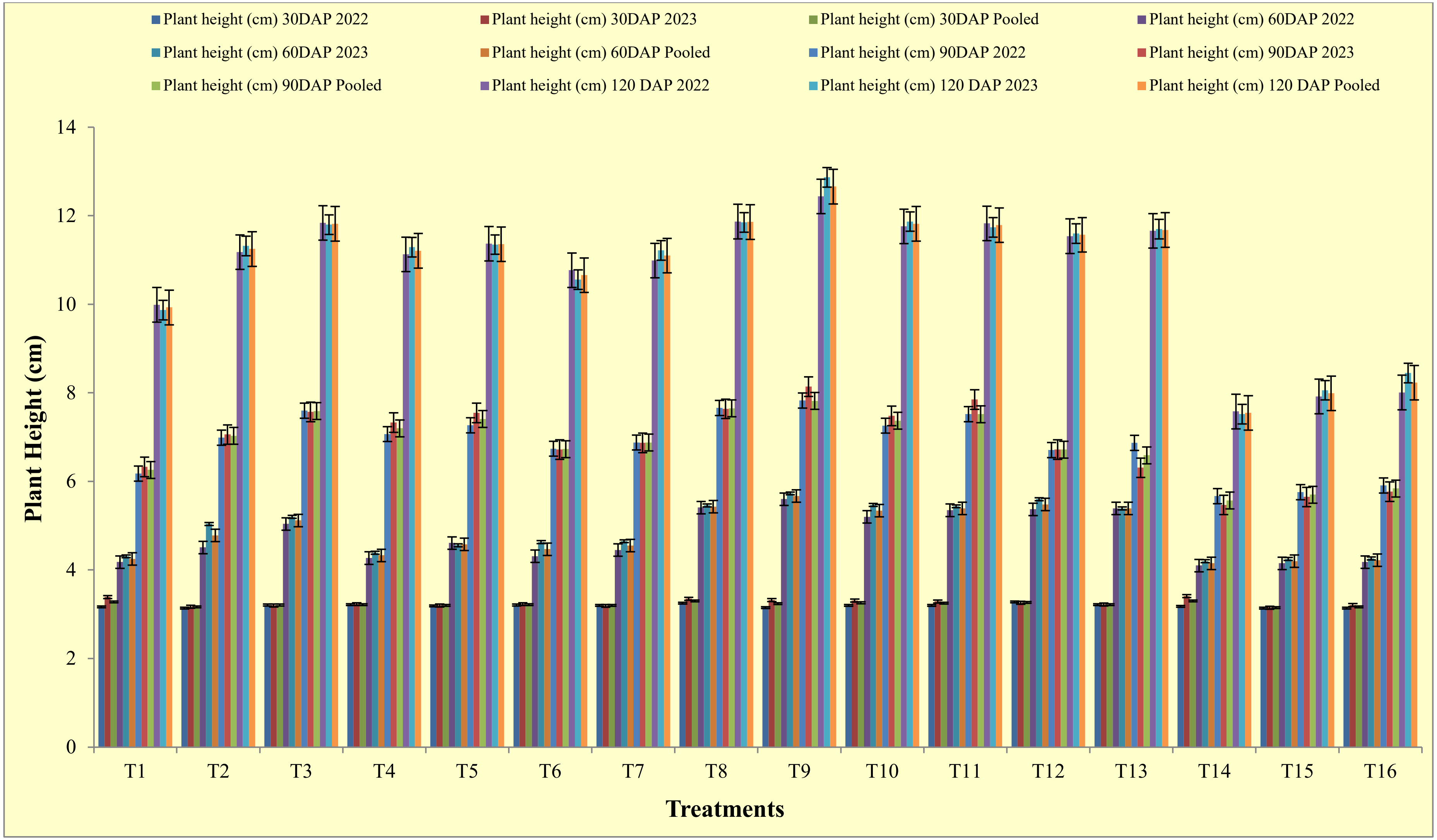

Figure 4.1: Effect of nano urea in combination with *Azotobacter* on plant height in strawberry cv. Winter Dawn.

Foliar application of nano nitrogen has been shown to enhance plant height through several mechanisms. Firstly, nano-sized nitrogen particles have a higher surface area to volume ratio compared to conventional nitrogen fertilizers, allowing for better absorption and utilization by plant tissues. This efficient uptake facilitates increased nitrogen assimilation within the plant, leading to enhanced protein synthesis and ultimately, greater cell division and elongation, which contribute to increased plant height (Gu *et. al.* 2018). Additionally, nano nitrogen particles may also stimulate hormonal pathways responsible for growth promotion, such as auxin signalling (Sonkar *et. al.* 2021; Ghosh and Bera, 2021), further facilitating elongation of plant stems and leaves. Overall, the application of foliar nano nitrogen presents a promising avenue for promoting plant growth and development, with potential implications for improving crop productivity and yield.

4.1.2 Plant Spread (North-South)

Data allied to the plant spread (NS) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside of the Table 4.2 and visually elucideted in Figure 4.2. A thorough examination of the data indicates a noteworthy impact of nano urea on the plant spread (NS) of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the plant spread (NS) of strawberry cv. Winter Dawn during both years of the research experiment.

During the initial year (2022-23) the maximum data related to plant spread (11.43 cm) for 30th day was recorded under treatment T_8 (25% RDF + N_1 + *Azotobacter*) followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and treatment T_1 (control) having the values of 11.39 cm and 11.30 cm, respectively. The minimum plant spread (NS) was recorded under the treatment T_7 (75% RDF + N_2) with a value of 10.85 cm. The second-year trial (2023-24) recorded the maximum plant spread (NS) was recorded under treatment T_4 (50% RDF + N_1) having the value of 11.33 cm followed by T_3 (25% RDF + N_2) and T_{11} (25% RDF + N_2 + *Azotobacter*) with the values 11.31 cm and 11.30 cm, each. The control which was observed with 11.20 cm while the least plant spread (NS) was recorded under the treatment T_{16} (75% RDF + *Azotobacter*) having a value 10.81 cm. The pooled data for the years 2022-23 and 2023-24 revealed that utmost of the plant spread (NS) was listed under the treatment T_{11} (50% RDF + N_2 + *Azotobacter*) having the value 11.35 cm followed by T_3 (25% RDF + N_2) and T_4 (50%

RDF + N_1 + *Azotobacter*) with the value of 11.29 cm and 11.27 cm, respectively. The control treatment T_1 was recorded 11.20 cm while the minimum plant spread (NS) was recorded under the treatment T_7 (75% RDF + N_2) with the value of 10.85 cm.

The significant maximum data at 60th day during the first experimental trial (2022-23) was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) with a value of 16.10 cm followed by T_3 (25% RDF + N_2) and T_8 (25% RDF + N_1 + *Azotobacter*) having the values of 15.61 cm and 15.36 cm, respectively against the control (T_1) which was recorded 13.47 cm. The minimum value for plant spread (NS) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*) having value 12.30 cm. During the second-year trial (2023-24), themaximum significant plant spread (NS) was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) with the value of 16.70 cm followed by T_3 (25% RDF + N_2) and T_{10} (50% RDF + N_1 + *Azotobacter*) having the value of 15.82 cm and 15.78 cm, respectively against the control (T_1) which was recorded 13.20 cm. The minimum plant spread (11.87 cm) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*). The pooled data for the both years (2022-23 as well as 2023-24) revealed the maximum plant spread NS (16.40 cm) under treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_{10} (50% RDF + N_1 + *Azotobacter*) with the value of 15.61 cm and 15.29 cm, respectively. The control treatment T_1 was recorded with 13.30 cm while the minimum (12.09 cm) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*).

During the first- year experiment (2022-23), the maximum plant spread (NS) at 90th day was recorded 18.00 cm under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_8 (25% RDF + N_1 + *Azotobacter*) having the value of 17.30 cm and 17.20 cm, each. The control (T_1) was recorded with 15.08 of plant spread (NS) while the utmost was listed under the treatment T_{14} (25% RDF + *Azotobacter*) with the value of 14.73 cm. The second-year trial (2023-24) recorded the maximum plant spread (18.69 cm) NS under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and T_3 (25% RDF + N_2) having the values 17.56 cm and 17.49 cm while the control (T_1) recorded 15.71 cm plant spread and minimum (14.59 cm) was recorded under T_{14} (25% RDF + *Azotobacter*). The pooled data for the both years (2022-23 as well as 2023-24) elucidated that the utmost plant spread (18.35 cm) was listed under treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_8 (25% RDF + N_1 + *Azotobacter*) having values 17.40 cm and 17.10 cm while the control (T_1) recorded 15.40 cm plant spread

(NS). The minimum plant spread (14.66 cm) NS was recorded under the treatment T_{14} (25% RDF + *Azotobacter*).

The significant maximum plant spread (22.4 cm) at 120^{th} day during the initial experimental year (2022-23) was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_8 (25% RDF + N_1 + *Azotobacter*) having the values of 21.1 cm and 21.0 cm, respectively while the control (T_1) recorded 17.4 cm plant spread (NS). The nadir plant spread (16.1 cm) NS was listed under the treatment T_{14} (25% RDF + *Azotobacter*). During the second experimental trial (2023-24), the maximum growth in plant spread (22.76 cm) was observed under treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_8 (25% RDF + N_1 + *Azotobacter*) and T_3 (25% RDF + N_2) having the values of 21.90 cm and 21.83 cm, each. The control (T_1) was recorded with 18.10 cm of plant spread (NS) while the minimum (16.05 cm) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*). The pooled data for the years 2022-23 and 2023-24 revealed that the utmost plant spread (NS) was listed with 22.58 cm under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_8 (25% RDF + N_1 + *Azotobacter*) having the similar values of 21.47 cm, each. The control recorded 17.77 cm plant spread (NS) while the minimum (16.06 cm) remained under the treatment T_{14} (25% RDF + *Azotobacter*).

In the cultivation of strawberries, the combined use of nano urea and *Azotobacter* has shown promise in enhancing the overall plant spread, an important factor for yielding high-quality fruit. Nano urea, due to its nanoparticle size, provides a more controlled and efficient release of nitrogen, a critical nutrient for the vegetative growth that underpins plant spread. The improved nitrogen availability supports the development of broader and healthier leaves and stronger runners, which are vital for the plant's vegetative expansion (Zheng and Lv. (2023). Concurrently, *Azotobacter* contributes to plant health by fixing atmospheric nitrogen, thus supplementing the soil's nitrogen content (Sumbul *et. al.* 2020), and by producing natural growth-promoting substances such as cytokinin and gibberellins (Kukreja *et. al.* 2004). These substances further stimulate the growth of strawberry plants, enhancing leaf size and runner formation. Moreover, the presence of *Azotobacter* can improve soil structure and fertility, promoting better root development that supports more extensive and robust plant spread (Minuț *et. al.* 2022). Therefore, the synergistic action of nano urea and *Azotobacter* not only maximizes nitrogen utilization but also directly influences the mechanisms that drive vegetative expansion, crucial for the successful cultivation of strawberries. This dual

Table 4.2: Effect of nano urea in combination with *Azotobacter* on plant spread (NS) in strawberry cv. Winter Dawn.

Treatments	Plant Spread (NS) (cm)											
	30DAP			60DAP			90DAP			120 DAP		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	11.30^{i}	11.10^{a}	11.20^{ab}	13.47^{c}	13.20^{b}	13.33^{c}	15.08^{c}	15.71^{bc}	15.40^{bc}	17.4^{c}	18.10^{c}	17.77^{c}
T_2	11.23^{e}	11.14^{a}	11.19^{ab}	14.70^{defgh}	14.17^{c}	14.44^{d}	16.41^{e}	16.51^{cdef}	16.46^{d}	18.9^{f}	18.89^{cd}	18.90^{e}
T_3	11.26^{f}	11.31^{a}	11.29^{ab}	15.40^{i}	15.82^{f}	15.61^{i}	17.30^{h}	17.49^{gh}	17.40^{e}	21.1^{h}	21.83^{g}	21.47^{h}
T_4	11.21^{d}	11.33^{a}	11.27^{ab}	14.47^{def}	14.97^{cde}	14.72^{cde}	16.07^{d}	16.37^{cdef}	16.22^{d}	18.0^{d}	20.18^{ef}	19.09^{e}
T_5	11.19^{c}	11.05^{a}	11.12^{ab}	14.63^{defgh}	14.75^{cde}	14.69^{de}	16.50^{e}	16.31^{cdef}	16.41^{d}	18.2^{de}	18.20^{c}	18.20^{cd}
T_6	11.23^{e}	11.04^{a}	11.14^{ab}	14.23^{d}	14.39^{cd}	14.31^{d}	15.57^{c}	15.77^{bcd}	15.67^{c}	19.0^{fg}	19.35^{de}	19.18^{ef}
T_7	10.85^{a}	10.86^{a}	10.85^{a}	14.37^{de}	14.53^{cd}	14.45^{d}	16.07^{d}	16.66^{efg}	16.37^{d}	18.3^{e}	18.30^{c}	18.30^{d}
T_8	11.43^{k}	10.98^{a}	11.2^{ab}	15.10^{hi}	15.48^{ef}	15.29^{ghi}	17.10^{gh}	17.10^{fgh}	17.10^{e}	21.0^{h}	21.90^{gh}	21.47^{h}
T_9	11.24^{e}	10.88^{a}	11.06^{ab}	16.10^{j}	16.70^{g}	16.40^{j}	18.00^{i}	18.69^{i}	18.35^{f}	22.4^{i}	22.76^{h}	22.58^{i}
T_{10}	11.28^{gh}	10.91^{a}	11.10^{ab}	14.93^{fghi}	15.78^{f}	15.36^{hi}	16.87^{f}	17.16^{fgh}	17.01^{e}	19.0^{fg}	20.22^{ef}	19.6^{fg}
T_{11}	11.39^{j}	11.30^{a}	11.35^{b}	15.03^{ghi}	15.02^{de}	15.03^{efg}	16.97^{fg}	17.56^{h}	17.26^{e}	19.2^{g}	20.56^{f}	19.88^{g}
T_{12}	10.98^{b}	11.18^{a}	11.08^{ab}	14.60^{defg}	14.80^{cde}	14.70^{de}	16.37^{e}	16.73^{def}	16.49^{d}	18.0^{d}	20.04^{ef}	19.02^{e}
T_{13}	11.29^{hi}	10.96^{a}	11.13^{ab}	14.83^{efgh}	14.77^{cde}	14.80^{def}	16.53^{e}	16.22^{cde}	16.38^{d}	19.0^{fg}	20.24^{ef}	19.62^{fg}
T_{14}	11.26^{f}	11.15^{a}	11.21^{ab}	12.30^{a}	11.87^{a}	12.09^{a}	14.73^{a}	14.59^{a}	14.66^{a}	16.1^{a}	16.05^{a}	16.06^{a}
T_{15}	11.19^{c}	10.91^{a}	11.05^{ab}	12.53^{ab}	12.65^{b}	12.59^{b}	14.90^{ab}	14.61^{a}	14.75^{a}	16.2^{a}	16.39^{ab}	16.31^{a}
T_{16}	11.27^{fg}	10.81^{a}	11.04^{ab}	12.77^{b}	13.02^{b}	12.90^{bc}	14.97^{b}	15.10^{ab}	15.03^{ab}	16.8^{b}	17.14^{b}	16.95^{b}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

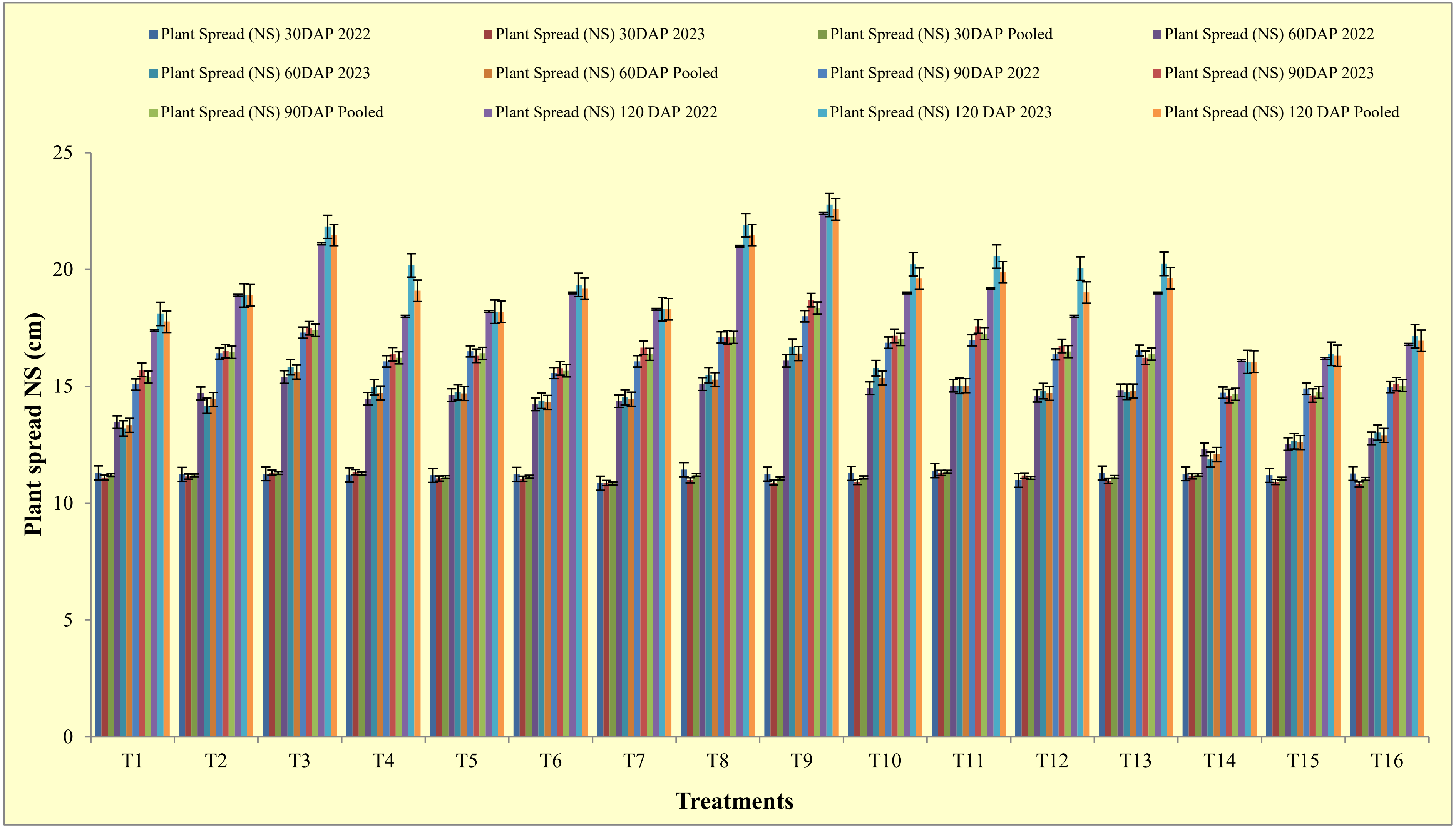

Figure 4.2: Effect of nano urea in combination with *Azotobacter* on plant spread (NS) in strawberry cv. Winter Dawn.

approach could significantly impact sustainable strawberry farming by increasing plant spread and potentially improving fruit yield and quality (Sharma *et. al.* 2023).

4.1.3 Plant Spread (East-West)

The data concerning the lateral expansion of plants (EW) alongside the fluctuations in plant spread over the course of the two experimental years (2022-23 and 2023-24) are detailed in Table 4.3 and elucidated in Figure 4.3. Analysis of the data reveals a noteworthy impact of nano urea on the lateral expansion of Winter Dawn cultivar strawberries throughout both years of the research investigation.

In the initial experimental year (2022-23), at 30th day, the maximum plant spread in east west direction (12.40 cm) was recorded under treatment T_3 (25% RDF + N_2). It was followed by T_{10} (50% RDF + N_1 + *Azotobacter*) and T_1 (control) having the values of 12.33 cm and 12.27 cm, each. The least value (11.83 cm) for plant spread in East West (EW) direction was recorded under treatment T_5 (50% RDF + N_2). During the second-year trial (2023-24), the maximum growth in plant spread (EW) at 30 days was recorded under treatment T_5 (50% RDF + N_1) with the value of 12.57 cm which was followed by T_8 (25% RDF + N_1 + *Azotobacter*) and control (T_1) having the value 12.55 cm and 12.45 cm, respectively. The minimum value (11.41 cm) was observed under the treatment T_7 (75% RDF + N_2). The pooled data for the years 2022-23 and 2023-24 revealed that the maximum average plant spread (EW) at 30 days was observed under T_1 (control) having the value of 12.36 cm and it was followed by T_4 (50% RDF + N_1) and T_8 (25% RDF + N_1 + *Azotobacter*) with the values of 12.28 cm and 12.23 cm respectively. The minimum (11.82 cm) was recorded under T_7 (75% RDF + N_2).

Data recorded at 60th day for the initial experimental year (2022-23) for plant spread (EW) showed the significant maximum growth under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) with the value of 17. 23 cm which was followed by T_3 (25% RDF + N_2) and T_8 (25% RDF + N_1 + *Azotobacter*) having the value of 16.80 cm and 16.10 cm, respectively. Subsequently, the second-year trial (2023-24) at same recording interval showed the maximum growth in plant spread (EW) under treatment T_9 (25% RDF + N_2 + *Azotobacter*) having the value of 18.17 cm. It was followed by T_{10} (50% RDF + N_1 + *Azotobacter*) and T_8 (25% RDF + N_1 + *Azotobacter*) with the values of 17.00 cm and 16.62 cm, respectively while the control (T_1) treatment recorded less with the growth of 14.02 cm of plant spread (EW) and the nadir of plant spread (11.47 cm) EW was listed under the treatment T_{14} (25% RDF + *Azotobacter*). The combined data for both the years 2022-23 and 2023-24 recorded the maximum plant spread (EW) under the treatment of T_9 (25% RDF + N_2 + *Azotobacter*) with a value of 17.70. It was followed by T_3 (25% RDF + N_2) and T_8 (25% RDF + N_1 + *Azotobacter*) with the values of 16.63 cm and 16.36 cm, respectively while the control (T_1) was recorded less with the value of 14.08 cm of plant spread. Least plant spread (EW) at 60th days after planting was recorded under the treatment T_{14} (25% RDF + *Azotobacter*) where the recorded value was 11.47 cm.

The observations at 90th day during initial experiment (2022-23), recorded the maximum plant spread (EW) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) having value of 19.40 cm followed by T_3 (25% RDF + N_2) and T_8 (25% RDF + N_1 + *Azotobacter*) with the value of 19.00 cm and 18.13 cm, each. The control (T_1) was recorded with 16.27 cm of plant spread (EW) while the minimum (14.17 cm) was observed under T_{14} (25% RDF + *Azotobacter*). The second-year trial (2023-24) data revealed the maximum growth in plant spread (EW) under the treatment T_{11} (50% RDF + N_2 + *Azotobacter*) having the value of 20.82 cm followed by T_9 (25% RDF + N_2 + *Azotobacter*) and T_{10} (50% RDF + N_1 + *Azotobacter*) with the value of 20.28 cm 19.96 cm, each. The control (T_1) was recorded with 16.15 cm of plant spread (EW) while the minimum (14.38 cm) was observed under the treatment T_{14} (25% RDF + *Azotobacter*). The pooled data for the both years (2022-23 as well as 2023-24) revealed the maximum growth of plant spread (EW) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) with the value of 19.84 cm subsequently by the treatment T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*) with the values of 19.39 and 19.35 cm, respectively. The control (T_1) recorded 16.21 cm of plant spread (EW) while the minimum 14.28 cm of plant spread (EW) was observed under the treatment T_{14} (25% RDF + *Azotobacter*).

The observation at 120th day during first year trial (2022-23) recorded the maximum plant spread (EW) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) having a value of 22.00 cm followed by T_3 (25% RDF + N_2) and T_8 (25% RDF + N_2 + *Azotobacter*) with the values of 21.23 cm and 20.37 cm of plant spread (EW), respectively. The control (T_1) was recorded with 18.30 cm while the minimum plant spread 16.07 cm (EW) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*). In the second-year trial (2023-24), the maximumplant spread (EW) was measured under T_9 (25% RDF + N_2 + *Azotobacter*) having a value of 22.53 cm followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 +

Azotobacter) with the values of 21.75 cm and 21.36 cm, respectively. The control (T_1) recorded 18.33 cm of spread (EW) while the treatment T_{14} (25% RDF + *Azotobacter*) recorded the minimum plant spread (EW). Pooling the data for both the years (2022-23 and 2023-24) revealed that the maximum plant spread (EW) was measured under T_9 (25% RDF + N_2 + *Azotobacter*) having a value of 22.26 cm followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*) with the values of 21.49 cm and 20.71 cm. The control treatment T_1 remained with 18.32 cm of plant spread (EW) while the minimum (16.40 cm) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*).

The use of nano urea in combination with *Azotobacter* has been effective in improving the growth of strawberry plants, particularly in increasing the spread of the plant, which is essential for high-quality fruit production. Nano urea, with its tiny particle size, allows for a more efficient and gradual release of nitrogen, essential for the vegetative growth that enhances plant spread. This ensures better development of leaves and stronger runners, which are crucial for the plant's expansion. Simultaneously, *Azotobacter* aids plant health by fixing nitrogen from the atmosphere, thus enhancing soil nitrogen levels (Sumbul *et. al.* 2020), and by generating growth-promoting hormones like cytokinin and gibberellins (Kukreja *et. al.* 2004). These hormones promote further growth in leaf size and runner production. Additionally, *Azotobacter* helps improve the soil's structure and fertility, which supports healthier root development and consequently a more expansive and robust plant spread. Therefore, the combined use of nano urea and *Azotobacter* not only optimizes nitrogen use but also plays a critical role in the vegetative growth processes essential for effective strawberry farming, potentially leading to better fruit yield and quality (Sharma *et. al.* 2023).

The cultivation of strawberries benefits significantly from the combined use of nano urea and *Azotobacter,* which enhances plant spread, a key element in producing high-quality fruit. Nano urea offers a more efficient nitrogen release due to its smaller particle size, promoting the growth of wider leaves and robust runners essential for the plant's expansion (Zheng and Lv., 2023). In parallel, *Azotobacter* enriches soil nitrogen through atmospheric nitrogen fixation (Sumbul *et. al.* 2020) and produces plant growth hormones such as cytokinin and gibberellins, boosting leaf and runner growth (Kukreja *et. al.* 2004). Additionally, *Azotobacter* can enhance soil quality and structure, leading to better root growth that supports an increased and healthier plant spread (Minuț *et. al.* 2022). This

Table 4.3: Effect of nano urea in combination with *Azotobacter* on plant spread (EW) in strawberry cv. Winter Dawn.

Treatments	Plant Spread (EW) (cm)											
	30DAP			60DAP			90DAP			120 DAP		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_{1}	12.27^{a}	12.45^{a}	12.36^{a}	14.13^{d}	14.02^{c}	14.08^{d}	16.27^{d}	16.15^{bc}	16.21^{c}	18.30^{c}	18.33^{c}	18.32^{c}
T_{2}	11.93^{a}	11.94^{a}	11.94^{a}	15.60^{h}	15.28^{de}	15.44^{fg}	17.53^{f}	17.72^{d}	17.63^{fg}	19.77^{g}	20.07^{de}	19.92^{fg}
T_{3}	12.40^{a}	11.48^{a}	11.94^{a}	16.80^{k}	16.46^{fg}	16.63^{k}	19.00^{i}	19.77^{e}	19.39^{gh}	21.23^{j}	21.75^{gh}	21.49^{j}
T_{4}	12.00^{a}	12.57^{a}	12.28^{a}	15.17^{g}	16.08^{efg}	15.63^{gh}	17.40^{f}	17.92^{d}	17.66^{fg}	19.23^{f}	20.22^{de}	19.73^{fgh}
T_{5}	11.90^{a}	12.13^{a}	11.98^{a}	15.60^{h}	16.75^{g}	16.18^{hi}	17.63^{fg}	18.15^{d}	17.89^{f}	19.67^{a}	20.39^{e}	20.03^{gh}
T_{6}	12.03^{a}	12.03^{a}	12.03^{a}	14.53^{e}	15.12^{d}	14.83^{e}	16.60^{e}	17.29^{cd}	16.95^{d}	18.57^{cd}	19.97^{de}	19.27^{ef}
T_{7}	12.23^{a}	11.41^{a}	11.82^{a}	14.87^{f}	15.17^{d}	15.02^{ef}	16.57^{de}	17.41^{cd}	16.99^{de}	18.73^{de}	19.36^{d}	19.05^{d}
T_{8}	11.90^{a}	12.55^{a}	12.23^{a}	16.10^{j}	16.62^{fg}	16.36^{ij}	18.13^{h}	19.52^{e}	18.83^{g}	20.37^{i}	20.63^{ef}	20.50^{hi}
T_{9}	12.07^{a}	11.74^{a}	11.90^{a}	17.23^{l}	18.17^{h}	17.70^{k}	19.40^{j}	20.28^{e}	19.84^{h}	22.00^{k}	22.53^{h}	22.26^{k}
T_{10}	12.33^{a}	11.58^{a}	11.96^{a}	15.50^{h}	17.00^{g}	16.25^{ij}	17.47^{f}	19.96^{e}	18.71^{g}	19.50^{fg}	19.90^{de}	19.70^{fgh}
T_{11}	12.00^{a}	11.82^{a}	11.91^{a}	15.83^{i}	16.57^{fg}	16.20^{ij}	17.87^{gh}	20.82^{e}	19.35^{gh}	20.07^{h}	21.36^{fg}	20.71^{i}
T_{12}	11.93^{a}	11.93^{a}	11.93^{a}	14.80^{f}	15.72^{def}	15.26^{efg}	16.83^{e}	17.69^{d}	17.26^{def}	18.87^{e}	19.84^{de}	19.35^{efg}
T_{13}	12.07^{a}	12.38^{a}	12.22^{a}	15.43^{h}	16.41^{fg}	15.92^{hi}	17.47^{f}	18.08^{d}	17.78^{f}	19.50^{a}	20.23^{de}	19.87^{fg}
T_{14}	12.07^{a}	11.88^{a}	11.97^{a}	12.13^{a}	11.47^{a}	11.80^{a}	14.17^{a}	14.38^{a}	14.28^{a}	16.07^{a}	16.73^{ab}	16.40^{a}
T_{15}	11.90^{a}	12.34^{a}	12.12^{a}	12.60^{b}	12.21^{ab}	12.41^{b}	14.53^{b}	14.46^{a}	14.50^{ab}	16.15^{a}	16.38^{a}	16.38^{a}
T_{16}	12.23^{a}	12.06	12.15^{a}	13.50^{c}	12.69^{b}	13.10^{c}	14.97^{c}	14.92^{ab}	14.95^{b}	17.20^{b}	17.34^{b}	17.27^{b}

T_{1}: RDF (PAU recommendation), T_{2}: 25% RDF + N_{1}, T_{3}: 25% RDF + N_{2}, T_{4}: 50% RDF + N_{1}, T_{5}: 50% RDF + N_{2}, T_{6}: 75% RDF + N_{1}, T_{7}: 75% RDF + N_{2}, T_{8}: 25% RDF + N_{1}+ *Azotobacter*, T_{9}: 25% RDF + N_{2}+ *Azotobacter*, T_{10}: 50% RDF + N_{1}+ *Azotobacter*, T_{11}: 50% RDF + N_{2}+ *Azotobacter*, T_{12}: 75% RDF + N_{1}+ *Azotobacter*, T_{13}: 75% RDF + N_{2}+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_{1}: 300 ppm Nano Urea, N_{2}: 400 ppm Nano Urea*

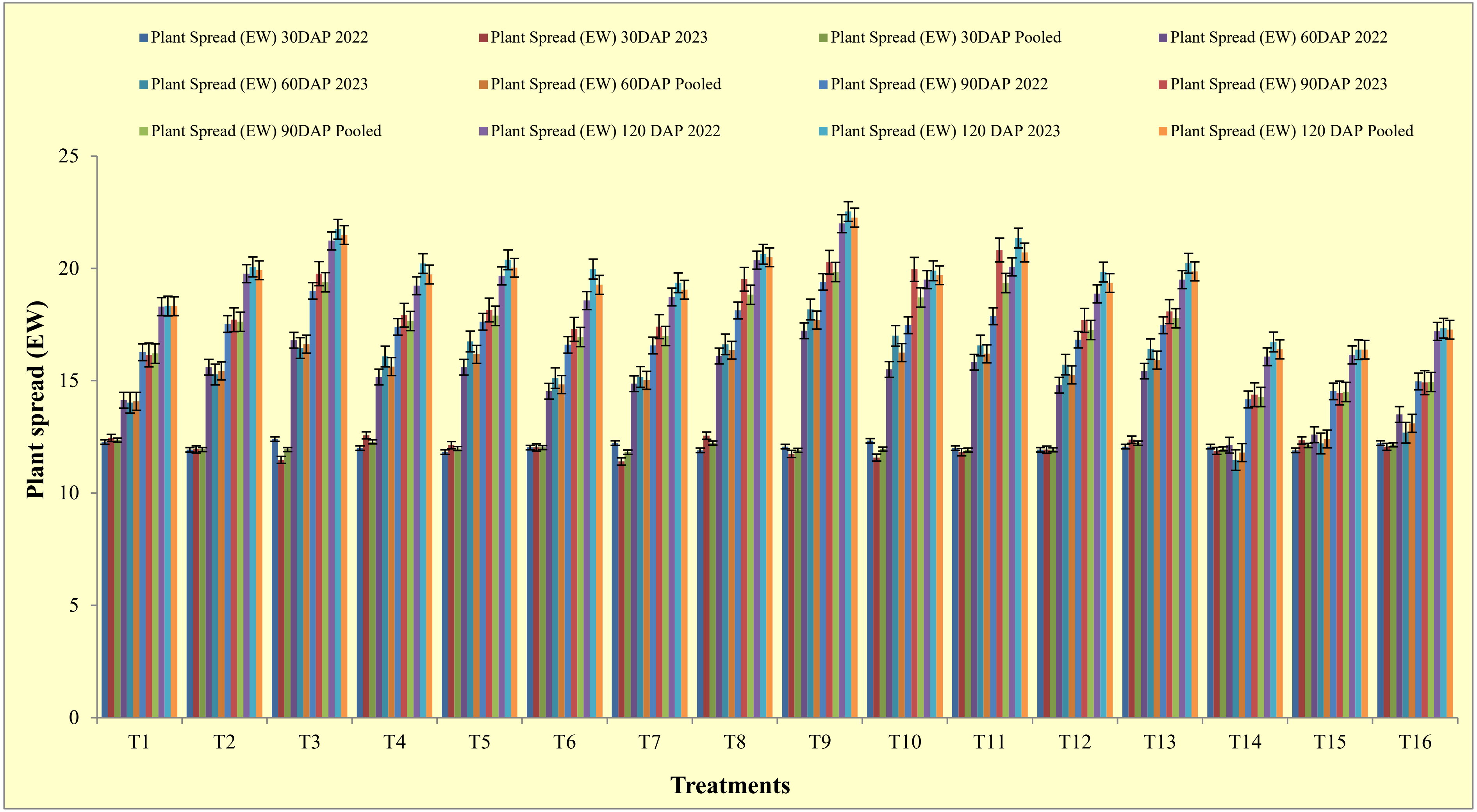

Figure 4.3: Effect of nano urea in combination with *Azotobacter* on plant spread (EW) in strawberry cv. Winter Dawn.

combined approach leverages enhanced nitrogen efficiency and supports growth mechanisms vital for robust strawberry cultivation, potentially raising both the yield and quality of the fruit (Sharma *et. al.* 2023). This method holds great potential for advancing sustainable practices in strawberry farming.

4.1.4 Chlorophyll Index (spad value)

Data related to the chlorophyll index (spad value) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside the Table 4.4 and elucidated inside the Figure 4.4. A thorough examination of the data indicates a noteworthy impact of nano urea on the chlorophyll index of Strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the chlorophyll index Strawberry cv. Winter Dawn during both years of the research experiment. This suggests that the application of nano urea has a notable effect on the chlorophyll index of the strawberry plants, showcasing its potential impact on the overall development of the crop.

During the first experimental year (2022-23), the chlorophyll index recorded at 30th day showed the maximum observations under the treatment T_4 (50% RDF + N_1) having an index value of 47.85 followed by T_8 (25% RDF + N_1 + *Azotobacter*) and T_2 (25% RDF + N_1) with the index value of 47.78 and 47.77, respectively. The control treatment (T_1) recorded a chlorophyll index of 47.56 while the minimum chlorophyll index was recorded under treatment T_5 (50% RDF + N_2) and T_{15} (50% RDF + *Azotobacter*) with the value of 47.54 each. In the second year (2023-24) experimental trial, the maximum chlorophyll index was observed under treatment control (T_1)having a value of 48.59 followed by T_{13} (75% RDF + N_2 + *Azotobacter*) and T_3 (25% RDF + N_1) with the value of 48.56 and 48.30, respectively. The pooled data for the both years (2022-23 and 2023-24) revealed that the maximum chlorophyll index (48.09) was recorded under T_{13} (75% RDF + N_2 + *Azotobacter*) followed by T_1 (control) and T_2 (25% RDF + N_1) with a value of 48.08 and 48.00, respectively. The least value (47.21) for chlorophyll index was recorded under treatment T_{12} (75% RDF + N_1 + *Azotobacter*).

In the initial experimental year (2022-23), the maximum chlorophyll index (51.46) at 60th day was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and T_{10} (50% RDF + N_1 + *Azotobacter*) having the value of 51.15 and 50.87, respectively. The control treatment (T_1) recorded a chlorophyll index of 48.96 while the least value for chlorophyll index (48.28) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*). During the second trial (2023-24), the maximum chlorophyll index (52.86) was recorded under treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_8 (25% RDF + N_1 + *Azotobacter*) and T_{11} (50% RDF + N_2 + *Azotobacter*) with the value of 51.64 and 51.48, respectively as against the control treatment (T_1) which was recorded 49.81 while the minimum value for chlorophyll index (48.24) was recorded under treatment T_{14} (25% RDF + *Azotobacter*). Pooling the data for both the years (2022-23 and 2023-24) showed the maximum observance of chlorophyll index (52.49) under T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and T_8 (25% RDF + N_1 + *Azotobacter*) having the values of 51.31 and 51.14, respectively. The control treatment (T_1) recorded a chlorophyll index of 49.39 while the least value (48.26) was recorded under T_{14} (25% RDF + *Azotobacter*).

During the first-year experimental research trial (2022-23), maximum chlorophyll index (53.37) at 90th day was observed under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_8 (25% RDF + N_1 + *Azotobacter*) with the values of 52.93 and 51.20 μmol m^{-2}, respectively. The control treatment (T_1) recorded a chlorophyll index of 50.86 μmol m^{-2} while the minimum chlorophyll index of 49.02 was recorded under the treatment T_{14} (25% RDF + *Azotobacter*). The second-year trial (2023-24) recorded the maximum chlorophyll index value (55.08) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + *Azotobacter*) and T_{10} (50% RDF + N_1 + *Azotobacter*) with the values of 54.78 and 54.38, respectively. The control treatment (T_1) recorded a chlorophyll index of 51.91 while the least value (49.36) for chlorophyll index was recorded under T_{14} (25% RDF + *Azotobacter*). Pooling the data for both the years (2022-23 and 2023-24) showed the maximum chlorophyll index (54.23) under T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_8 (25% RDF + N_1 + *Azotobacter*) with the value of 53.86 and 54.23, respectively. The control observed a chlorophyll index of 51.39 while the minimum value (49.19) was recorded under T_{14} (25% RDF + *Azotobacter*).

Observations at 120 DAP during the first year of research study (2022-23) revealed maximum chlorophyll index value (55.97) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_2 (25% RDF + N_1) with the values of 55.01 and 54.70, respectively. The control treatment (T_1) recordedchlorophyll index of 52.60

while the least value (50.09) was recorded under T_{14} (25% RDF + *Azotobacter*). The second-year trial (2023-24) recorded the maximum growth in chlorophyll index (55.80) under T_3 (25% RDF + N_2) followed by T_8(25% RDF + N_1 + *Azotobacter*) and T_2 (25% RDF + N_1) having the value 54.78 and 54.50, respectively. The control was recorded with 53.45 chlorophyll index while the minimum value (50.66) was recorded under T_{14} (25% RDF + *Azotobacter*). Pooling the data for both the years (2022-23 and 2023-24) showed the maximum chlorophyll index (55.41) under T_3 (25% RDF + N_2) followed by T_9 (25% RDF + N_2 + *Azotobacter*) and T_8 (25% RDF + N_1 + *Azotobacter*) having the value of 55.10 and 54.73, respectively. The control (T_1) recorded 53.03 chlorophyll indexe while the least value (50.38) was recorded under T_{14} (25% RDF + *Azotobacter*).

The integration of nano urea with *Azotobacter* in strawberry cultivation has been shown to expedite the enhancement of the chlorophyll index more effectively than conventional urea (Maity *et. al.* 2024). This outcome is primarily due to the more efficient delivery mechanism of nano urea, which, due to its nanoparticle formulation, provides a higher surface area for interaction with plant roots, ensuring a more controlled and sustained release of nitrogen (Iqbal, 2024). This increased efficiency in nitrogen delivery is crucial for chlorophyll synthesis, as nitrogen is a key component of chlorophyll molecules (Javed *et. al.* 2022). Furthermore, *Azotobacter* enhances this process by not only fixing atmospheric nitrogen, which adds to the nitrogen available to the plant, but also by producing natural growth stimulants that include phytohormones. These hormones promote further green leaf development, thereby increasing the chlorophyll content and improving the photosynthetic capacity of the plant. Thus, the synergistic use of nano urea and *Azotobacter* not only optimizes nitrogen utilization but also significantly boosts the chlorophyll index in strawberries, leading to better growth and potentially higher yields than those achieved with conventional urea. This dual approach reflects a shift towards more sustainable and efficient agricultural practices, particularly in enhancing key physiological parameters like chlorophyll levels in crop plants.

The mechanism involves the nanoparticles' unique ability to penetrate plant tissues more efficiently than conventional nitrogen forms (Hong *et. al.* 2021). Once absorbed by the leaves, nano nitrogen facilitates a more immediate and localized response in nitrogen metabolism (Ji, *et. al.* 2023). This direct supply boosts the synthesis of chlorophyll molecules, which are critical for photosynthesis and overall plant health (Paradiso *et. al.* 2023).

Table 4.4: Effect of nano urea in combination with *Azotobacter* on chlorophyll index (Spad value) in strawberry cv. Winter Dawn.

Treatments	Chlorophyll Index (spad value)											
	30DAP			60DAP			90DAP			120 DAP		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	47.56^{a}	48.59^{a}	48.08^{a}	48.96^{abc}	49.81^{abcd}	49.39^{ab}	50.86^{bcd}	51.91^{b}	51.39^{b}	52.60^{b}	53.45^{b}	53.03^{a}
T_2	47.77^{a}	48.22^{a}	48.00^{a}	49.92^{abcde}	50.47^{cde}	50.20^{bc}	52.72^{def}	53.64^{cdefg}	53.18^{efg}	54.70^{def}	54.50^{bc}	54.60^{defg}
T_3	47.61^{a}	48.30^{a}	47.95^{a}	50.24^{cde}	50.48^{cde}	50.36^{bc}	52.93^{ef}	54.78^{fg}	53.86^{g}	55.01^{ef}	55.80^{c}	55.41^{h}
T_4	47.85^{a}	46.88^{a}	47.37^{a}	49.63^{abcd}	49.36^{abc}	49.49^{ab}	51.92^{def}	53.98^{defg}	52.95^{defg}	53.45^{abc}	54.43^{bc}	53.94^{bcdef}
T_5	47.54^{a}	47.37^{a}	47.46^{a}	49.81^{abcde}	50.59^{cde}	50.20^{bc}	51.91^{def}	52.68^{bcd}	52.29^{bcdef}	53.57^{bcde}	53.68^{b}	53.63^{bcde}
T_6	47.69^{a}	48.03^{a}	47.86^{a}	49.68^{abcd}	48.68^{ab}	49.18^{ab}	50.87^{bcd}	52.16^{bc}	51.51^{bc}	52.38^{b}	54.18^{b}	53.28^{bc}
T_7	47.78^{a}	47.88^{a}	47.83^{a}	49.77^{abcd}	50.31^{bcde}	50.04^{bc}	51.20^{cde}	51.97^{b}	51.59^{bcd}	52.48^{b}	53.25^{b}	52.87^{b}
T_8	47.83^{a}	46.93^{a}	47.38^{a}	50.63^{de}	51.64^{ef}	51.14^{cd}	52.82^{ef}	54.37^{efg}	53.60^{fg}	54.67^{def}	54.78^{bc}	54.73^{fgh}
T_9	47.64^{a}	47.43^{a}	47.54^{a}	51.46^{e}	52.86^{f}	52.16^{d}	53.37^{f}	55.08^{g}	54.23^{g}	55.97^{f}	54.23^{bc}	55.10^{gh}
T_{10}	47.59^{a}	47.78^{a}	47.69^{a}	50.87^{de}	50.95^{cde}	50.91^{c}	52.07^{def}	54.38^{efg}	53.23^{efg}	53.77^{bcde}	54.19^{b}	53.98^{bcdef}
T_{11}	47.56^{a}	47.29^{a}	47.42^{a}	51.15^{de}	51.48^{def}	51.31^{cd}	51.92^{def}	53.85^{defg}	52.89^{cdefg}	54.13^{cde}	54.46^{bc}	54.29^{cdefg}
T_{12}	47.67^{a}	46.76^{a}	47.21^{a}	49.95^{bcde}	50.60^{cde}	50.28^{bc}	51.30^{cde}	52.92^{bcde}	52.11^{bcde}	52.95^{ab}	53.83^{b}	53.39^{bcd}
T_{13}	47.62^{a}	48.56^{a}	48.09^{a}	50.08^{bcde}	50.82^{cde}	50.45^{bc}	51.53^{def}	53.33^{bcdef}	52.43^{bcdef}	53.04^{ab}	54.13^{b}	53.59^{bcde}
T_{14}	47.57^{a}	47.21^{a}	47.39^{a}	48.28^{a}	48.24^{a}	48.26^{a}	49.02^{a}	49.36^{a}	49.19^{a}	50.09^{a}	50.66^{a}	50.38^{a}
T_{15}	47.54^{a}	47.40^{a}	47.47^{a}	48.48^{ab}	48.57^{a}	48.52^{a}	49.24^{ab}	49.71^{a}	49.48^{a}	50.37^{a}	50.79^{a}	50.58^{a}
T_{16}	47.60^{a}	47.11^{a}	47.36^{a}	48.63^{abc}	48.33^{a}	48.48^{a}	49.57^{abc}	49.89^{a}	49.73	50.63^{a}	51.46^{a}	51.04^{a}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

***Note:** N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

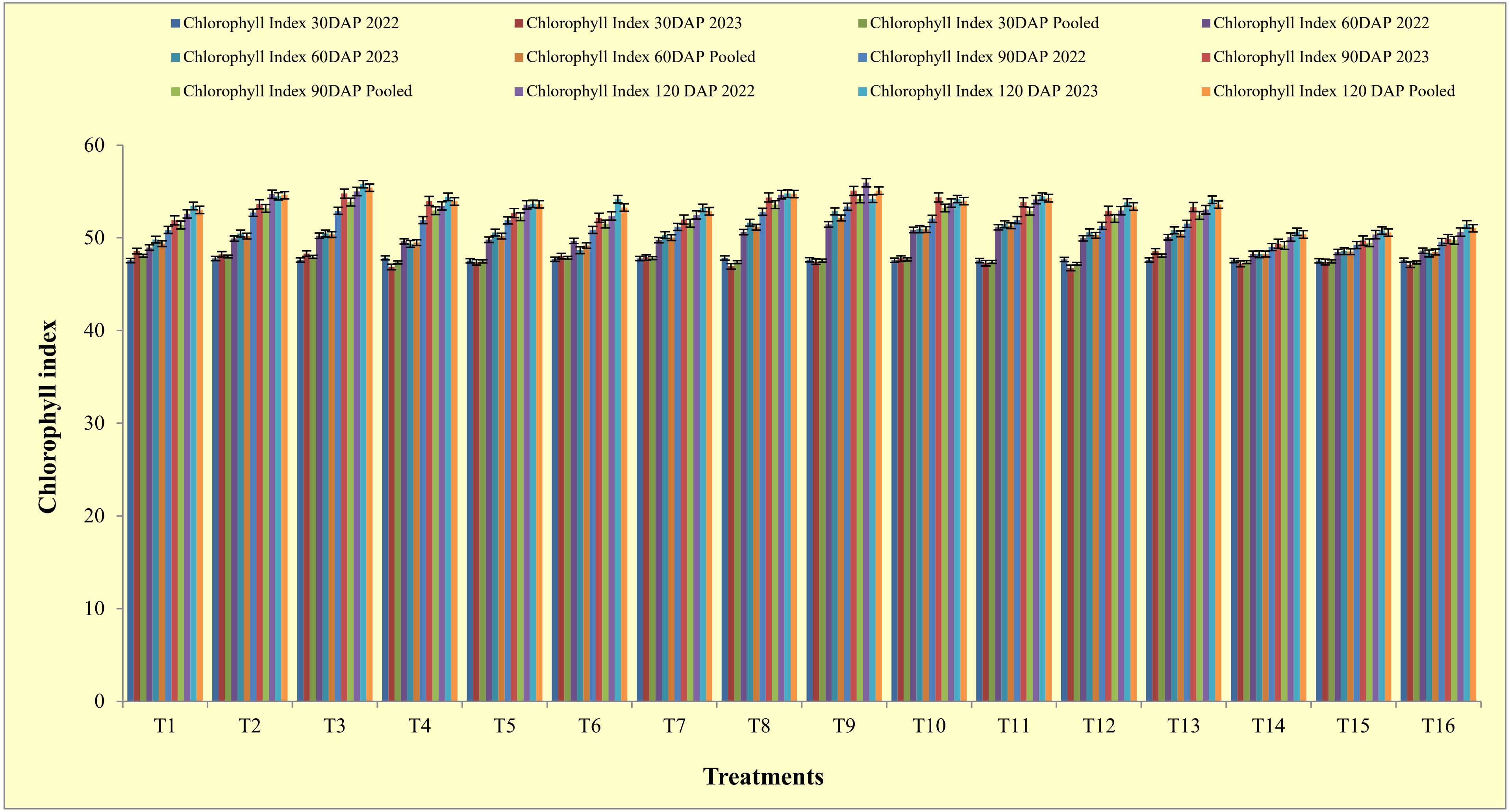

Figure 4.4: Effect of nano urea in combination with *Azotobacter* on chlorophyll index in strawberry cv. Winter Dawn.

The increased chlorophyll content not only improves photosynthetic efficiency but also contributes to greater biomass production and potentially higher yields (Burgess *et. al.* 2023). This targeted delivery system of nano nitrogen ensures that nutrients are more readily available to the plant, thereby optimizing nutrient use efficiency and promoting the chlorophyll index in the crop.

4.1.5 Number of flowers (per plant)

Data related to the flowers in number and its variation over the two experimental years (2022-23) is provided in Table 4.5 and visually depicted in Figure 4.5. A thorough examination of the data indicates a noteworthy impact of nano urea on the number of flowers of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the number of flowers strawberry cv. Winter Dawn during both years of the research experiment. This suggests that the application of nano urea has a notable effect on the number of flowers of the strawberry plants, showcasing its potential impact on the overall development of the crop.

During the first trial (2022-23) and second trial (2023-24), data recording for 30^{th} day exhibited nil flower emergences on strawberry plants. Combining the data for both the years (2022-23 and 2023-24) showed no existence of flowering during first data recording.

In the initial experimental trial (2022-23) the maximum data on 60^{th} day for number of flowers was recoded under T_9 (25% RDF + N_2 + *Azotobacter*) and T_3 (25% RDF + N_2) having a similar value of 2.67 flowers per plant followed by T_{10} (50% RDF + N_1 + *Azotobacter*), T_{11} (50% RDF + N_2 + *Azotobacter*), T_{12} (75% RDF + N_1 + *Azotobacter*) and T_{13} (50% RDF + N_2 + *Azotobacter*) with the similar value of 2.33 flowers per plant. The control was recorded with the value of 2.00 flowers per plant while the least number of flowers per plant (1.67) were recorded under T_{14} (25% RDF + *Azotobacter*). The second-year trial (2023-24) recorded the maximum growth for number of flowers per plant under the treatment T_{11} (50% RDF + N_2 + *Azotobacter*) with the value of 2.67 followed by T_3 (25% RDF + N_2), T_9 (50% RDF + N_2 + *Azotobacter*) and T_{10} (25% RDF + N_1 + *Azotobacter*) having a similar value of 2.33 flowers per plant. Pooling the data signified the maximum presence of number of flowers per plant under the treatment T_3 (25% RDF + N_2), T_9 (25% RDF + N_2 + *Azotobacter*) and T_{11} (50% RDF + N_2 + *Azotobacter*) with a similar value of

2.33 followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*) having the value of 1.13 and 1.12. The control (T_1) recorded 0.71 flowers while the least number of flowers (0.52) were recorded under T_{14} (25% RDF + *Azotobacter*).

During the initial trial (2022-24) the maximum presence on 90th day of number of flowers was recorded under T_9 (25% RDF + N_2 + *Azotobacter*) and T_{11} (50% RDF + N_2 + *Azotobacter*) having a similar value of 9.33 flowers per plant followed by T_2 (25% RDF + N_1), T_3 (25% RDF + N_2), T_{10} (50% RDF + N_1 + *Azotobacter*) and T_{13} (75% RDF + N_2 + *Azotobacter*) with the similar value of 8.67 flowers per plant. The control (T_1) treatment recorded 7.33 flowers per plant while the minimum number of flowers per plant (6.33) was recorded under T_{14} (25% RDF + *Azotobacter*). In the second year (2023-24) the maximum emergence of flowers per plant was recorded under T_9 (25% RDF + N_2 + *Azotobacter*) and T_{11} (50% RDF + N_2 + *Azotobacter*) having a similar value of 8.67 flowers per plant followed by T_8 (25% RDF + N_1 + *Azotobacter*) and T_{10} (50% RDF + N_1 + *Azotobacter*) with the similar value of 8.33 flowers per plant. The control was recorded with 6.67 flowers per plant while the least or minimum value was recorded under T_{14} (25% RDF + *Azotobacter*) having the value of 6.00 flowers per plant. Pooling the data for both the years revealed that the maximum emergence of number of flowers per plant (9.00) were recorded under treatment T_9 (25% RDF + N_2 + *Azotobacter*) and T_{11} (50% RDF + N_2 + *Azotobacter*) with a similar value followed by T_8 (50% RDF + N_1 + *Azotobacter*) and T_{10} (50% RDF + N_1 + *Azotobacter*) with the value of 8.67 and 8.50 flowers per plant, respectively.

The on-going first year trial (2022-23) recorded maximum number of flowers per plant at 120th day under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) having a value of 22.33 flowers per plant followed by T_3 (25% RDF + N_2), T_8 (25% RDF + N_1 + *Azotobacter*) and T_{11} (50% RDF + N_2 + *Azotobacter*) with the similar value of 21.67 flowers per plant. The control (T_1) was recorded with 20.33 flowers per plant while the least number of flowers were recorded under T_{14} (25% RDF + *Azotobacter*) having a value of 14.34 flowers per plant. During the second year (2023-24) of research study, the utmost emergence in number of flowers per plant (21.67) was occurred under treatment T_2 (25% RDF + N_1) followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and T_3 (25% RDF + N_2) having similar values of 21.33 flowers per plant. The control was recorded with 20.33 flowers per plant while the least count of flowers per plant was recorded under T_{14} (25% RDF + *Azotobacter*) with a value of 15.33 flowers per plant. Combining the data for both the years (2022-23 and 2023-24), revealed utmost number of flowers per plant (21.50) under the treatment T_3 (50% RDF + N_2), T_9 (25%

RDF + N_2 + *Azotobacter*) and T_{11} (50% RDF + N_2 + *Azotobacter*) with the similar value which was followed by T_2 (25% RDF + N_1) and T_8 (25% RDF + N_1 + *Azotobacter*) with the similar value recorded 21.33 flowers per plant. The control was recorded with 20.33 flowers per plant while on the other side, the least number of flowers per plant recorded under T_{14} (25% RDF + *Azotobacter*) with a value of 14.84 flowers per plant.

In strawberry cultivation, the combination of nano urea as a foliar application and *Azotobacter* as a basal dose has been observed to significantly enhance the number of flowers more rapidly than when using conventional urea. This improved flowering is attributable to the more efficient uptake and utilization of nitrogen provided by nano urea (AS *et. al.* 2023). Its nano-sized particles allow for better adherence to leaf surfaces and more effective absorption through stomata (Yu *et. al.* 2024), thus providing a direct, targeted nutrient boost that supports the development of reproductive structures like flowers (Hu and Xianyu, 2021) In addition, *Azotobacter*, applied as a basal dose, enriches the soil not just by fixing atmospheric nitrogen but also through the production of phytohormones that promote flower induction and development (Niranjan *et. al.* 2024). These bacteria also improve soil structure and fertility, facilitating better root growth and nutrient absorption (Zhou *et. al.* 2023). The synergistic effects of using nano urea for immediate nutrient needs via foliar feed and *Azotobacter* for long-term soil health and nutrient provisioning result in a more robust flowering response compared to traditional urea applications (Kralova and Jampílek, 2022). This strategy not only ensures that plants have access to essential nutrients during critical growth phases but also aligns with sustainable agriculture practices by reducing nitrogen loss and enhancing overall plant health. Rohi *et. al.* (2019) found the similar effect of nano urea on the flowers of olive (*Olea europaea* L.) where the foliar application of nano urea demonstrated the higher number of flowers than the conventional urea application. In addition to this, Bhatti *et. al.* (2023) examined the similar significant effect on *Psidium guajava* L. (guava) cv. Lucknow-49 whereas the enhancement was found inside of the number of flowers when application of nano urea was given before flowering. Further, it was explained that the foliar application of nano fertilizer can aid the metabolic roles of nitrogen in flowering and fruiting faster by incorporating the supply of carbohydrates (necessary for the growth of flower bud, initiation and development).

Table 4.5: Effect of nano urea in combination with *Azotobacter* on number of flowers in strawberry cv. Winter Dawn.

Treatments	Number of flowers (per plant)											
	30DAP			60DAP			90DAP			120 DAP		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	0^{a}	0^{a}	0^{a}	2.0^{a}	1.67^{a}	1.83^{a}	7.33^{abc}	6.67^{ab}	7.00^{ab}	20.33^{cd}	20.33^{b}	20.33^{cd}
T_2	0^{a}	0^{a}	0^{a}	2.33^{a}	2.00^{a}	2.17^{a}	8.67^{def}	7.00^{ab}	7.83^{ef}	21.00^{cde}	21.67^{b}	21.33^{cd}
T_3	0^{a}	0^{a}	0^{a}	2.67^{a}	2.33^{a}	2.50^{a}	8.67^{def}	7.67^{bcd}	8.17^{fhg}	21.67^{de}	21.33^{b}	21.50^{d}
T_4	0^{a}	0^{a}	0^{a}	2.33^{a}	2.00^{a}	2.17^{a}	8.00^{cde}	7.00^{ab}	7.50^{cde}	20.67^{cd}	20.00^{b}	20.33^{cd}
T_5	0^{a}	0^{a}	0^{a}	2.33^{a}	2.00^{a}	2.17^{a}	8.33^{cdef}	7.33^{bc}	7.83^{ef}	21.33^{cde}	20.67^{b}	21.00^{cd}
T_6	0^{a}	0^{a}	0^{a}	2.00^{a}	2.00^{a}	2.00^{a}	7.67^{bcd}	6.67^{ab}	7.17^{abc}	20.00^{c}	21.00^{b}	20.50^{cd}
T_7	0^{a}	0^{a}	0^{a}	2.00^{a}	1.67^{a}	1.83^{a}	8.00^{cde}	7.00^{ab}	7.50^{cde}	20.33^{cd}	20.00^{b}	20.17^{c}
T_8	0^{a}	0^{a}	0^{a}	2.33^{a}	2.00^{a}	2.17^{a}	9.00^{ef}	8.33^{cd}	8.67^{hi}	21.67^{de}	20.33^{b}	21.00^{cd}
T_9	0^{a}	0^{a}	0^{a}	2.67^{a}	2.33^{a}	2.50^{a}	9.33^{f}	8.67^{d}	9.00^{i}	22.33^{e}	20.67^{b}	21.50^{d}
T_{10}	0^{a}	0^{a}	0^{a}	2.33^{a}	2.33^{a}	2.33^{a}	8.67^{def}	8.33^{cd}	8.50^{ghi}	21.33^{cde}	20.67^{b}	21.00^{cd}
T_{11}	0^{a}	0^{a}	0^{a}	2.33^{a}	2.67^{a}	2.50^{a}	9.33^{f}	8.67^{d}	9.00^{i}	21.67^{de}	21.33^{b}	21.50^{d}
T_{12}	0^{a}	0^{a}	0^{a}	2.33^{a}	2.00^{a}	2.17^{a}	8.33^{cdef}	7.00^{ab}	7.67^{def}	20.67^{cd}	21.00^{b}	20.83^{cd}
T_{13}	0^{a}	0^{a}	0^{a}	2.33^{a}	2.00^{a}	2.17^{a}	8.67^{def}	7.33^{bc}	8.00^{efg}	20.67^{cd}	20.33^{b}	20.50^{cd}
T_{14}	0^{a}	0^{a}	0^{a}	1.67^{a}	1.67^{a}	1.67^{a}	6.33^{a}	6.00^{a}	6.17^{a}	14.34^{a}	15.33^{a}	14.84^{a}
T_{15}	0^{a}	0^{a}	0^{a}	2.00^{a}	2.00^{a}	2.00^{a}	6.67^{ab}	7.00^{ab}	6.83^{b}	15.00^{ab}	15.67^{a}	15.33^{ab}
T_{16}	0^{a}	0^{a}	0^{a}	2.00^{a}	2.00^{a}	2.00^{a}	7.33^{abc}	7.00^{ab}	7.17^{abc}	16.00^{b}	16.00^{a}	16.00^{b}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

***Note:** N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

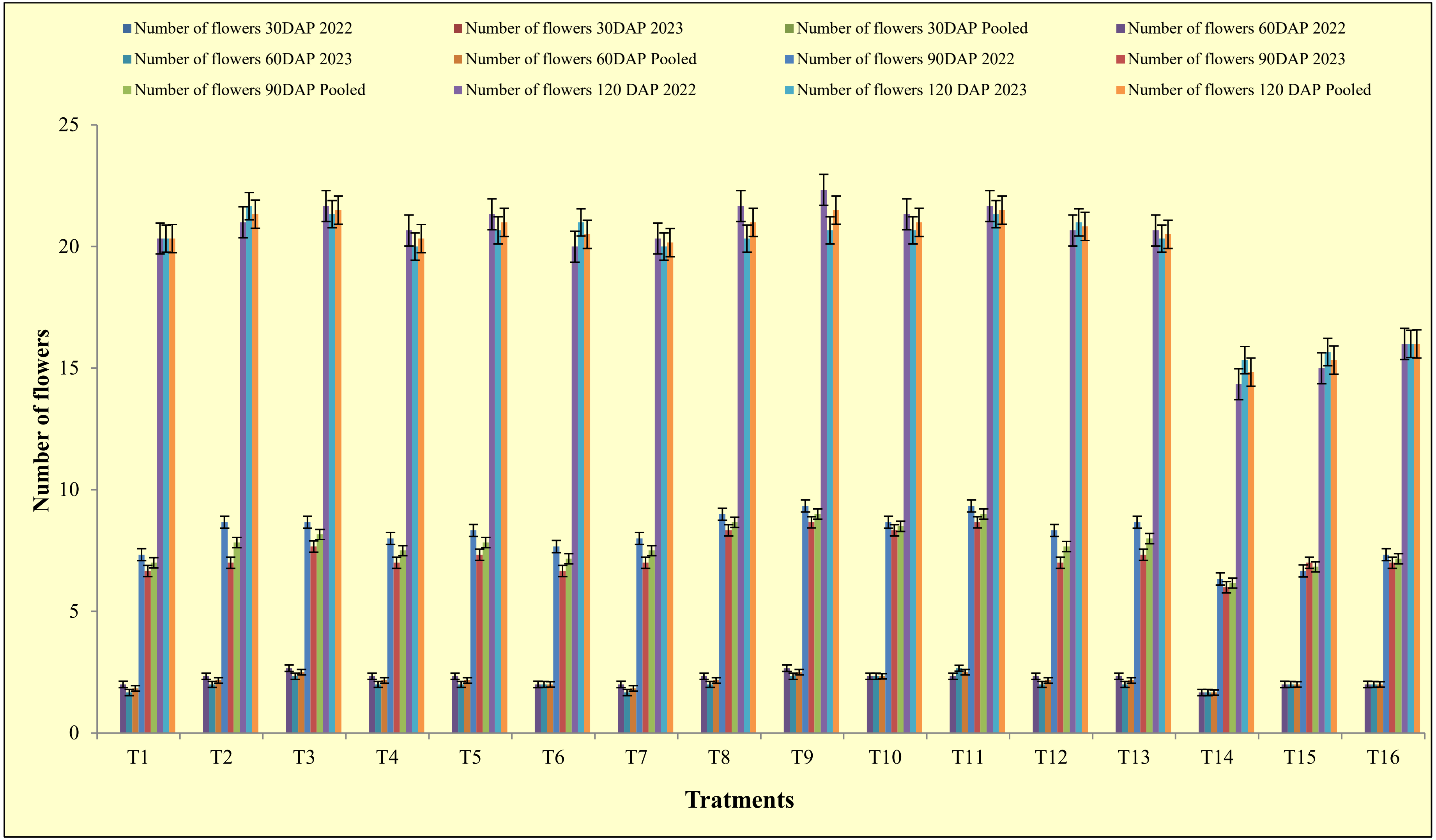

Figure 4.5: Effect of nano urea in combination with *Azotobacter* on number of flowers in strawberry cv. Winter Dawn.

4.1.6 Number of leaves (per plant)

Data related to the leaves in number per plant and its variation over the two experimental years (2022-23) is provided inside of the Table 4.6 and visually elucidated inside of the Figure 4.6. A thorough examination of the data indicates a noteworthy impact of nano urea on the number of leaves of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the number of leaves strawberry cv. Winter Dawn during both years of the research experiment.

In the initial year (2022-23) experiment the utmost number of leaves per plant (3.7) on 30th day were listed under treatment T_1 (Control) followed by T_2 (25% RDF + N_1) and T_9 (25% RDF + N_2 + *Azotobacter*) having values of 3.6 and 3.6 leaves per plant, respectively. The least number of leaves per plant (2.7) were recorded under T_{13} (75% RDF + N_2 + *Azotobacter*). During the second year trial (2023-24), the maximum number of flowers per plant (4.3) was recorded under treatment T_5 (50% RDF + N_2) followed by T_1 (Control) and T_6 (75% RDF + N_1) having the value of 3.9 and 3.8 leaves per plant, respectively. The least number of leaves per plant (3.2) were recorded under T_{12} (75% RDF + N_1 + *Azotobacter*). Pooling the data for both years (2022-23 and 2023-24) revealed the utmost number of leaves per plant (3.82) under T_1 (control) followed by T_5 (50% RDF + N_2) and T_{10} (50% RDF + N_1 + *Azotobacter*) having the values 3.72 and 3.70 leaves per plant, respectively.

During the first research trial (2022-23 and 2023-24), the maximum number of leaves on 60th day were recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) having the value of 6.6 leaves per plant which was followed by T_3 (50% RDF + N_1 + *Azotobacter*) and T_3 (25% RDF + N_2) with the value of 6.4 and 6.3 leaves per plant, respectively. The control treatment (T_1) recorded 5.6 leaves per plant while the least number of leaves were recorded under the treatment T_{14} (25% RDF + *Azotobacter*) with a value of 5.8 leaves per plant. The second-year trial recorded maximum leaves per plant (6.9) under T_{10} (50% RDF + N_1 + *Azotobacter*) followed by T_9 (25% RDF + N_2 + *Azotobacter*) and T_8 (25% RDF + N_1 + *Azotobacter*) with the values of 6.8 and 6.5 leaves per plant, the control (T_1) was recorded with 5.5 leaves per plant while the least value for the same was recorded under treatment T_1

(25% RDF + *Azotobacter*) having the value 5.1 leaves per plant. Pooling the data for both years (2022-23 and 2023-24) revealed maximum observance related to leaves per plant under (6.70) was recorded under T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_{10} (50% RDF + N_1 + *Azotobacter*) and T_8 (25% RDF + N_1 + *Azotobacter*) having values6.63 and 6.30 leaves per plant, respectively.

The first-year experimental trial (2022-23) significantly recorded maximum number of leaves on 90th day under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) having a value of 12.2 leaves per plant followed by T_3 (25% RDF + N_2) and T_8 (25% RDF + N_1 + *Azotobacter*) with the value of 11.6 and 11.1 leaves per plant, respectively. The control was recorded with 9.1 leaves per plant while the least value (8.3) was found under the treatment T_{14} (25% RDF + *Azotobacter*). The second-year trial (2023-24) recorded the maximum leaves per plant (14.0) under T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_{10} (50% RDF + N_1 + *Azotobacter*) and T_3 (25% RDF + N_2) having values 12.5 and 12.3 leaves per plant, respectively. The control treatment (T_1) recorded the leaves per plant with the value of 8.8 while the least value was recorded under the treatment T_{14} (25% RDF + *Azotobacter*). The combined data for both the years (2022-23 and 2023-24) revealed the maximum number of leaves per plant (13.10) under T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_8 (25% RDF + N_1 + *Azotobacter*) with the values 11.93 and 11.58 leaves per plant, respectively. The control (T_1) was recorded with 8.97 leaves per plant while the least value (7.95) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*).

In the initial year (2022-23), the data recording on 120th day reflected the significant growth in number of leaves per plant. The maximum numbers of leaves per plant (17.3) were recorded under T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*) having values 16.5 and 15.8 leaves per plant, respectively. The control treatment (T_1) recorded 13.5 leaves per plant while the least value (11.9) was recorded under T_{14} (25% RDF + *Azotobacter*). The second-year trial (2023-24) recorded maximum growth in number of flowers under T_9 (25% RDF + N_2 + *Azotobacter*) significantly with a value 18.3 leaves per plant followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and T_3 (25% RDF + N_2) having values 17.9 and 17.5 leaves per plant, respectively. Combining the data for both the years (2022-23 and 2023-24) revealed the maximum growth in number of leaves under T_9 (25% RDF + N_2 + *Azotobacter*) with a value of 17.78 leaves per plant followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*) having values 17.02 and 16.87 leaves per plant, respectively. The control

Table 4.6: Effect of nano urea in combination with *Azotobacter* on number of leaves in strawberry cv. Winter Dawn.

Treatments	Number of leaves (per plant)											
	30DAP			60DAP			90DAP			120 DAP		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T$_{1}$	3.7^{a}	3.9^{ab}	3.82^{a}	5.6^{a}	5.5^{a}	5.57^{ab}	9.1^{c}	8.8^{ab}	8.97^{b}	13.5^{c}	14.0^{b}	13.75^{b}
T$_{2}$	3.6^{a}	3.5^{ab}	3.58^{a}	6.0^{bcd}	6.2^{b}	6.10^{cd}	10.6^{hi}	10.1^{c}	10.35^{de}	15.0^{f}	16.3^{cdef}	15.67^{def}
T$_{3}$	3.5^{a}	3.5^{ab}	3.50^{a}	6.3^{def}	6.2^{b}	6.27^{d}	11.6^{k}	12.3^{e}	11.93^{h}	16.5^{h}	17.5^{fgh}	17.02^{g}
T$_{4}$	3.2^{a}	3.4a^{b}	3.30^{a}	6.1^{bcd}	6.2^{b}	6.12^{cd}	9.7^{e}	10.6^{cd}	10.13^{cde}	14.3^{d}	16.8^{defg}	15.55^{def}
T$_{5}$	3.1^{a}	4.3^{b}	3.72^{a}	6.2^{cde}	6.3^{bc}	6.22^{d}	10.0^{f}	10.8^{cd}	10.37^{de}	14.6^{e}	17.1^{efgh}	15.85^{ef}
T$_{6}$	3.4^{a}	3.8^{ab}	3.58^{a}	6.2^{cde}	6.1^{b}	6.12^{cd}	9.4^{d}	10.6^{cd}	9.97^{cd}	13.8^{c}	15.4^{c}	14.62^{c}
T$_{7}$	3.0^{a}	3.4^{ab}	3.20^{a}	6.1^{cde}	6.2^{b}	6.17^{cd}	9.5^{d}	9.8^{bc}	9.65^{c}	14.3^{de}	15.7^{cd}	15.03^{cd}
T$_{8}$	3.3^{a}	3.3^{a}	3.27^{a}	6.1^{cde}	6.5^{bcd}	6.30^{d}	11.1^{j}	12.1^{e}	11.58^{gh}	15.7^{g}	16.5^{cdef}	16.10^{f}
T$_{9}$	3.6^{a}	3.4^{ab}	3.50^{a}	6.6^{f}	6.8^{cd}	6.70^{e}	12.2^{l}	14.0^{f}	13.10^{i}	17.3^{i}	18.3^{h}	17.78^{h}
T$_{10}$	3.3^{a}	4.1^{ab}	3.70^{a}	6.4^{ef}	6.9^{d}	6.63^{e}	10.6^{h}	12.5^{e}	11.57^{gh}	15.0^{f}	16.8^{defg}	15.93^{ef}
T$_{11}$	3.4^{a}	3.6^{ab}	3.47^{a}	6.1^{cde}	6.3^{bcd}	6.23^{d}	10.8^{i}	12.0^{e}	11.42^{gh}	15.8^{g}	17.9^{gh}	16.87^{g}
T$_{12}$	3.5^{a}	3.2^{a}	3.35^{a}	6.0^{bcd}	6.3^{bc}	6.15^{cd}	10.0^{f}	11.4^{de}	10.73^{ef}	14.3^{d}	15.7^{cd}	15.00^{cd}
T$_{13}$	2.7^{a}	3.7^{ab}	3.17^{a}	6.1^{cde}	6.2^{b}	6.15^{cd}	10.3^{g}	12.1^{e}	11.20^{fg}	14.6^{de}	16.2^{cde}	15.38^{de}
T$_{14}$	3.3^{a}	3.2^{a}	3.27^{a}	5.8^{ab}	5.1^{a}	5.43^{a}	8.3^{a}	7.6^{a}	7.95^{a}	11.9^{a}	11.4^{a}	11.67^{a}
T$_{15}$	3.2^{a}	3.7^{ab}	3.45^{a}	5.9^{bc}	5.2^{a}	5.57^{ab}	8.5^{b}	8.0^{a}	8.27^{a}	12.1^{a}	11.2^{a}	11.63^{a}
T$_{16}$	3.3^{a}	3.3^{a}	3.32^{a}	6.1^{cde}	5.6^{a}	5.85^{bc}	8.6^{b}	8.1^{a}	8.35^{a}	12.5^{b}	11.7^{a}	12.08^{a}

T$_{1}$: RDF (PAU recommendation), T$_{2}$: 25% RDF + N$_{1}$, T$_{3}$: 25% RDF + N$_{2}$, T$_{4}$: 50% RDF + N$_{1}$, T$_{5}$: 50% RDF + N$_{2}$, T$_{6}$: 75% RDF + N$_{1}$, T$_{7}$: 75% RDF + N$_{2}$, T$_{8}$: 25% RDF + N$_{1}$+ *Azotobacter*, T$_{9}$: 25% RDF + N$_{2}$+ *Azotobacter*, T$_{10}$: 50% RDF + N$_{1}$+ *Azotobacter*, T$_{11}$: 50% RDF + N$_{2}$+ *Azotobacter*, T$_{12}$: 75% RDF + N$_{1}$+ *Azotobacter*, T$_{13}$: 75% RDF + N$_{2}$+ *Azotobacter*, T$_{14}$: 25% RDF + *Azotobacter*, T$_{15}$: 50% RDF + *Azotobacter*, T$_{16}$: 75% RDF + *Azotobacter*.

Note: *N$_{1}$: 300 ppm Nano Urea, N$_{2}$: 400 ppm Nano Urea*

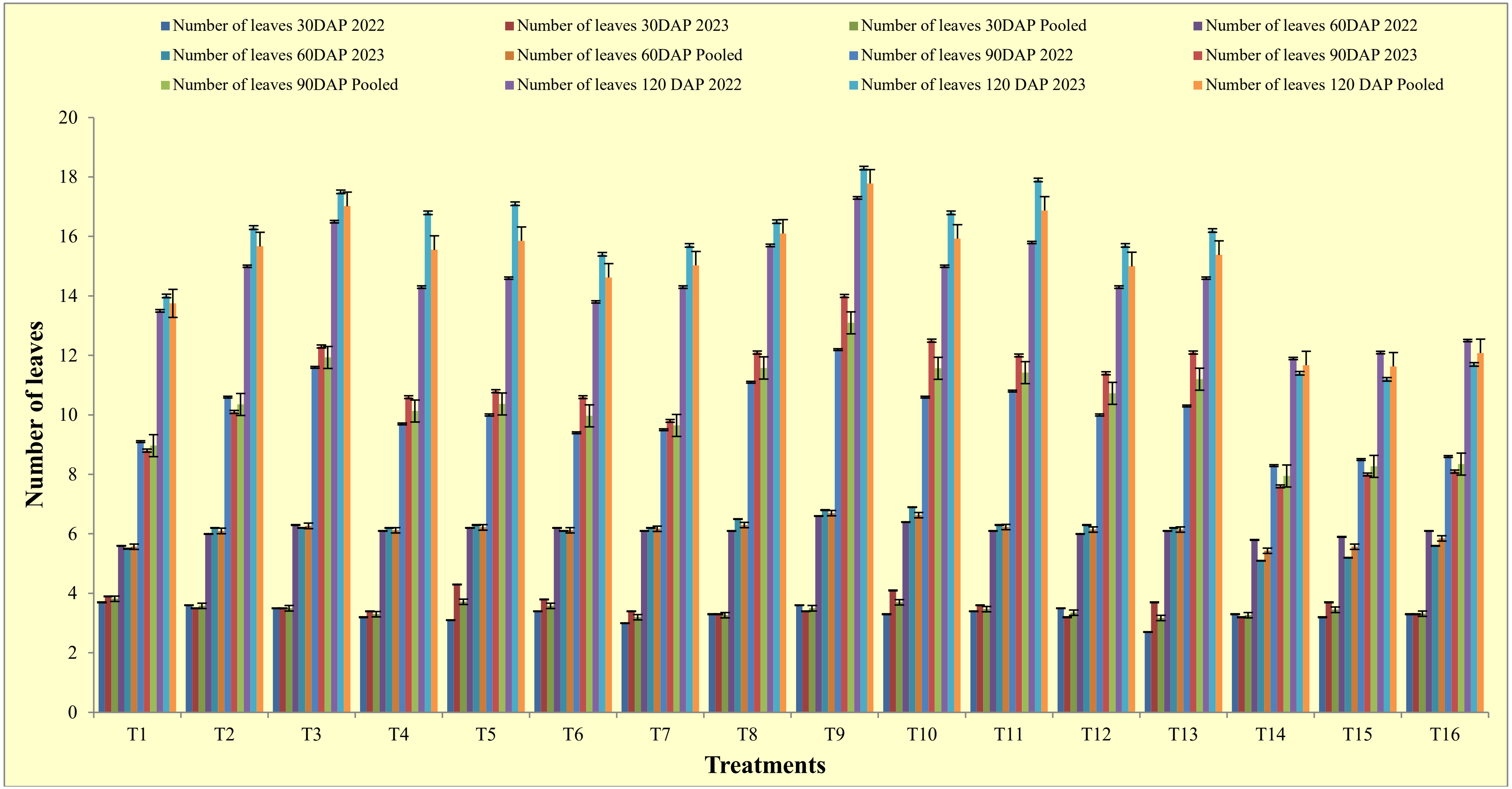

Figure 4.6: Effect of nano urea in combination with *Azotobacter* on number of leaves in strawberry cv. Winter Dawn.

treatment (T_1) recorded 13.75 leaves per plant while the least value (11.67 leaves per plant) was recorded under treatment T_{14} (25% RDF + *Azotobacter*).

The application of nano urea combined with *Azotobacter* has shown potential in significantly enhancing the number and spread of leaves in strawberry plants, which is critical for photosynthesis and, ultimately, fruit production (Maity *et. al.* 2024). Nano urea delivers nitrogen more efficiently due to its smaller particle size (Kumar *et. al.* 2023), which increases the surface area for absorption, ensuring that the plants receive a steady and more readily available supply of this crucial nutrient (Yadav *et. al.* 2023). This enhanced nitrogen availability directly supports the formation of new leaves and the expansion of existing ones. Concurrently, *Azotobacter*, as a nitrogen-fixing bacterium (Ouyang *et. al.* 2024), not only aids in supplementing additional nitrogen but also secretes phytohormones such as auxins and gibberellins. These hormones are known to promote leaf cell division and enlargement, thus further accelerating leaf development and expansion (Wu *et. al.* 2021). Additionally, the presence of *Azotobacter* in the rhizosphere can enhance soil health, improving the nutrient uptake (Sumbul et. al, 2020) capabilities of the strawberry plants. Through these mechanisms, the combined use of nano urea and *Azotobacter* effectively promotes a denser and faster leaf development, which is essential for creating a larger photosynthetic area, thus supporting better overall plant growth and productivity in strawberries. This approach offers a sustainable and efficient way to boost leaf biomass, which is pivotal for any strategy aimed at enhancing the yield and quality of strawberry crops. A research study by Zahedi *et. al.* (2019) demonstrated the effectiveness of nano fertilizers on the pomegranate (*Punica granatum* L.) which resulted in improved leaves in number of the tree.

4.2 Fruit physical parameters

4.2.1 Number of fruits (per plant)

Data related to the fruits in number per plant and its variation over the two experimental years (2022-23) is provided in Table 4.7 and visually depicted in Figure 4.7. A thorough examination of the data indicates a noteworthy impact of nano urea on the number of fruits of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the number of fruits strawberry cv. Winter Dawn during both years of the research experiment.

On-going first year trial (2022-23) and second year trial (2023-24) as well recorded no fruit appearance per plant on 30th day under any of the treatments. Pooling the data for both the years remained with null observation in number of fruits.

The first-year experimental trial (2022-23) recorded the maximum fruit growth at 60th day under treatment T_9 (25% RDF + N_2 + *Azotobacter*) with 2.67 fruits per plant followed by T_{11} (50% RDF + N_2 + *Azotobacter*), T_3 (25% RDF + N_2) and T_{10} (50% RDF + N_1 + *Azotobacter*) with values 2.33, 2.00 and 2.00 numbers of fruits per plant, respectively. The control treatment (T_1) recorded 1.00 fruits per plant while the least value (0.34 fruits per plant) was observed under treatment T_{14} (25% RDF + *Azotobacter*). The second-year experimental research trial (2023-24) recorded maximum fruits under T_{11} (50% RDF + N_2 + *Azotobacter*) with a value of 2.33 fruits per plant followed by T_9 (25% RDF + N_2 + *Azotobacter*) and T_8 (25% RDF + N_1 + *Azotobacter*) with 2.00 and 1.67 fruits per plant, respectively. The control treatment (T_1) recorded 0.67 fruits per plant while the least value (0.00) was recorded under T_{14} (25% RDF + *Azotobacter*). Combining the data for both the years (2022-23 and 2023-24) found maximum number of fruits per plant under treatment T_9 (25% RDF + N_2 + *Azotobacter*) and T_{11} (50% RDF + N_2 + *Azotobacter*) with value of 2.33 fruits per plant in each, followed by T_3 (25% RDF + N_2) T_8 (25% RDF + N_1 + *Azotobacter*) and T_{10} (50% RDF + N_1 + *Azotobacter*) having values 1.67 fruits per plant, each. The control treatment (T_1) was recorded with 0.83 fruits per plant while the least value (0.17 fruits per plant) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*).

In the first-year trial (2022-23) at 90th day, the treatment T_9 (25% RDF + N_2 + *Azotobacter*) recorded the maximum number of fruits per plant (8.33) followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*) with values of 7.87 and 7.67 fruits per plant, respectively. The control treatment (T_1) recorded 6.33 fruits per plant while the least (3.44 fruits per plant) were recorded under the treatment T_{14} (25% RDF + *Azotobacter*). The second-year experiment (2023-24) recorded the maximum number of fruits per plant (7.97) under the treatment T_{11} (50% RDF + N_2 + *Azotobacter*) followed by T_8 (25% RDF + N_1 + *Azotobacter*) and T_{12} (75% RDF + N_1 + *Azotobacter*) having values of 7.20 and 7.00 fruits per plant, respectively. The treatment control (T_1) recorded 5.33 fruits per plant while the least (3.33 fruits per plant) were recorded under T_{14} (25% RDF + *Azotobacter*). Combining the data for both the years (2022-23 and 2023-24) revealed the maximum number of fruits per plant (7.82) under the treatment T_{11} (50% RDF + N_2 + *Azotobacter*) followed by treatment T_9 (25% RDF + N_2 + *Azotobacter*) and treatment T_8 (25% RDF + N_1 + *Azotobacter*) having values of 7.61 and 7.40 fruits per plant, respectively.

During the first-year trial (2022-23) at 120th day, the treatment T_3 (25% RDF + N_2) recorded the maximum number of fruits per plant (20.67) significantly, followed by T_8 (25% RDF + N_1 + *Azotobacter*) and T_9 (25% RDF + N_2 + *Azotobacter*) having values 20.63 and 20.57 fruits per plant, respectively. The control was recorded with 20.33 fruits per plant while the least (14.34 fruits per plant) were recorded under the treatment T_{14} (25% RDF + *Azotobacter*). The second year (2023-24) trial recorded the maximum number of fruits per plant (23.16) under treatment T_2 (25% RDF + N_1) followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and T_6 (75% RDF + N_1) having values 21.00 and 20.97 fruits per plant, respectively. The control treatment (T_1) recorded 20.07 fruits per plant while least (14.70 fruits per plant) were recorded under the treatment T_{14} (25% RDF + *Azotobacter*). Combining the both year (2022-23 and 2023-24) data revealed maximum number of fruits per plant (21.75) under the treatment T_2 (25% RDF + N_1) followed by T_6 (75% RDF + N_1) and T_9 (25% RDF + N_2 + *Azotobacter*) with values 20.68 and 20.62 fruits per plant, respectively. The control recorded 20.20 fruits per plant while the least (14.52 fruits per plant) was recorded under the treatment T_{14} (25% RDF + N_2 + *Azotobacter*).

The integration of nano urea with *Azotobacter* has emerged as a promising approach in enhancing fruit production, particularly in crops like strawberries. This innovative technique capitalizes on the synergistic effects of nano-scale urea particles and the beneficial bacteria *Azotobacter*, which collectively stimulate plant growth and development (Ravishankar and Ambati, 2019). Nano urea, due to its smaller particle size, facilitates better nutrient uptake by plants, ensuring efficient utilization of nitrogen, a crucial element for fruit development (Subramani *et. al.* 2023). Additionally, the presence of *Azotobacter* further enhances nitrogen availability through biological nitrogen fixation, thereby reducing the dependency on conventional urea fertilizers and mitigating the risk of environmental pollution associatedwith their overuse (Chaudhary *et. al.* 2020). This symbiotic relationship between nano urea and *Azotobacter* not only optimizes nutrient utilization but also promotes overall plant health,leading to increased flower formation and ultimately, higher fruit yields in strawberries. The implications of this research extend beyond mere agricultural productivity; it offers a sustainable solution to address the challenges of nutrient management and environmental sustainability in modern agriculture. Through comprehensive field trials and physiological analyses, this study aims to elucidate the underlying mechanisms

Table 4.7: Effect of nano urea in combination with *Azotobacter* on number of fruits in strawberry cv. Winter Dawn.

Treatments	Number of Fruits (per plant)											
	30DAP			60DAP			90DAP			120 DAP		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	0^{a}	0^{a}	0^{a}	1.00^{abc}	0.67^{abc}	0.83^{abc}	6.33^{c}	5.33^{bcd}	5.83^{c}	20.33^{b}	20.07^{cde}	20.20^{b}
T_2	0^{a}	0^{a}	0^{a}	1.33^{abcd}	0.67^{abc}	1.00^{abc}	7.33^{def}	6.67^{ef}	7.00^{def}	20.33^{c}	23.16^{f}	21.75^{c}
T_3	0^{a}	0^{a}	0^{a}	2.00^{cde}	1.33^{bcde}	1.67^{cd}	7.87^{cd}	4.67^{bc}	6.27^{cd}	20.67^{b}	19.73^{bcd}	20.20^{b}
T_4	0^{a}	0^{a}	0^{a}	1.33^{abcd}	1.00^{abcd}	1.17^{bc}	6.67^{cd}	5.67^{cde}	6.17^{cd}	20.50^{b}	20.00^{cde}	20.25^{b}
T_5	0^{a}	0^{a}	0^{a}	0.67^{ab}	0.67^{abc}	0.67^{ab}	7.67^{def}	6.00^{de}	6.83^{cdef}	20.50^{b}	18.83^{b}	19.66^{b}
T_6	0^{a}	0^{a}	0^{a}	0.67^{ab}	0.67^{abc}	0.67^{ab}	6.88^{cd}	5.67^{cde}	6.27^{cd}	20.39^{b}	20.97^{e}	20.68^{b}
T_7	0^{a}	0^{a}	0^{a}	0.67^{ab}	1.33^{bcde}	1.00^{abc}	7.00^{cde}	6.33^{def}	6.67^{cde}	20.17^{b}	19.92^{cde}	20.04^{b}
T_8	0^{a}	0^{a}	0^{a}	1.67^{bcde}	1.67^{cde}	1.67^{cd}	7.60^{ef}	7.20^{fg}	7.40^{ef}	20.63^{b}	20.33^{cde}	20.48^{b}
T_9	0^{a}	0^{a}	0^{a}	2.67^{e}	2.00^{de}	2.33^{d}	8.33^{ef}	6.88^{efg}	7.61^{ef}	20.57^{b}	20.67^{de}	20.62^{b}
T_{10}	0^{a}	0^{a}	0^{a}	2.00cde	1.33^{bcde}	1.67^{cd}	7.00^{cde}	6.33^{def}	6.67^{cde}	20.20^{b}	19.44^{bc}	19.82^{b}
T_{11}	0^{a}	0^{a}	0^{a}	2.33^{de}	2.33^{e}	2.33^{d}	7.67^{f}	7.97^{g}	7.82^{f}	19.67^{b}	21.00^{e}	20.33^{b}
T_{12}	0^{a}	0^{a}	0^{a}	1.33^{abcd}	1.00^{abcd}	1.17^{bc}	7.03^{def}	7.00^{efg}	7.02^{def}	20.33^{b}	20.81^{de}	20.57^{b}
T_{13}	0^{a}	0^{a}	0^{a}	1.67^{bcde}	1.00^{abcd}	1.33^{bc}	7.33^{cde}	6.00^{de}	6.67^{cde}	20.13^{b}	19.94^{cde}	20.04^{b}
T_{14}	0^{a}	0^{a}	0^{a}	0.34^{a}	0.00^{a}	0.17^{a}	3.44^{a}	3.33^{a}	3.39^{a}	14.34^{a}	14.70^{a}	14.52^{a}
T_{15}	0^{a}	0^{a}	0^{a}	0.67^{ab}	0.33^{ab}	0.50^{ab}	4.33^{b}	4.33^{ab}	4.33^{b}	14.80^{a}	13.59^{a}	14.20^{a}
T_{16}	0^{a}	0^{a}	0^{a}	1.00^{abc}	0.67^{abc}	0.83^{abc}	4.63^{b}	4.67^{bc}	4.65^{b}	14.87^{a}	14.48^{a}	14.67^{a}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

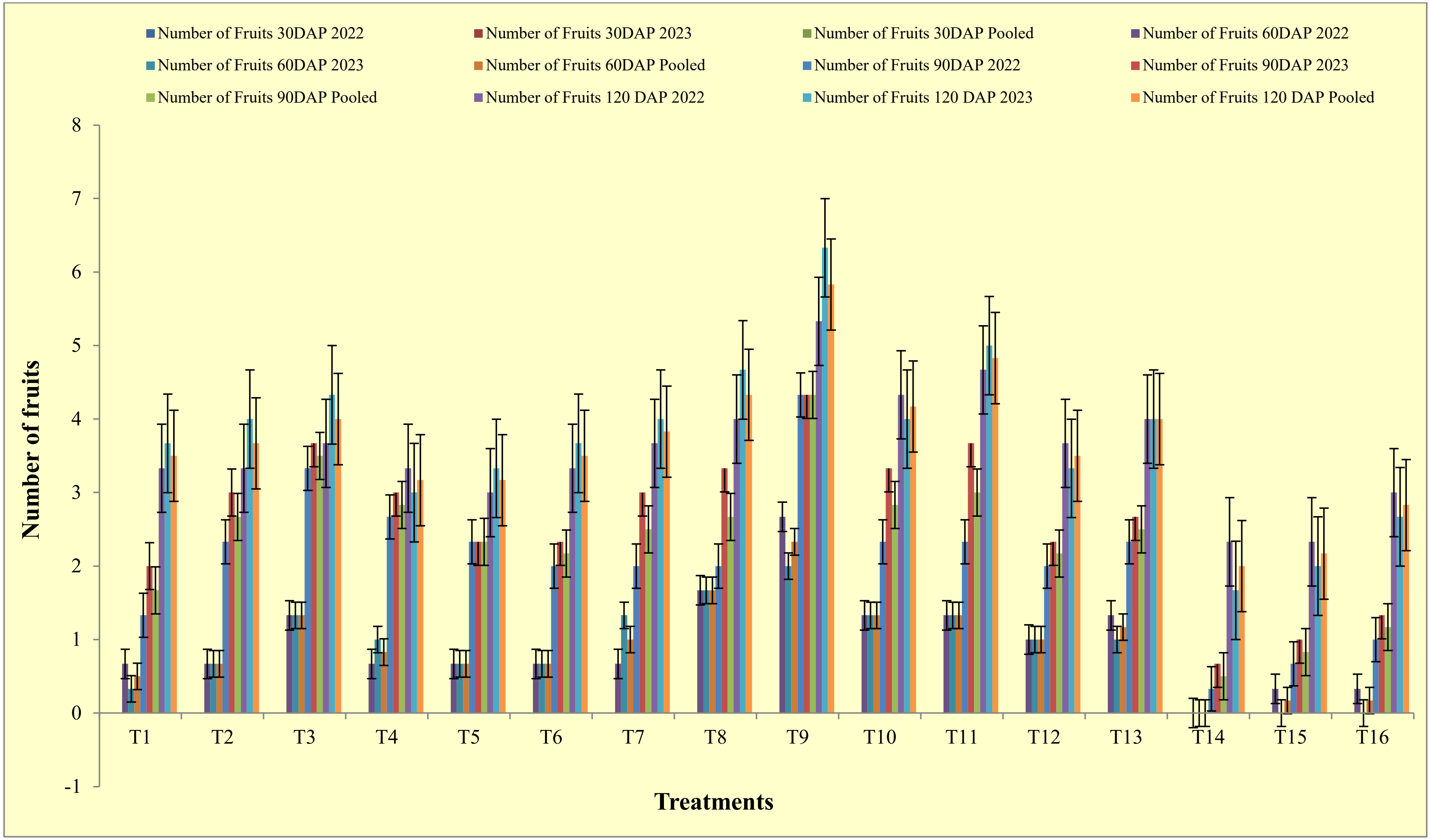

Figure 4.7: Effect of nano urea in combination with *Azotobacter* on number of fruits in strawberry cv. Winter Dawn.

driving the observed increase in fruit numbers, contributing valuable insights to the scientific community and paving the way for practical applications in agricultural systems worldwide.

The findings demonstrated similarities with the research conducted by Hashemabadi *et. al.* (2019), where significant observations were made regarding the number of fruits in strawberry. These results were attained subsequent to the application of nano nitrogen in conjunction with bio fertilizers, which collectively enhanced plant nutrition and facilitated accelerated growth, resulting in a greater yield of fruits compared to the control treatment.

4.2.2 Average fruit weight (gm)

Data pertaining average weight of the fruit (gm) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside of the Table 4.8 and visually depicted inside the Figure 4.8. A thorough examination of the data reveals a noteworthy impact of nano urea on the average fruit weight (gm) of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the average fruit weight (gm) of strawberry cv. Winter Dawn during both years of the research experiment.

The initial year experiment (2022-23) recorded the maximum average fruit weight (21.87 gm) under the treatment T_3 (25% RDF + N_2) followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and T_9 (25% RDF + N_2 + *Azotobacter*) having the values 20.01 gm and 19.86 gm, respectively. The control treatment (T_1) recorded 11.38 gm average fruit weight while the minimum average fruit weight (7.60 gm) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*).

The second-year research experiment (2023-24) recorded the maximum average fruit weight (19.62 gm) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*) having the values 19.57 gm and 18.82 gm, respectively. The control was recorded with 11.53 gm of average fruit weight while the least average fruit weight (8.34) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*).

Combining the data for both the years (2022-23 and 2023-24) revealed that the maximum average fruit weight (20.74 gm) was observed under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*)

Table 4.8: Effect of nano urea in combination with *Azotobacter* on average fruit weight in strawberry cv. Winter Dawn.

Treatments	Average fruit weight (g)		
	2022-23	2023-24	Pooled
T_1	11.38^{d}	11.53^{c}	11.46^{c}
T_2	16.14^{i}	16.40^{ef}	16.27^{efg}
T_3	20.01^{n}	19.57^{h}	19.79^{i}
T_4	15.61^{g}	15.73^{e}	15.67^{e}
T_5	16.20^{j}	15.92^{e}	16.06^{ef}
T_6	14.89^{e}	13.86^{d}	14.37^{d}
T_7	15.06^{f}	14.04^{d}	14.55^{d}
T_8	16.11^{i}	17.19^{efg}	16.65^{gh}
T_9	21.87^{o}	19.62^{h}	20.74^{j}
T_{10}	18.87^{l}	17.97^{fgh}	18.42^{h}
T_{11}	19.86^{m}	18.82^{gh}	19.34^{i}
T_{12}	16.02^{h}	15.92^{e}	15.97^{ef}
T_{13}	17.07^{k}	16.81^{ef}	16.94^{g}
T_{14}	7.60^{a}	8.34^{a}	7.97^{a}
T_{15}	8.23^{c}	9.55^{ab}	8.89^{b}
T_{16}	8.06^{b}	10.44^{bc}	9.25^{b}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

Figure 4.8: Effect of nano urea in combination with *Azotobacter* on average fruit weight in strawberry cv. Winter Dawn.

with the values 19.79 gm and 19.34 gm, respectively. The control treatment (T_1) was recorded with 11.46 gm of average fruit weight while the minimum average fruit weight (7.97) was observed under the treatment T_{14} (25% RDF + *Azotobacter*).

The utilization of nano urea combined with *Azotobacter* presents a compelling strategy in augmenting the average fruit weight of strawberries (Thirugnanasambandan, 2018). This innovative approach harnesses the unique properties of nano-scale urea particles alongside the symbiotic relationship with *Azotobacter* to enhance the nutritional status and physiological processes of strawberry plants. Observations indicate that nitrogen release from urea-upgraded hydroxyapatite nanoparticles is twice as long, spanning 60 days of plant growth, in comparison to conventional fertilizers which typically release nitrogen over a period of 30 days (Gupta *et. al.* 2024). Results obtained from Sharma *et. al.* (2021) revealed that nano urea, characterized by its reduced particle size, facilitates improved nutrient uptake efficiency, particularly nitrogen, which plays a vital role in fruit development and weight. By providing a more readily available and accessible nitrogen source, nano urea ensures optimal nutrient utilization within the plant, thereby promoting enhanced fruit growth and development. Furthermore, the presence of *Azotobacter* further enriches the soil with bioavailable nitrogen through biological nitrogen fixation, supplementing the plant's nitrogen requirements and fostering sustained growth. This synergistic interaction between nano urea and *Azotobacter* not only enhances the nutritional status of the plant but also promotes physiological mechanisms conducive to increasing fruit weight. Through rigorous field trials and physiological analyses, this study aims to elucidate the intricate mechanisms underlying the observed increase in average fruit weight, contributing valuable insights to optimize strawberry production practices and address the challenges of food security and sustainable agriculture.

4.2.3 Fruit volume (cc)

Data concerning fruit volume (cc) and its variation over the two experimental years (2022-23 and 2023-24) is provided in Table 4.9 and visually depicted in Figure 4.9. A thorough examination of the data indicates a noteworthy impact of nano urea on the fruit volume of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the average fruit volume of strawberry cv. Winter Dawn during both years of the research experiment.

Initial year research year trial (2022-23) recorded the maximum fruit volume (21.95 cc) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*) having the values 20.09 cc and 19.94 cc, respectively. The control was recorded with 11.46 cc of fruit volume while the minimum (7.68 cc) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*) followed by T_{15} (50% RDF + *Azotobacter*) having the value of 8.31 cc.

The second-year trial (2023-24) recorded the maximum fruit volume (19.65 cc) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*) having the value of 19.60 cc and 18.85 cc. The control was recorded with 11.56 cc while the minimum (8.37 cc) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*) followed by T_{15} (50% RDF + *Azotobacter*) with the value of 9.58 cc.

Combining the data for both the years (2022-23 and 2023-24) revealed the maximum presence of fruit volume (20.82 cc) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*) having the value of 19.86 cc and 19.41 cc, respectively. The control was recorded with 11.53 cc of fruit volume while nadir was recorded under the treatment T_{14} (25% RDF + *Azotobacter*) with the value of 8.04 cc followed by T_{15} (50% RDF + *Azotobacter*) with the value of 8.96 cc.

The integration of nano urea with *Azotobacter* presents a promising avenue for enhancing fruit volume in strawberries. This innovative approach leverages the unique properties of nano-scale urea particles in conjunction with the beneficial effects of *Azotobacter* to optimize the growth and development of strawberry plants (Yadav *et. al.* 2023). Nano urea, characterized by its reduced particle size, facilitates efficient nutrient uptake, particularly nitrogen, which is essential for fruit development and volume. By providing a more readily available and accessible nitrogen source, nano urea ensures sustained nutrient availability throughout the plant's growth cycle, thereby promoting enhanced fruit expansion.

Additionally, the presence of *Azotobacter* further enhances nitrogen availability through biological nitrogen fixation, supplementing the plant's nitrogen requirements and

Table 4.9: Effect of nano urea in combination with *Azotobacter* on fruit volume in strawberry cv. Winter Dawn.

Treatments	Fruit volume (cc)		
	2022-23	2023-24	Pooled
T_1	11.46^{d}	11.56^{c}	11.53^{c}
T_2	16.22^{i}	16.43^{ef}	16.34^{efg}
T_3	20.09^{n}	19.60^{h}	19.86^{i}
T_4	15.68^{g}	15.76^{e}	15.74^{e}
T_5	16.28^{j}	15.95^{e}	16.13^{ef}
T_6	14.97^{e}	13.89^{d}	14.45^{d}
T_7	15.14^{f}	14.07^{d}	14.62^{d}
T_8	16.19^{i}	17.22^{efg}	16.72^{fg}
T_9	21.95^{o}	19.65^{h}	20.82^{j}
T_{10}	18.94^{l}	18.00^{fgh}	18.49^{h}
T_{11}	19.94^{m}	18.85^{gh}	19.41^{i}
T_{12}	16.10^{h}	15.95^{e}	16.04^{ef}
T_{13}	17.15^{k}	16.84^{ef}	17.01^{g}
T_{14}	7.68^{a}	8.37^{a}	8.04^{a}
T_{15}	8.31^{c}	9.58^{ab}	8.96^{b}
T_{16}	8.14^{b}	10.47^{bc}	9.32^{b}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

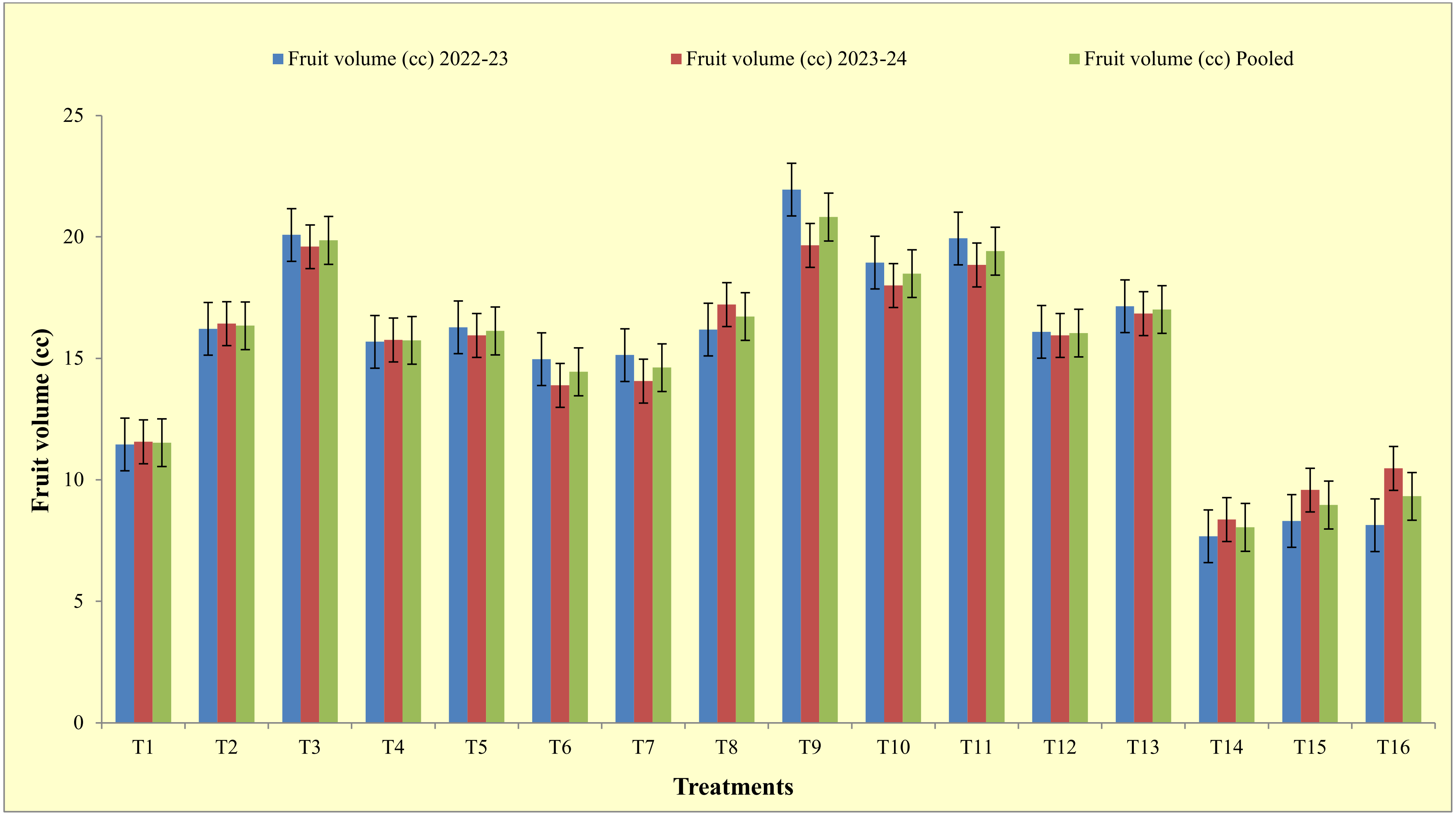

Figure 4.9: Effect of nano urea in combination with *Azotobacter* on fruit volume in strawberry cv. Winter Dawn.

supporting robust fruit development. This synergistic interaction between nano urea and *Azotobacter* not only improves nutrient uptake but also stimulates physiological processes that contribute to increased fruit volume. Through comprehensive field trials and physiological analyses, this study aims to elucidate the mechanisms underlying the observed enhancement in fruit volume, offering valuable insights for optimizing strawberry production practices and addressing the challenges of agricultural sustainability and food security.

The results align closely with the research conducted by Kalil and Aareji (2022), which emphasized the significant impact of nanoparticle application on enhancing fruit volume in strawberry crops compared to untreated fruits. Their study corroborated the efficacy of nanoparticles in augmenting fruit size, attributing this effect to the specialized properties of nanoparticles. Specifically, the application of nanoparticles facilitated substantial improvements in fruit volume, surpassing the growth observed in fruits not treated with nanoparticles. This underscores the potential of nanoparticle technology to revolutionize agricultural practices by promoting superior fruit development and yield.

4.2.4 Fruit yield per plant (gm)

Data pertaining fruit yield per plant (gm) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside the Table 4.10 and visually elucided inside the Figure 4.10. A thorough examination related to the data signifies a noteworthy impact of nano urea on the fruit yield plant^{-1} (gm) of strawberry cv. Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the fruit yield per plant (gm) of strawberry cv. Winter Dawn during both years of the research experiment.

Initial year research year trial (2022-23) recorded the maximum fruit yield per plant (688.75 gm) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*) having the values 608.90 gm per plant and 575.84 gm per plant, respectively. The control (T_1) treatment recorded 316.09 gm fruit yield plant^{-1} while the minimum fruit yield plant^{-1} (138.33 gm) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*).

The second-year research experimental trial (2023-24) recorded the maximum fruit yield per plant (586.58 gm) under the treatment T_{11} (50% RDF + N_2 + *Azotobacter*) followed by T_9 (25% RDF + N_2 + *Azotobacter*) and T_3 (25% RDF + N_2) having the values 580.46 gm and 504.24 gm per plant, respectively. The control was recorded with 301.49 gm fruit yield per plant while the minimum fruit yield per plant (150 gm) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*).

Pooling the data for both the experimental trials (2022-23 and 2023-24) uncovered that the utmost fruit yield plant^{-1} (634.61 gm) was observed by the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and T_3 (25% RDF + N_2) with the values 581.21 gm and 556.57 gm per plant, respectively. The control treatment (T_1) was recorded with 308.79 gm fruit yield plant^{-1} while the minimum fruit yield plant^{-1} (144.63 gm) was recorded under T_{14} (25% RDF + *Azotobacter*).

The amalgamation of nano urea with *Azotobacter* represents a pioneering approach to enhancing fruit yield per plant in strawberries (Chakraborty and Akhtar, 2021). This innovative strategy capitalizes on the combined benefits of nano-scale urea particles and the symbiotic relationship with *Azotobacter* to optimize the growth and productivity of strawberry plants. Nano urea, distinguished by its diminutive particle size, facilitates enhanced nutrient uptake, particularly nitrogen and according to Davarpanah *et. al.* (2017), this plays a pivotal role in fruit development and yield. By delivering nitrogen in a more accessible and efficient manner, nano urea ensures sustained nutrient availability throughout the plant's growth cycle (Guo *et. al.* 2018), thereby promoting increased flower formation and fruit set (Kumar *et. al.* 2023). Moreover, the presence of *Azotobacter* further augments nitrogen availability through biological nitrogen fixation (Nag *et. al.* 2020), supplementing the plant's nitrogen requirements and fostering overall plant health (Rizvi and Khan 2018). This synergistic interaction between nano urea and *Azotobacter* not only optimizes nutrient utilization (Kannoj *et. al.* 2022) but also stimulates physiological processes conducive to greater fruit yield per plant (Shahrajabian *et. al.* 2023). Through rigorous field trials and physiological analyses, this study endeavors to unravel the underlying mechanisms driving the observed increase in fruit yield, offering valuable insights for advancing strawberry cultivation practices and addressing global food security challenges in sustainable agriculture.

The mechanism underlying the enhancement in fruit yield attributed to nitrogen on strawberries is a complex interplay of physiological processes fundamental to plant growth and development. Nitrogen, as a primary macronutrient, exerts profound effects on various aspects of strawberry physiology, ultimately leading to enhanced fruit production.

Table 4.10: Effect of nano urea in combination with *Azotobacter* on yield per plant in strawberry cv. Winter Dawn.

Treatments	Yield per Plant (g)		
	2022-23	2023-24	Pooled
T_1	316.09^{c}	301.49^{d}	308.79^{d}
T_2	458.06^{e}	500.91^{h}	479.49^{h}
T_3	608.90^{i}	504.24^{h}	556.57^{j}
T_4	444.04^{e}	420.37^{f}	432.21^{f}
T_5	458.24^{e}	406.63^{f}	432.44^{f}
T_6	417.13^{d}	379.12^{e}	398.12^{e}
T_7	412.95^{d}	388.01^{e}	400.48^{e}
T_8	465.29^{ef}	502.91^{h}	484.10^{h}
T_9	688.75^{j}	580.46^{j}	634.61^{l}
T_{10}	541.45^{g}	487.86^{h}	514.66^{i}
T_{11}	575.84^{h}	586.58^{j}	581.21^{k}
T_{12}	446.94^{e}	459.51^{g}	453.22^{g}
T_{13}	486.43^{f}	453.71^{g}	470.07^{h}
T_{14}	138.33^{a}	150.92^{a}	144.63^{a}
T_{15}	151.92^{ab}	174.90^{b}	163.41^{b}
T_{16}	170.38^{b}	207.46^{c}	188.92^{c}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

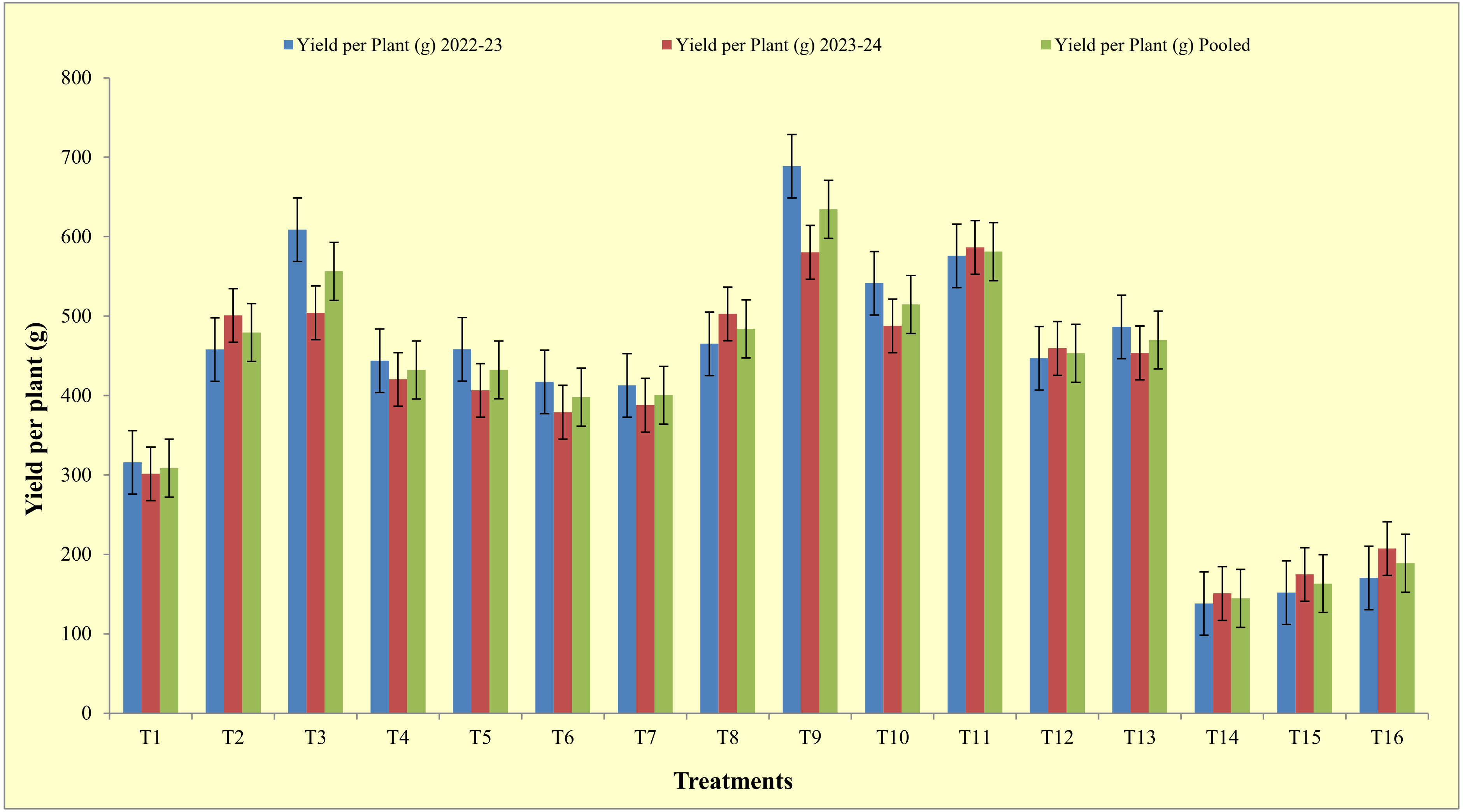

Figure 4.10: Effect of nano urea in combination with *Azotobacter* on yield per plant in strawberry cv. Winter Dawn.

Firstly, nitrogen availability stimulates vegetative growth by promoting the synthesis of chlorophyll, thus bolstering photosynthetic activity and providing the necessary energy for robust plant development. This vigor translates into increased canopy size and foliage density, facilitating better light interception and nutrient assimilation, which are critical for optimal fruiting. Additionally, nitrogen plays a pivotal role in reproductive processes, particularly in flower formation and fruit set (Erel *et. al.* 2008). Adequate nitrogen levels encourage the development of more flower buds and promote higher rates of successful pollination, leading to improved fruit set and reduced flower abortion. Furthermore, nitrogen influences fruit growth directly by fueling the synthesis of proteins, enzymes, and other essential compounds involved in cell division, expansion, and fruit maturation (Duran *et. al.* 2020; Famiani *et. al.* 2020). Moreover, nitrogen regulates hormonal balance within the plant, particularly cytokinins, which govern cell division (Zalabák *et. al.* 2013) and differentiation, thus orchestrating the developmental processes crucial for fruit yield (Karmakar *et. al.* 2023). Overall, the nuanced effects of nitrogen on plant physiology underscore its indispensable role in optimizing fruit yield in strawberries, emphasizing the importance of balanced nitrogen management strategies for sustainable strawberry production. Through comprehensive understanding of these mechanisms, this study aims to contribute valuable insights to optimize nitrogen utilization practices, thereby enhancing fruit yield and ensuring food security in agricultural systems.

4.3 Qualitative parameters

4.3.1 Titratable acidity (%)

Data concerning Titratable acidity (%) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside of the Table 4.11 and visually depicted inside of the Figure 4.11. A thorough examination regarding the data indicates a noteworthy impact of nano urea on the Titratable acidity of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the Titratable acidity of strawberry cv. Winter Dawn during both years of the research experiment.

The first-year trial (2022-23) recorded the maximum titratable acidity (0.57) under the treatment T_{16} (75% RDF + *Azotobacter*) followed by T_{14} (25% RDF + *Azotobacter*) and T_{15} (75% RDF + *Azotobacter*) having values 0.56 per cent and 0.56 per cent, respectively. The control (T_1) treatment recorded the acidity with a value of 0.55. The least titratable acidity (0.42 %) was recorded under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) significantly. It was followed by T_{10} (50% RDF +N_2 + *Azotobacter*) and T_8 (25% RDF +N_1 + *Azotobacter*) having values 0.43 per cent and 0.45 per cent, respectively.

The second-year trial (2023-24) recorded the highest titratable acidity (0.59 %) under the treatment control (T_1) followed by T_{16} (75% RDF + *Azotobacter*) and T_{15} (50% RDF + *Azotobacter*) having values 0.58 per cent as well as 0.56 per cent, respectively. The least titratable acidity (0.43 %) was listed under T_{11} (50% RDF +N_2 + *Azotobacter*) followed by T_9 (25% RDF +N_2 + *Azotobacter*), T_8 (25% RDF +N_2 + *Azotobacter*) and T_3 (25% RDF +N_2) with the values 0.44 per cent, 0.46 per cent and 0.46 per cent, respectively.

The combined data for both the years (2022-23 and 2023-24) revealed that the maximum titratable acidity (0.58 %) was observed under the treatment T_{16} (75% RDF + *Azotobacter*) followed by control (T_1) and T_{15} (50% RDF + *Azotobacter*) with the value of 0.57 per cent as well as 0.57 per cent, respectively. The minimum titratable acidity (0.43 %) was listed under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_{11} (25% RDF +N_2 + *Azotobacter*) and T_{10} (25% RDF +N_2 + *Azotobacter*) having values 0.45 per cent and 0.47 per cent, respectively.

The integration of nano urea with *Azotobacter* presents a novel approach to modulating the acidity of strawberries, a key attribute influencing fruit quality and consumer preference. This innovative strategy harnesses the synergistic effects of nano-scale urea particles and the beneficial bacteria *Azotobacter* to influence the biochemical pathways involved in fruit acidity regulation. Nano urea, characterized by its reduced particle size, facilitates efficient nutrient uptake, particularly nitrogen, which plays a crucial role in fruit metabolism and acidity modulation (Iqbal *et. al.* 2019). By providing a readily available nitrogen source, nanourea ensures optimal nutrient availability throughout the plant's growth cycle, thus influencing the synthesis and metabolism of organic acids in strawberries (As *et. al.* 2023). Additionally, the presence of *Azotobacter* further enhances nitrogen availability through biological nitrogen fixation, supplementing the plant's nitrogen requirements and fostering overall plant health (Ouyang *et. al.* 2024). This enhanced nitrogen supply may lead to a more balanced nutrient status within the plant, potentially influencing the production and accumulation of organic acids in the fruit (Zheng *et. al.* 2023). Furthermore, *Azotobacter* has been reported to produce certain enzymes and metabolites that can directly or indirectly

Table 4.11: Effect of nano urea in combination with *Azotobacter* on titratable acidity in strawberry cv. Winter Dawn.

Treatments	Titratable acidity (%)		
	2022-23	2023-24	Pooled
T_1	0.55^{e}	0.59^{c}	0.57^{h}
T_2	0.47^{bc}	0.48^{de}	0.48^{c}
T_3	0.51^{d}	0.46^{fg}	0.49^{cd}
T_4	0.55^{e}	0.51^{ef}	0.53^{f}
T_5	0.54^{e}	0.48^{ef}	0.51^{e}
T_6	0.57^{e}	0.55d	0.56^{gh}
T_7	0.57^{e}	0.53^{ef}	0.55^{g}
T_8	0.47^{bc}	0.46^{ef}	0.47^{bc}
T_9	0.42^{a}	0.44^{g}	0.43^{a}
T_{10}	0.46^{b}	0.47^{fg}	0.47^{bc}
T_{11}	0.48^{bc}	0.43^{g}	0.45^{b}
T_{12}	0.49^{cd}	0.50^{ef}	0.50^{de}
T_{13}	0.48^{bcd}	0.49^{ef}	0.49^{cd}
T_{14}	0.56^{e}	0.56^{a}	0.56^{gh}
T_{15}	0.56^{e}	0.57^{ab}	0.57^{gh}
T_{16}	0.57^{e}	0.58^{bc}	0.58^{h}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

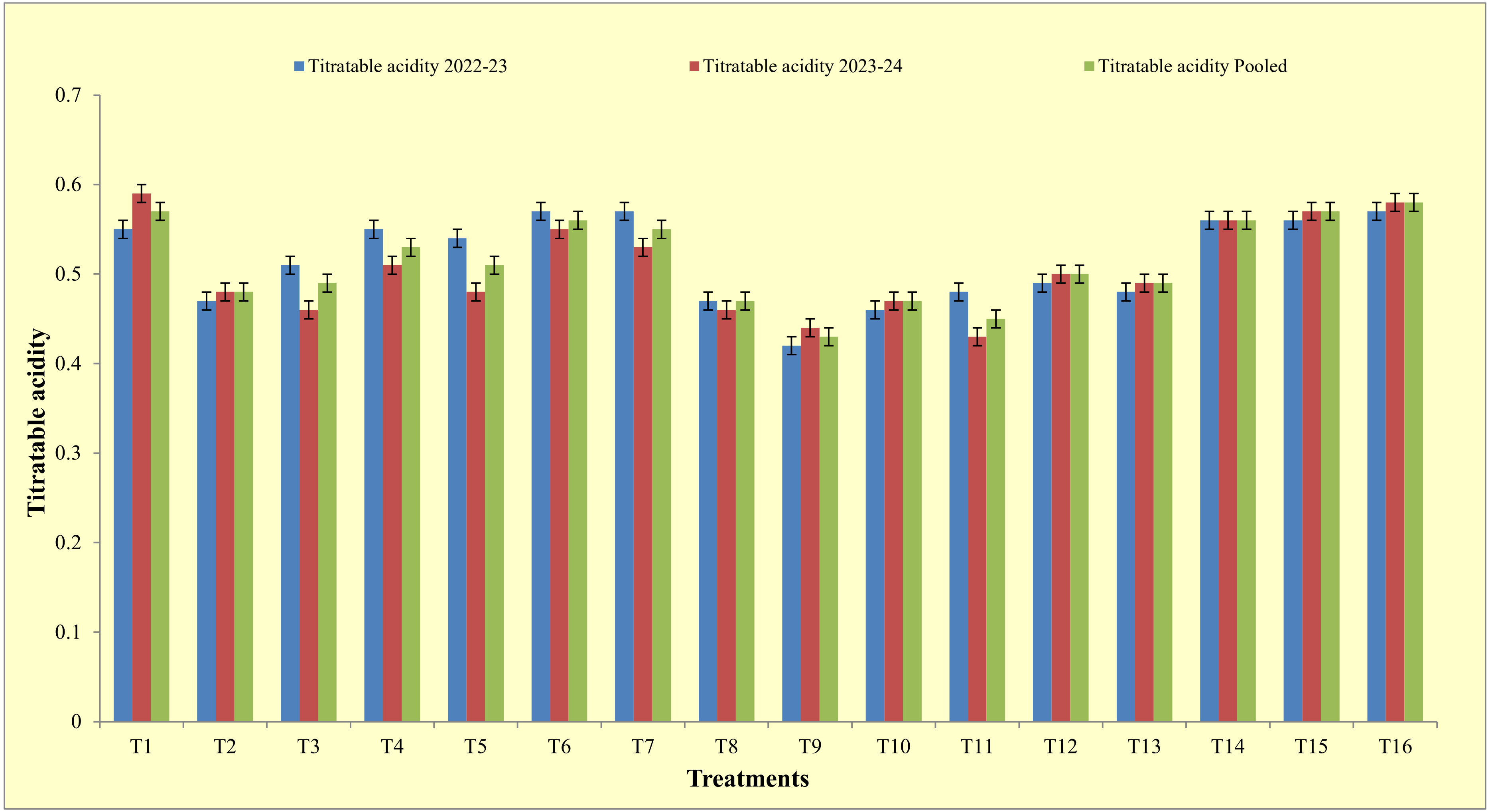

Fig 4.11: Effect of nano urea in combination with *Azotobacter* on titratable acidity in strawberry cv. Winter Dawn.

Impact fruit acidity through modulation of physiological processes (Borah *et. al.* 2023). Through rigorous field trials and biochemical analyses, this study aims to elucidate the specific mechanisms by which nano urea with *Azotobacter* influences fruit acidity in strawberries, offering valuable insights for optimizing fruit quality and meeting consumer preferences in strawberry production.

The integrated use of nano urea and *Azotobacter* could potentially lead to a more nutrient profile, particularly by modulating the nitrogen levels in the plant. Increased nitrogen availability can alter the synthesis of organic acids in the fruit (Famiani *et. al.* 2015), thereby influencing their overall acidity. For example, nitrogen has been known to affect the synthesis of malic acid and citric acid in fruits, which are primary determinants of fruit acidity. The mechanism likely involves the regulation of key enzymes involved in the TCA cycle and nitrogen metabolism pathways (Nunes *et. al.* 2010), which are influenced by nitrogen availability. Furthermore, the enhanced microbial activity in the soil, mediated by *Azotobacter*, may lead to a slight increase in soil pH (Aasfar *et. al.* 2021), contributing indirectly to decreased acidity in the plant tissues through altered uptake of minerals and nutrients that affect fruit composition and pH (Etienne *et. al.* 2013). This hypothesis aligns with studies suggesting that soil microbiota and nutrient management can significantly impact fruit quality attributes, including acidity (Ferrarezi *et. al.* 2022).

4.3.2 Total soluble solid (°brix)

Data pertaining Total soluble solid (TSS) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside the Table 4.12 and visually depicted inside the Figure 4.12. A thorough examination of the data indicates a noteworthy impact of nano urea on the Total soluble solid (TSS) of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the Total soluble solid (TSS) of strawberry cv. Winter Dawn during both years of the research experiment.

During the first research trial (2022-24), the maximum total soluble solid (9.10 °brix) was recorded under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_{11} (50% RDF +N_2 + *Azotobacter*) and T_3 (25% RDF +N_2) with the values 8.47 and 8.43, respectively. The control treatment (T_1) recorded 6.93 °brix TSS while the minimum total soluble solid (5.07) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*).

During the second-year research trial (2023-24), the maximum total soluble solid (8.83 ^{o}brix) was recorded under the treatment T_{11} (50% RDF +N_2 + *Azotobacter*) followed by T_9 (25% RDF +N_2 + *Azotobacter*) and T_{10} (50% RDF +N_2 + *Azotobacter*) with the values 8.80 ^{o}brix and 8.40 ^{o}brix, respectively. The control treatment (T_1) recorded 6.53^{o}brix TSS while the least value of total soluble solid (5.57) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*).

Pooling the data for both the years (2022-23 and 2023-24) revealed that the maximum total soluble solid (8.95 ^{o}brix) was observed under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_{11} (50% RDF +N_2 + *Azotobacter*) and T_3 (25% RDF +N_2) with values 8.65 ^{o}brix and 8.40 ^{o}brix, respectively. The control treatment (T_1) recorded 6.73 ^{o}brix total soluble solid while the minimum value of TSS (5.32) was observed under T_{14} (25% RDF + *Azotobacter*).

The incorporation of nano urea with *Azotobacter* in agricultural practices has shown promising potential for enhancing fruit quality, particularly in strawberries. The observed increase in total soluble solids (TSS) in fruits treated with nano urea and *Azotobacter* can be attributed to several synergistic mechanisms. Firstly, nano urea, with its nano-sized particles, facilitates a controlled and sustained release of nitrogen, ensuring a steady supply of this essential nutrient to the strawberry plants throughout their growth stages (Nehra *et. al.* 2024). This optimized nitrogen delivery promotes robust plant growth and development, leading to improved fruit quality attributes, including enhanced TSS accumulation. Additionally, the presence of *Azotobacter*, a nitrogen-fixing bacterium, further augments nitrogen availability in the rhizosphere through biological nitrogen fixation, thereby supplementing the plants' nitrogen requirements. This enhanced nitrogen uptake and utilization by the strawberry plants promote physiological processes associated with sugar synthesis and accumulation in the fruits, consequently contributing to elevated TSS levels (Almohammedi *et. al.* 2023). Furthermore, the symbiotic relationship between *Azotobacter* and the strawberry plants may induce systemic changes in plant metabolism, hormone regulation, and nutrient assimilation pathways, further enhancing fruit quality characteristics, including TSS content (Negi *et. al.* 2021). Overall, the combined application of nano urea and *Azotobacter* presents a sustainable approach to optimizing fruit quality in strawberries by promoting balanced nutrient uptake, enhancing physiological processes, and ultimately leading to increased TSS accumulation.

Table 4.12: Effect of nano urea in combination with *Azotobacter* on total soluble solid in strawberry cv. Winter Dawn.

Treatments	Total soluble solids (ºbrix)		
	2022-23	**2023-24**	**Pooled**
T_1	6.93^{cd}	6.53^{c}	6.73^{c}
T_2	6.60^{bc}	7.73^{de}	7.17^{cd}
T_3	8.43^{fg}	8.37^{fg}	8.40^{hij}
T_4	7.67^{def}	8.00^{ef}	7.83^{efg}
T_5	7.97^{ef}	8.10^{ef}	8.03^{efgh}
T_6	7.40^{cde}	7.40^{d}	7.40^{de}
T_7	8.00^{ef}	8.00^{ef}	8.00^{efgh}
T_8	7.23^{cde}	8.10^{ef}	7.67^{def}
T_9	9.10^{g}	8.80^{g}	8.95^{i}
T_{10}	8.20^{efg}	8.40^{fg}	8.30^{fgh}
T_{11}	8.47^{fg}	8.83^{g}	8.65^{hi}
T_{12}	7.80^{def}	7.93^{ef}	7.87^{efg}
T_{13}	7.93^{ef}	8.07^{ef}	8.00^{efgh}
T_{14}	5.07^{a}	5.57^{a}	5.32^{a}
T_{15}	5.80^{ab}	5.60^{ab}	5.70^{ab}
T_{16}	5.93^{ab}	6.07^{bc}	6.00^{b}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

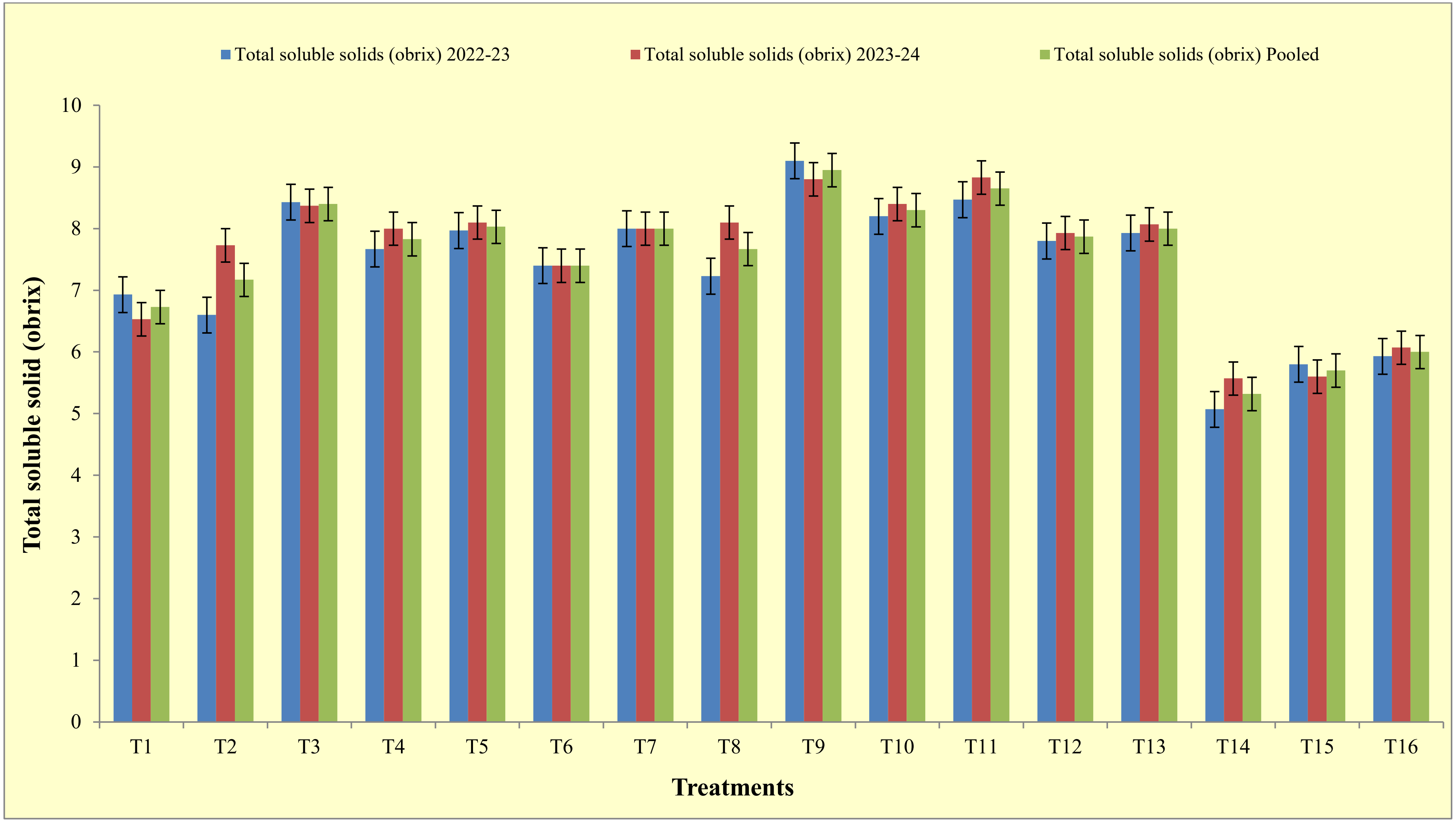

Figure 4.12: Effect of nano urea in combination with *Azotobacter* on total soluble solid in strawberry cv. Winter Dawn.

The research outcomes align closely with the investigation conducted by Kumar *et. al.* (2023), who explored the impact of nano urea and the biofertisol on mango (*Mangifera indica*), yielding maximal total soluble solids (TSS) content. Similarly, Tripathi *et. al.* (2016) observed heightened TSS levels in strawberries following treatment with *Azotobacter*. Therefore, the amalgamation of these approaches holds promise for enhancing fruit quality, encompassing TSS levels, through synergistic mechanisms.

4.3.3 TSS: Acid ratio

Data associated to TSS: acid ratio and its variation over the two experimental years (2022-23 and 2023-24) is provided inside the Table 4.13 and visually depicted inside Figure 4.13. A thorough examination regarding the data indicates a noteworthy impact of nano urea on the TSS: Acid ratio of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the TSS: Acid ratio of strawberry cv. Winter Dawn during both years of the research experiment.

During the first-year trial (2022-23), the utmost TSS: acid ratio (21.73) was listed by the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_{10} (50% RDF +N_1 + *Azotobacter*) and T_{11} (50% RDF +N_2 + *Azotobacter*) significantly having the values 17.83 and 17.76, respectively. The control (T_1) was recorded with the value of 12.65 while the least TSS: Acid ratio (9.00) was observed under the treatment T_{14} (25% RDF + *Azotobacter*).

In the second-year research trial (2023-24) maximum TSS: Acid ratio (20.71) was followed under the treatment T_{11} (50% RDF +N_2 + *Azotobacter*) followed by T_9 (25% RDF +N_2 + *Azotobacter*) and T_3 (25% RDF +N_2) having the value 20.16 and 18.06, respectively. The control treatment (T_1) was recorded with the value of 11.01 while the nidar TSS: acid ratio (9.88) was listed by T_{14} (25% RDF + *Azotobacter*).

The combined data for both the years (2022-23 and 2023-24) revealed that the maximum presence of TSS: Acid ratio (20.94) was observed under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_{11} (50% RDF +N_2 + *Azotobacter*) and T_{10} (50% RDF +N_1 + *Azotobacter*) having values 19.23 and 17.79, respectively. The control was recorded with the value of 11.83 while the minimum TSS: Acid ratio (9.44) was under the treatment T_9 (25% RDF + *Azotobacter*).

Table 4.13: Effect of nano urea in combination with *Azotobacter* on TSS: acid ratio in strawberry cv. Winter Dawn.

Treatments	TSS: Acid ratio		
	2022-23	**2023-24**	**Pooled**
T_1	12.65^{bc}	11.01^{a}	11.83^{b}
T_2	13.94^{cd}	16.01^{cd}	14.98^{d}
T_3	16.54^{cd}	18.06^{f}	17.30^{f}
T_4	13.98^{cde}	15.80^{cd}	14.89^{d}
T_5	14.66^{cde}	16.76^{def}	15.71^{de}
T_6	13.07^{bc}	13.37^{b}	13.22^{c}
T_7	13.96^{cd}	15.00^{c}	14.48^{d}
T_8	15.29^{cde}	17.69^{ef}	16.49^{ef}
T_9	21.73^{g}	20.16^{g}	20.94^{h}
T_{10}	17.83^{def}	17.75^{ef}	17.79^{f}
T_{11}	17.76^{fgh}	20.71^{g}	19.23^{g}
T_{12}	15.81^{cd}	15.76^{cd}	15.79^{de}
T_{13}	16.41^{cd}	16.59^{de}	16.50^{ef}
T_{14}	9.00^{a}	9.88^{a}	9.44^{a}
T_{15}	10.39^{ab}	9.82^{a}	10.11^{a}
T_{16}	10.42^{ab}	10.41^{a}	10.41^{a}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

Figure 4.13: Effect of nano urea in combination with *Azotobacter* on TSS: acid ratio in strawberry cv. Winter Dawn.

The utilization of nano urea in combination with *Azotobacter* presents a novel strategy for enhancing the TSS: acid ratio in strawberries, thereby elevating fruit quality. This enhancement can be attributed to several underlying mechanisms. Firstly, nano urea, characterized by its nano-sized particles, facilitates a precise and sustained release of nitrogen, ensuring an optimized supply of this essential nutrient to strawberry plants. This optimized nitrogen availability promotes balanced growth and development, influencing the synthesis and accumulation of sugars relative to acids in the fruits (Famiani *et. al.* 2015). Secondly, the presence of *Azotobacter*, a nitrogen-fixing bacterium, further enhances nitrogen availability in the rhizosphere through biological nitrogen fixation. This increased nitrogen uptake and utilization by strawberry plants may induce systemic changes in plant metabolism, including alterations in sugar and acid metabolism. The symbiotic interaction between *Azotobacter* and strawberry plants enhances physiological processes involved in fruit development, potentially influencing the TSS: acid ratio (Kumar *et. al.* 2020). Furthermore, the combined application of nano urea and *Azotobacter* may stimulate the activity of enzymes involved in sugar synthesis and acid degradation, further optimizing the TSS: acid ratio in strawberries. Overall, the synergistic effects of nano urea and *Azotobacter* on nutrient availability, plant metabolism, and enzyme activity contribute to the elevation of the TSS: acid ratio in strawberries, thus enhancing fruit quality.

4.3.4 Ascorbic acid (mg/100 gm)

Data pertaining to Ascorbic acid (mg/100 gm) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside of the Table 4.14 and visually depicted inside of the Figure 4.14. A thorough examination with respect to the data indicates a noteworthy impact of nano urea on the Ascorbic acid (mg/100 gm) of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the Ascorbic acid (mg/100 gm) of strawberry cv. Winter Dawn during both years of the research experiment.

In the initial year research experiment (2022-23), the maximum presence of ascorbic acid (55.7 mg/ 100 gm) was observed under the treatment T_{11} (50% RDF + N_2 + *Azotobacter*) followed by T_9 (25% RDF + N_2 + *Azotobacter*), T_{10} (50% RDF + N_1 + *Azotobacter*) and T_{12} (75% RDF + N_1 + *Azotobacter*) having the values 55.0 mg/ 100 gm, 53.0 mg/ 100 gm and 53.0 mg/ 100 gm, respectively. The control treatment (T_1) recorded 46.7 md/100 gm ascorbic acid while the minimal ascorbic acid (42.0) was found under the treatment T_{14}

(25% RDF + *Azotobacter*).

During the second-year trial (2023-24), the maximum ascorbic acid (56.7 mg/ 100 gm) was found under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_{11} (50% RDF +N_2 + *Azotobacter*) and T_8 (25% RDF +N_1 + *Azotobacter*) having the values 55.7 mg^{-1} 100 g as well as 54.0 mg^{-1} 100 gm, respectively. The treatment control (T_1) was recorded with 46.0 mg/ 100 gm ascorbic acid while the nidar ascorbic acid (42.0 mg^{-1} 100 gm) was listed under the treatment T_{14} (50% RDF + *Azotobacter*).

Pooling the data for both the years (2022-23 and 2023-24) defined that the maximum ascorbic acid (55.83 mg/ 100 gm) was observed under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_{11} (50% RDF +N_2 + *Azotobacter*) and T_{10} (50% RDF +N_1 + *Azotobacter*) with the values of 55.67 mg/ 100 gm and 53.33 mg/ 100 gm. The data revealed that the minimum ascorbic acid (42.00 mg/ 100 gm) was observed under T_{14} (25% RDF + *Azotobacter*) while the control treatment (T_1) recorded 46.33 mg/100 gm ascorbic acid.

The application of nano urea in conjunction with *Azotobacter* offers a promising avenue for enhancing the ascorbic acid content of strawberries, thereby augmenting fruit quality. This enhancement is underpinned by several interconnected mechanisms. Firstly, nano urea, characterized by its nano-sized particles, facilitates a controlled and sustained release of nitrogen, ensuring an optimized supply of this vital nutrient to strawberry plants. Nitrogen is a key component in the synthesis of ascorbic acid, as it is required for the formation of amino acids, which serve as precursors in the biosynthetic pathway of ascorbic acid (Miret *et. al.* 2014). Therefore, the optimized nitrogen availability resulting from nano urea application promotes increased synthesis of ascorbic acid within the plan (WA Al-juthery and Hilal, 2020). Additionally, the presence of *Azotobacter*, a nitrogen-fixing bacterium, further enhances nitrogen availability in the rhizosphere through biological nitrogen fixation (Aasfar *et. al.* 2021). This augmented nitrogen uptake and utilization by strawberry plants may further stimulate the synthesis of ascorbic acid (Guerrero *et. al.* 2015).

Moreover, the symbiotic interaction between *Azotobacter* and strawberry plants may induce systemic changes in plant metabolism, including the activation of enzymes involved in ascorbic acid biosynthesis (Savita *et. al.* 2023). Furthermore, the combined application of nano urea and *Azotobacter* may enhance the antioxidant capacity of the plant, thereby protecting ascorbic acid from degradation and leading to its accumulation in the fruits.

Table 4.14: Effect of nano urea in combination with *Azotobacter* on ascorbic acid in strawberry cv. Winter Dawn.

Treatments	Ascorbic acid (mg/100 gm)		
	2022-23	2023-24	Pooled
T_1	46.7^{cd}	46.0^{c}	46.33^{c}
T_2	47.7^{de}	50.0^{de}	48.83^{de}
T_3	51.0^{fg}	53.0^{gh}	52.00^{ghi}
T_4	48.0^{ef}	51.0^{ef}	49.50^{def}
T_5	48.7^{def}	52.3^{fgh}	50.50^{efgh}
T_6	50.0^{efg}	50.0^{de}	50.00^{efg}
T_7	46.3^{bcd}	49.0^{d}	47.67^{cd}
T_8	50.7^{efg}	54.0^{hi}	52.33^{hi}
T_9	55.0^{h}	56.8^{k}	55.83^{j}
T_{10}	53.0^{gh}	53.7^{h}	53.33^{i}
T_{11}	55.7^{h}	55.7^{ij}	55.72^{j}
T_{12}	53.0^{gh}	51.7^{efg}	52.33^{hi}
T_{13}	50.0^{efg}	52.3^{fgh}	51.17^{fghi}
T_{14}	42.0^{a}	42.1^{a}	42.03^{a}
T_{15}	43.7^{ab}	43.8^{ab}	43.73^{ab}
T_{16}	44.3^{abc}	44.5^{bc}	44.42^{b}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

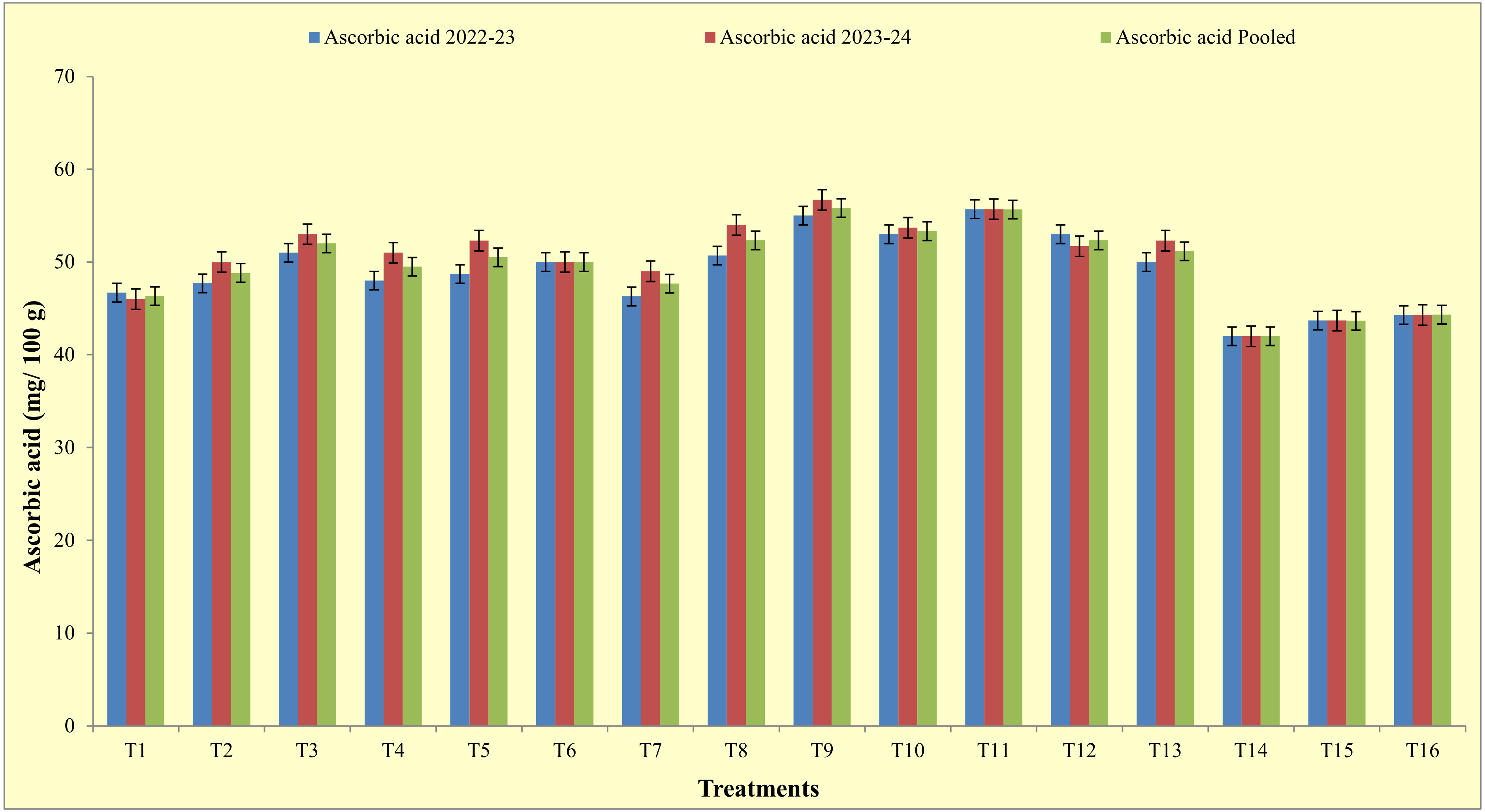

Figure 4.14: Effect of nano urea in combination with *Azotobacter* on ascorbic acid in strawberry cv. Winter Dawn.

Overall, the synergistic effects of nano urea and *Azotobacter* on nitrogen availability, plant metabolism, and antioxidant capacity contribute to rise in the ascorbic acid content inside of the strawberries, thus enhancing quality of the fruit as well as the nutritional value.

4.3.5 Total sugar (%)

Data allied to the total sugar (%) and its variation over the two experimental years (2022-23 and 2023-24) is provided in Table 4.15 and visually depicted in Figure 4.15. A thorough examination of the data indicates a noteworthy impact of nano urea on the total sugar (%) of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the total sugar (%) of strawberry cv. Winter Dawn during both years of the research experiment.

The first-year trial (2022-23) data showed maximum occurrence of total sugar under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) with a value 8.77 per cent which was followed by T_8 (25% RDF +N_2 + *Azotobacter*) and T_{11} (25% RDF +N_2 + *Azotobacter*) having values 8.50 per cent and 8.40 per cent, respectively. The least total sugar (6.30 %) was found under the treatment T_{14} (25% RDF + *Azotobacter*) while the control treatment (T_1) recorded 6.83 per cent total sugar. The second year (2023-24) data detailed the presence of maximum total sugar (0.03 %) was observed under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) while it was followed by T_8 (25% RDF +N_1 + *Azotobacter*) and T_{11} (50% RDF +N_2 + *Azotobacter*) with values 8.63 per cent and 8.60 per cent, respectively. The minimum total sugar (6.07 %) was observed under the treatment T_{14} (25% RDF + *Azotobacter*) while the control treatment (T_1) was recorded 6.83 per cent.

The aggregated data for the both years (2022-23 as well as 2023-24) revealed the utmost total sugar (8.90 %) was observed by the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_8 (25% RDF +N_1 + *Azotobacter*) and T_{11} (50% RDF +N_2 + *Azotobacter*) with values 8.57 per cent and 8.50 per cent, respectively. The control treatment (T_1) was recorded with 6.83 mg of total sugar while the minimum (6.18 mg) was found under the treatment T_{14} (25% RDF + *Azotobacter*).

The integration of nano urea with *Azotobacter* presents a promising strategy for augmenting the total sugar content of strawberries, thereby enhancing fruit quality.

Table 4.15: Effect of nano urea in combination with *Azotobacter* on total sugar in strawberry cv. Winter Dawn.

Treatments	Total sugars (%)		
	2022-23	2023-24	Pooled
T_1	6.83^{b}	6.83^{b}	6.83^{c}
T_2	7.43^{c}	7.97^{de}	7.70^{d}
T_3	8.17^{d}	8.24^{ef}	8.20^{fgh}
T_4	7.57^{b}	7.73^{cd}	7.65^{d}
T_5	7.60^{b}	8.07^{def}	7.83^{de}
T_6	7.57^{b}	7.57^{c}	7.57^{d}
T_7	7.60^{b}	7.77^{cd}	7.69^{d}
T_8	8.50^{de}	8.63^{g}	8.57^{i}
T_9	8.77^{e}	9.03^{h}	8.90^{j}
T_{10}	8.37^{de}	8.33^{fg}	8.35^{ghi}
T_{11}	8.40^{de}	8.60^{g}	8.50^{hi}
T_{12}	8.07^{d}	7.93^{de}	8.00^{ef}
T_{13}	8.13^{d}	8.23^{ef}	8.18^{gh}
T_{14}	6.30^{a}	6.07^{a}	6.18^{a}
T_{15}	6.44^{ab}	6.20^{a}	6.32^{ab}
T_{16}	6.50^{ab}	6.60^{b}	6.55^{bc}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.
Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

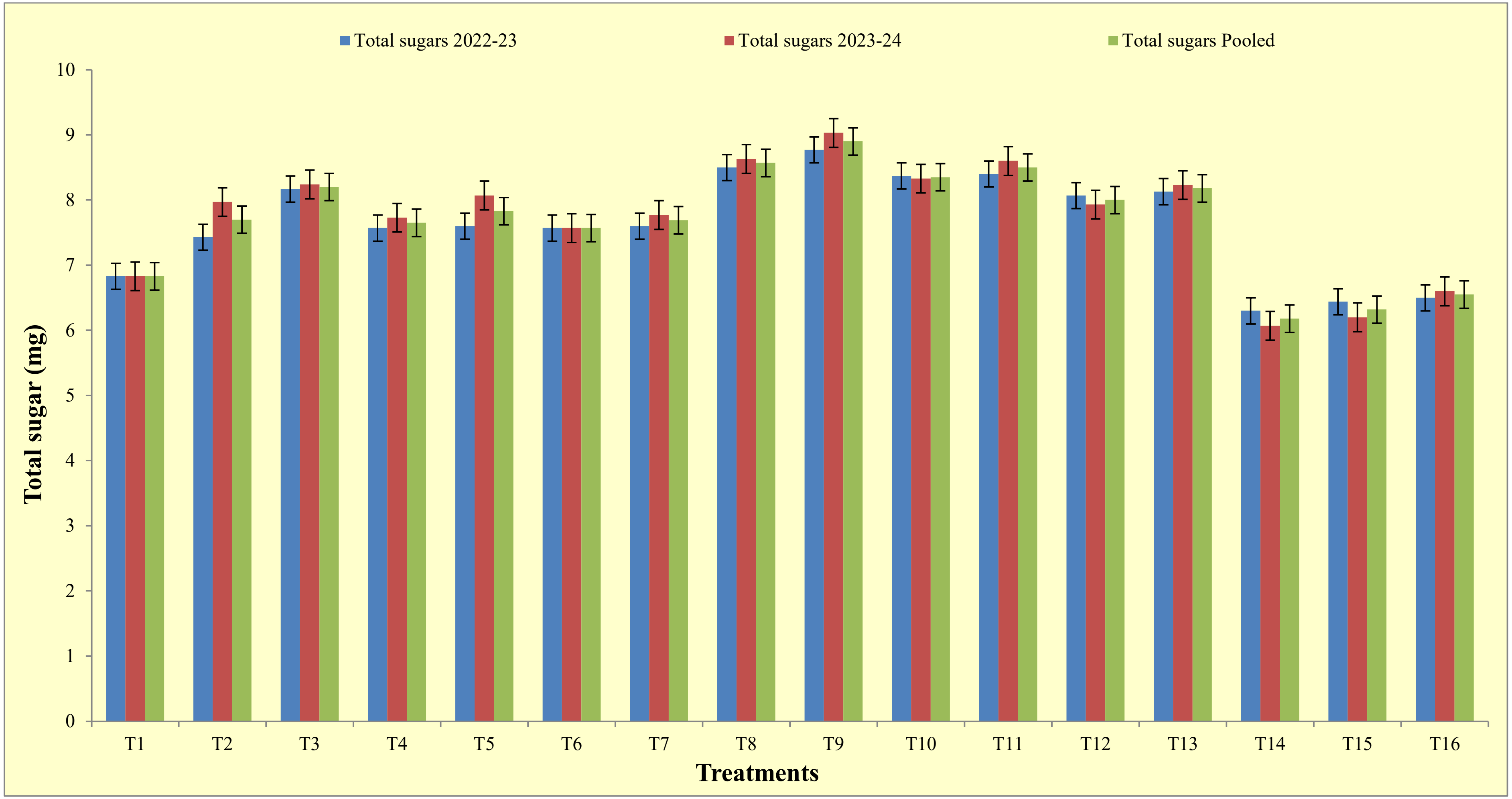

Figure 4.15: Effect of nano urea in combination with *Azotobacter* on total sugar in strawberry cv. Winter Dawn.

This enhancement is attributable to several interconnected mechanisms. Firstly, nano urea, characterized by its nano-sized particles, facilitates a controlled and sustained release of nitrogen, ensuring an optimized supply of this essential nutrient to strawberry plants. Nitrogen is a key component in the synthesis of amino acids, which serve as building blocks for sugars through various metabolic pathways (Ling *et. al.* 2023). Therefore, the optimized nitrogen availability resulting from nano urea application promotes increased synthesis of sugars (Li *et. al.* 2024) within the plant. Additionally, the presence of *Azotobacter*, a nitrogen-fixing bacterium, further enhances nitrogen availability in the rhizosphere through biological nitrogen fixation. This augmented nitrogen uptake and utilization by strawberry plants may further stimulate sugar synthesis (Kumar *et. al.* 2023). Moreover, the symbiotic interaction between *Azotobacter* and strawberry plants may induce systemic changes in plant metabolism, including the activation of enzymes involved in sugar biosynthesis pathways. Furthermore, the combined application of nano urea and *Azotobacter* may enhance photosynthetic activity and carbon assimilation, providing additional substrates for sugar synthesis. Overall, the synergistic effects of nano urea and *Azotobacter* on nitrogen availability, plant metabolism, and photosynthetic efficiency contribute to the increase in total sugar content in strawberries, thereby improving fruit quality and sweetness.

4.3.6 Reducing sugar (%)

Data affiliated to the reducing sugar (%) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside of the Table 4.16 and visually elucidated inside of the Figure 4.16. A thorough examination with respect to the data indicates a noteworthy impact of nano urea on the reducing sugar (%) of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the reducing sugar (%) of strawberry cv. Winter Dawn during both years of the research experiment.

The first-year trial (2022-23) data showed maximum reducing sugar (7.17 %) under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_{11} (50% RDF +N_2 + *Azotobacter*) and T_{10} (50% RDF +N_1 + *Azotobacter*) with the values 6.93 per cent and 6.87 mg, respectively. The control treatment (T_1) recorded 5.33 per cent of reducing sugar while the minimum reducing sugar (5.20 %) was found under the treatment T_{14} (25% RDF + *Azotobacter*).

The second-year research (2023-24) data revealed the maximum reducing sugar (6.83 per cent) under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_8 (25% RDF +N_1 + *Azotobacter*) and T_{11} (50% RDF +N_2 + *Azotobacter*) with the values of 7.00 per cent as well as 6.90 per cent, each. The treatment control (T_1) recorded 5.60 per cent of reducing sugar while the treatment T_{14} (25% RDF + *Azotobacter*) recorded the minimum reducing sugar with a value of 5.17 per cent.

The aggregated data for the both years (2022-23 as well as 2023-24) revealed the maximum presence of reducing sugar (7.23 %) under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_8 (25% RDF +N_1 + *Azotobacter*) and T_{11} (50% RDF +N_2 + *Azotobacter*) with the values of 7.02 per cent and 6.92 per cent, each. The treatment control (T_1) recorded 5.47 per cent in case of reducing sugar while least reducing sugar (5.18 %) was listed by treatment T_{14} (25% RDF + *Azotobacter*).

The combined application of nano urea with *Azotobacter* presents a promising strategy for augmenting the reducing sugar content of strawberries, thereby contributing to improved fruit quality. This enhancement is underpinned by a multifaceted interplay of mechanisms that optimize nutrient availability, plant metabolism, and microbial interactions (Bhattacharyya *et. al.* 2021). Firstly, nano urea, characterized by its nano-sized particles, facilitates a controlled and sustained release of nitrogen, ensuring an optimized supply of this essential nutrient to strawberry plants (Dimkpa *et. al.* 2020). Nitrogen serves as a key component in the synthesis of amino acids, which are precursors to reducing sugars (Lillo *et. al.* 2008). The enhanced nitrogen availability resulting from nano urea application promotes increased synthesis of reducing sugars within the plant (Sharma *et. al.* 2022).

Additionally, the presence of *Azotobacter*, a nitrogen-fixing bacterium, further enriches nitrogen availability in the rhizosphere through biological nitrogen fixation (Rodrigues *et. al.* 2018). This augmented nitrogen uptake and utilization by strawberry plants may further stimulate reducing sugar synthesis. Moreover, the symbiotic interaction between *Azotobacter* and strawberry plants might have induced systemic changes in plant metabolism, including the activation of enzymes involved in sugar biosynthesis pathways. Furthermore, *Azotobacter* contribute to the enhancement of soil microbial communities, promoting nutrient cycling and the availability of organic carbon sources that support sugar synthesis in strawberries.

Table 4.16: Effect of nano urea in combination with *Azotobacter* on reducing sugar in strawberry cv. Winter Dawn.

Treatments	Reducing sugar (%)		
	2022-23	**2023-24**	**Pooled**
T_1	5.33^{a}	5.60^{a}	5.47^{a}
T_2	5.90^{b}	6.03^{b}	5.97^{b}
T_3	6.60^{cdefg}	6.40^{bc}	6.50^{def}
T_4	6.33^{bcde}	6.27^{b}	6.30^{bcd}
T_5	6.10^{bc}	6.03^{b}	6.07^{bc}
T_6	6.13^{bcd}	6.23^{b}	6.18^{bcd}
T_7	6.47^{cdef}	6.43^{bc}	6.45^{cde}
T_8	7.03^{fg}	7.00^{de}	7.02^{g}
T_9	7.17^{g}	7.30^{e}	7.23^{g}
T_{10}	6.87^{efg}	6.83^{cd}	6.85^{efg}
T_{11}	6.93^{fg}	6.90^{de}	6.92^{fg}
T_{12}	6.73^{efg}	6.43^{bc}	6.58^{def}
T_{13}	6.67^{defg}	6.47^{bc}	6.57^{def}
T_{14}	5.20^{a}	5.17^{a}	5.18^{a}
T_{15}	5.24^{a}	5.27^{a}	5.25^{a}
T_{16}	5.17^{a}	5.53^{a}	5.35^{a}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

Figure 4.16: Effect of nano urea in combination with *Azotobacter* on reducing sugar in strawberry cv. Winter Dawn.

Overall, the synergistic effects of nano urea and *Azotobacter* on nitrogen availability, plant metabolism, and microbial interactions converge to increase the reducing sugar content in strawberries, thereby enhancing fruit sweetness and nutritional value.

The findings are closely aligned to the research study done by Davarpanah *et. al.* (2017) and Prasad and Mali (2000), where they elucidated the nitrogen fertilization has been shown to enhance the levels of total, reducing, and non-reducing sugars in pomegranate fruits as well as in guava (Sharma *et. al.* 2014). Furthermore, it is suggested that the increase in sugar content resulting from nitrogen fertilization may facilitate the uptake of other mineral nutrients, thereby improving the quality of the fruits (Sharma *et. al.* 2014).

4.3.7 Non reducing sugar (%)

Data allied to the non-reducing sugar (%) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside of the Table 4.17 and visually unveiled inside of the Figure 4.17. A thorough examination of the data indicates a noteworthy impact of nano urea on the non-reducing sugar (%) of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the non-reducing sugar (%) of strawberry cv. Winter Dawn during both years of the research experiment.

The first- year trial (2022-23) showed the maximum non reducing sugar (1.52 %) under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_3 (25% RDF +N_2 + *Azotobacter*), T_5 (50% RDF +N_2) and T_{10} (50% RDF +N_1 + *Azotobacter*) with the values of 1.49 per cent, 1.43 per cent as well as 1.43 per cent, respectively. The control treatment (T_1) recorded the non-reducing sugar 1.43 per cent while nidar non-reducing sugar (1.05 %) was reported by the treatment T_{14} (25% RDF + *Azotobacter*).

The second-year research (2023-24) data revealed the maximum non-reducing sugar (1.93 %) under the treatment T_5 (50% RDF +N_2) followed by T_2 (50% RDF +N_1) and T_3 (25% RDF +N_2) having the values of 1.84 per cent as well as 1.74 per cent, apiece. The treatment control (T_1) recorded 1.17 per cent in case of the non-reducing sugar while nidar value of non-reducing (0.86 %) was observed under the treatment T_{14} (25% RDF + *Azotobacter*).

Table 4.17: Effect of nano urea in combination with *Azotobacter* on non-reducing sugar in strawberry cv. Winter Dawn.

Treatments	Non-reducing sugar (%)		
	2022-23	2023-24	Pooled
T_1	1.43^{ab}	1.17^{ab}	1.30^{abcde}
T_2	1.46^{b}	1.84^{de}	1.65^{ef}
T_3	1.49^{ab}	1.74^{cde}	1.62^{ef}
T_4	1.17^{ab}	1.39^{abcd}	1.28^{abcde}
T_5	1.43^{ab}	1.93^{e}	1.68^{f}
T_6	1.36^{ab}	1.27^{abc}	1.31^{bcdef}
T_7	1.08^{a}	1.27^{abc}	1.17^{abcd}
T_8	1.39^{ab}	1.55^{bcde}	1.47^{cdef}
T_9	1.52^{b}	1.65^{bcde}	1.58^{ef}
T_{10}	1.43^{ab}	1.43^{abcd}	1.43^{cdef}
T_{11}	1.39^{ab}	1.62^{bcde}	1.50^{def}
T_{12}	1.27^{ab}	1.43^{abcd}	1.35^{bcdef}
T_{13}	1.39^{ab}	1.68^{bcde}	1.54^{def}
T_{14}	1.05^{a}	0.86^{a}	0.95^{a}
T_{15}	1.14^{ab}	0.89^{a}	1.01^{ab}
T_{16}	1.27^{ab}	1.01^{a}	1.14^{abc}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

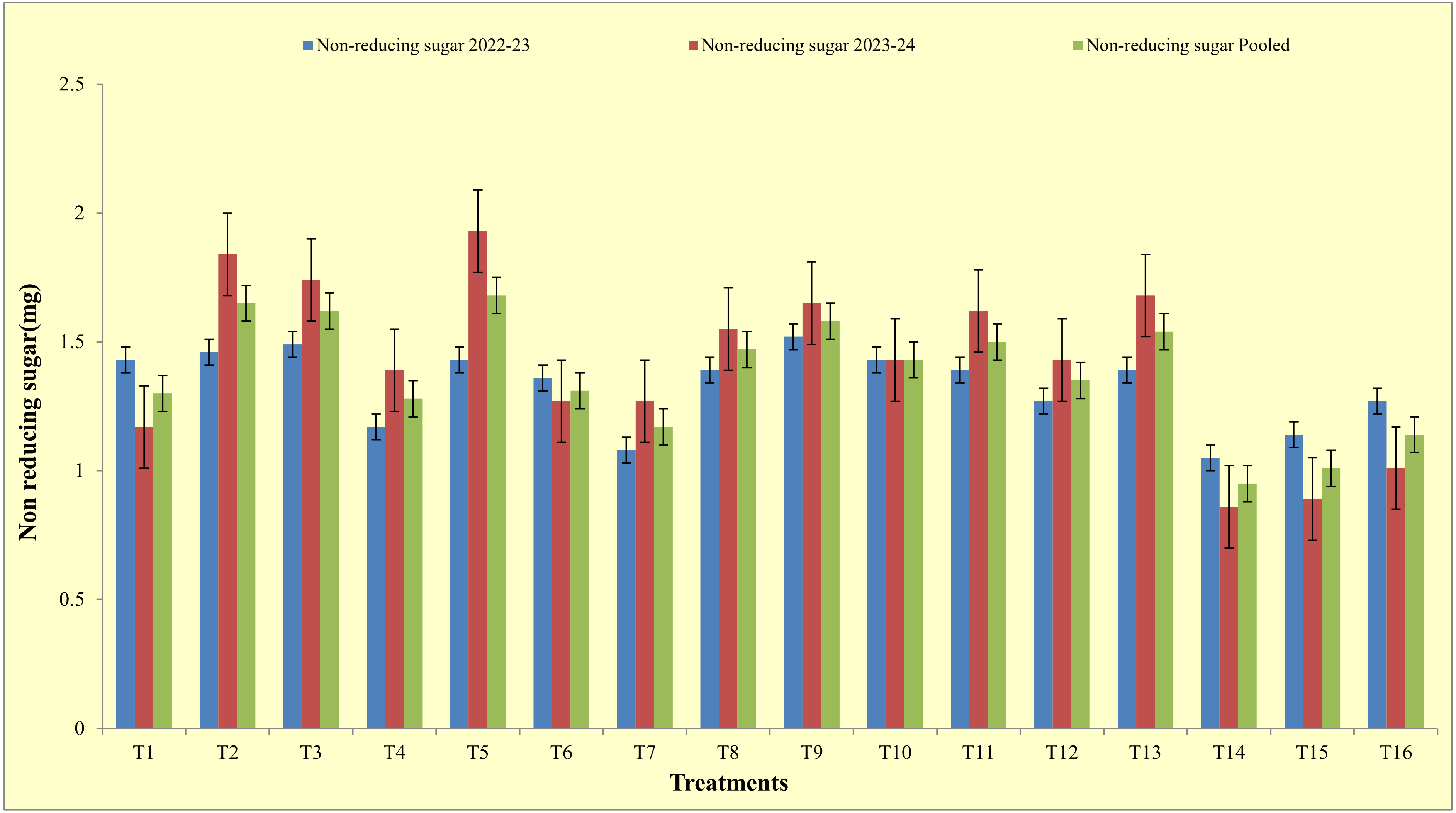

Figure 4.17: Effect of nano urea in combination with *Azotobacter* on non-reducing sugar in strawberry cv. Winter Dawn.

The aggirgated data for the both years (2022-23 as well as 2023-24) revealed the maximum non-reducing sugar (1.65 %) under the treatment T_2 (25% RDF $+N_1$) followed by T_3 (25% RDF $+N_2$) and T_3 (25% RDF $+N_2$) with the values of 1.65 per cent and 1.62 per cent. The control treatment recorded 1.30 per cent of non-reducing sugar while minimal value (0.95 %) in case of the non-reducing sugar was observed by treatment T_{14} (25% RDF + *Azotobacter*).

In discussing the enhancement of non-reducing sugar levels in plants treated with nano urea in conjunction with *Azotobacter*, several physiological and biochemical mechanisms need to be considered. Nano urea, due to its smaller particle size, offers improved nitrogen use efficiency compared to conventional urea (Kumar *et. al.* 2023). This enhanced efficiency primarily stems from the reduced volatilization and leaching losses, ensuring a more consistent and targeted delivery of nitrogen to the plant roots (Iqbal *et. al.* 2019). *Azotobacter*, a free-living nitrogen-fixing bacterium, not only contributes to additional nitrogen availability through biological fixation but also promotes plant growth through the production of phytohormones and other growth-enhancing substances (Jaiswal *et. al.* 2021).

The synergistic interaction between nano urea and *Azotobacter* potentially amplifies these effects. In terms of non-reducing sugar accumulation, the improved nitrogen status can influence the plant's carbohydrate metabolism. Nitrogen is a critical component of amino acids and proteins involved in enzymatic processes (Kishorekumar *et. al.* 2020), including those that convert reducing sugars into non-reducing sugar forms such as sucrose. Efficient nitrogen utilization thus supports the enzymatic activities required for these conversions, potentially increasing the accumulation of non-reducing sugars. Additionally, the growth-promoting effects induced by *Azotobacter* might alter the source-sink dynamics within the plant, favoring more energy and carbon allocation towards the synthesis and storage of non-reducing sugars (Vessey, 2003). Understanding the exact biochemical pathways and genetic expressions influenced by this combination could provide further insights into how these treatments synergistically enhance non-reducing sugar content in plants, contributing significantly to improved plant productivity and stress tolerance (Khan *et. al.* 2020).

4.4 Biochemical Parameters

4.4.1 Antioxidants [μ mol Trolox Equivalent (TE) /g Fresh Weight (FW)]

Data pertaining to antioxidants (μ mol TE/g FW) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside of the Table 4.18 and visually unveiled inside the Figure 4.18. A thorough examination of the data indicates a noteworthy impact of nano urea on the antioxidants (µ mol TE/g FW) of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the antioxidants (µ mol TE/g FW) of strawberry cv. Winter Dawn during both years of the research experiment.

The first-year trial (2022-23) data detailed about the maximum antioxidants (1.90 µ mol TE/g FW) were observed under the treatment T_{11} (50% RDF +N_2 + *Azotobacter*) followed by T_{10} (50% RDF +N_1 + *Azotobacter*) and T_{13} (75% RDF +N_2 + *Azotobacter*) having the similar values 1.87 µ mol TE/g FW and 1.87 µ mol TE/g FW, respectively. The control treatment (T_1) was observed with 1.48 µ mol TE/g FW antioxidants while the minimum antioxidants (1.22 µ mol TE/g FW) were observed under the treatment T_{14} (25% RDF + *Azotobacter*).

Second year trial (2023-24) data showed the maximum antioxidants (1.87 µ mol TE/g FW) under the treatment T_{11} (50% RDF +N_2 + *Azotobacter*) followed by T_9 (25% RDF +N_2 + *Azotobacter*) and T_{10} (50% RDF +N_1 + *Azotobacter*) having the values 1.86 µ mol TE/g FW and 1.85 µ mol TE/g FW, respectively. The minimum antioxidants (1.24 µ mol TE/g FW) were recorded under the treatment T_{14} (25% RDF + *Azotobacter*) and the control recorded 1.44 µ mol TE/g FW antioxidants.

Pooled data for both the trials (2022-23 and 2023-24) revealed the maximum of antioxidants were observed under the treatment T_{11} (50% RDF +N_2 + *Azotobacter*) with a value of 1.89 µ mol TE/g FW. It was followed by T_{10} (50% RDF +N_1 + *Azotobacter*) and T_{13} (75% RDF +N_2 + *Azotobacter*) with the values 1.86 µ mol TE/g FW and 1.84 µ mol TE/g FW, respectively. The control treatment recorded 1.46 µ mol TE/g FW antioxidants while the minimum antioxidants (1.46 µ mol TE/g FW) were recorded under T_{14} (25% RDF + *Azotobacter*).

In exploring the enhancement of antioxidant levels in strawberries through the application of nano urea and *Azotobacter*, it is crucial to understand the interconnected roles

Table 4.18: Effect of nano urea in combination with *Azotobacter* on antioxidants in strawberry cv. Winter Dawn.

Treatments	Antioxidants (µ mol TE/g FW)		
	2022-23	2023-24	Pooled
T_1	1.48[c]	1.44[c]	1.46[c]
T_2	1.61[d]	1.63[d]	1.62[d]
T_3	1.72[ef]	1.74[ef]	1.73[ef]
T_4	1.78[fg]	1.74[ef]	1.76[fg]
T_5	1.81[gh]	1.82[ghi]	1.82[hi]
T_6	1.80[gh]	1.78[fg]	1.79[gh]
T_7	1.84[ghi]	1.80[fg]	1.82[hi]
T_8	1.69[e]	1.71[e]	1.70[e]
T_9	1.80[gh]	1.86[hi]	1.83[hi]
T_{10}	1.87[hi]	1.85[hi]	1.86[ij]
T_{11}	1.90[i]	1.87[i]	1.89[j]
T_{12}	1.85[ghi]	1.80[fg]	1.82[hi]
T_{13}	1.87[hi]	1.81[gh]	1.84[hij]
T_{14}	1.22[a]	1.24[a]	1.23[a]
T_{15}	1.38[b]	1.36[b]	1.37[b]
T_{16}	1.40[b]	1.40[bc]	1.40[b]

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

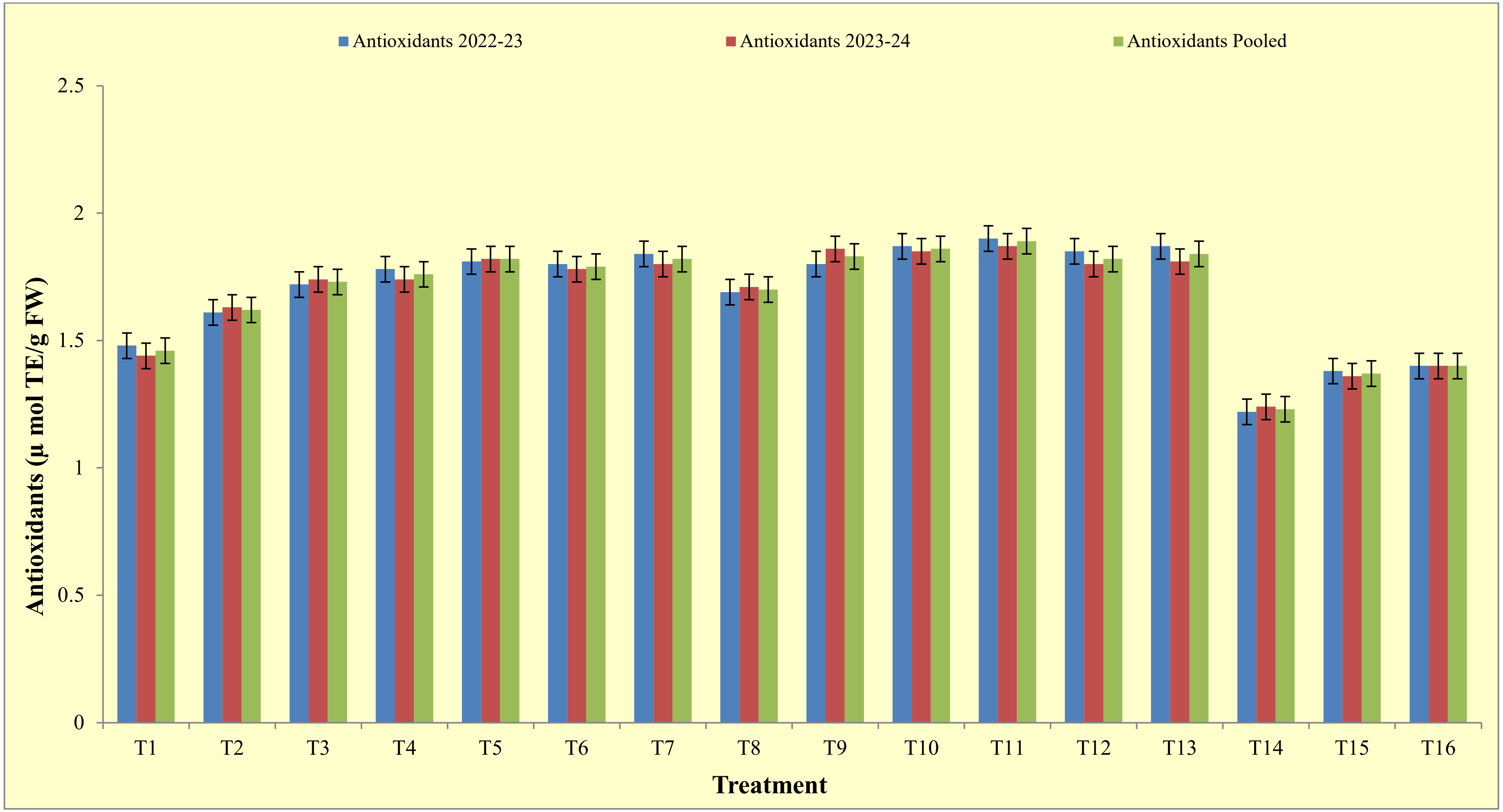

Figure 4.18: Effect of nano urea in combination with *Azotobacter* on antioxidants in strawberry cv. Winter Dawn.

of nitrogen availability and microbial interactions. Nano urea offers a significant advantage over conventional urea formulations due to its enhanced solubility and uptake efficiency, which can lead to more effective nitrogen assimilation by plants (Kumar *et. al.* 2023). Improved nitrogen availability is essential for the synthesis of primary and secondary metabolites (Mahajan *et. al.* 2020), including antioxidant compounds such as flavonoids and phenolic acids, which are abundant in strawberries (Wu *et. al.* 2024).

Azotobacter, as a plant growth-promoting rhizobacterium (Hindersah *et. al.* 2020), not only assists in nitrogen fixation but also influences various physiological processes in plants (Singh et. al, 2022), including hormonal balance and immune responses (Borah *et. al.* 2023). This bacterium has been found to induce systemic resistance and stress tolerance in plants (Kiran *et. al.* 2022), which can be associated with elevated levels of endogenous signaling molecules like salicylic acid and jasmonic acid (Sevim *et. al.* 2023). These molecules are known to mediate the production of antioxidants (Woch *et. al.* 2023).

The combination of nano urea and *Azotobacter* potentially creates a synergistic effect, optimizing nitrogen use and stimulating the plant's intrinsic defense mechanisms. This dual action can lead to a more robust antioxidant system in strawberries, characterized by increased concentrations of antioxidants that not only protect the plants from oxidative stress but also improve the nutritional quality of the fruit. Future studies should focus on quantifying the specific changes in antioxidant profiles in strawberries treated with nano urea and *Azotobacter* and determining the underlying molecular pathways involved. This research will contribute to a deeper understanding of how agronomic practices can be aligned with plant physiology to enhance fruit quality and plant health.

4.4.2 Anthocyanin (mg/ 100 g pulp)

Data pertaining to anthocyanin (mg per 100 g pulp) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside of the Table 4.19 and visually unveiled inside the Figure 4.19. A thorough examination with respect to the data indicates a noteworthy impact of nano urea on the anthocyanin content of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the anthocyanin content of strawberry cv. Winter Dawn during both years of the research experiment.

The first trial (2022-23) data revealed the maximum anthocyanin (0.274 mg per 100 g pulp) recorded under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_8 (25% RDF +N_1 + *Azotobacter*) and T_{10} (50% RDF +N_1 + *Azotobacter*) having the similar values 0.268 mg per 100 g pulp and 0.268 mg per 100 g pulp, respectively. The minimum anthocyanin (0.203 mg per 100 g pulp) was recorded under T_{14} (25% RDF + *Azotobacter*) while the control treatment (T_1) was recorded with 0.235 mg per 100 g pulp.

In the second-year research trial (2023-24) data revealed the maximum anthocyanin (0.276 mg per 100 g pulp) was recorded under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) while it was followed by T_8 (25% RDF +N_1 + *Azotobacter*) and T_3 (25% RDF +N_2) with values 0.274 mg per 100 g pulp and 0.273 mg per 100 g pulp, respectively. The minimum anthocyanin content (0.207 mg per 100 g pulp) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*) while the control treatment (T_1) recorded 0.233 mg per 100 g of the pulp.

Combining the data for the both years (2022-23 as well as 2023-24) revealed maximum anthocyanin (0.275 mg per 100 g pulp) was recorded under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_8 (25% RDF +N_1 + *Azotobacter*) and T_3 (25% RDF +N_2) with similar values 0.270 mg per 100 g pulp and 0.270 mg per 100 g of the pulp, apiece. The treatment control (T_1) listed 0.234 mg per 100 g pulp (anthocyanin) while the minimum 0.205 mg per 100 g pulp was recorded under treatment (T_{14}).

The potential for enhancing anthocyanin content in strawberries through the combined application of nano urea and *Azotobacter* presents a promising avenue for agricultural innovation aimed at improving fruit quality and nutritional value. Nano urea, characterized by its significantly reduced particle size compared to conventional urea, ensures a more efficient delivery and uptake of nitrogen (Kumar *et. al.* 2023). This efficient nitrogen utilization is pivotal for the synthesis of amino acids that are precursors to anthocyanins (Meng *et. al.* 2020), the pigments responsible for the red color in strawberries and other fruits (Sirijan *et. al.* 2020). Efficient nitrogen assimilation influences the phenylpropanoid pathway (Tang *et. al.* 2020), which is directly involved in anthocyanin biosynthesis (Liu *et. al.* 2021), suggesting that enhanced nitrogen availability could lead to increased anthocyanin production (Al-Qadi, and Ameen, 2013).

Azotobacter contributes further to this effect by its nitrogen-fixing capabilities and its

Table 4.19: Effect of nano urea in combination with *Azotobacter* on anthocyanin in strawberry cv. Winter Dawn.

Treatments	Anthocyanin (mg/ 100 g pulp)		
	2022-23	2023-24	Pooled
T_1	0.235^{d}	0.233^{c}	0.234^{c}
T_2	0.248^{e}	0.257^{d}	0.252^{d}
T_3	0.269^{ij}	0.273^{e}	0.271^{h}
T_4	0.252^{ef}	0.255^{d}	0.253^{de}
T_5	0.258^{fgh}	0.260^{d}	0.259^{fg}
T_6	0.254^{fg}	0.257^{d}	0.256^{ef}
T_7	0.257^{fgh}	0.258^{d}	0.258^{gh}
T_8	0.268^{i}	0.274^{e}	0.271^{h}
T_9	0.274^{j}	0.276^{e}	0.275^{h}
T_{10}	0.268^{i}	0.270^{e}	0.269^{h}
T_{11}	0.263^{hi}	0.271^{e}	0.267^{h}
T_{12}	0.259^{gh}	0.269^{e}	0.264^{g}
T_{13}	0.261^{h}	0.271^{e}	0.266^{h}
T_{14}	0.203^{a}	0.207^{a}	0.205^{a}
T_{15}	0.209^{b}	0.211^{a}	0.210^{a}
T_{16}	0.216^{c}	0.224^{b}	0.220^{b}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

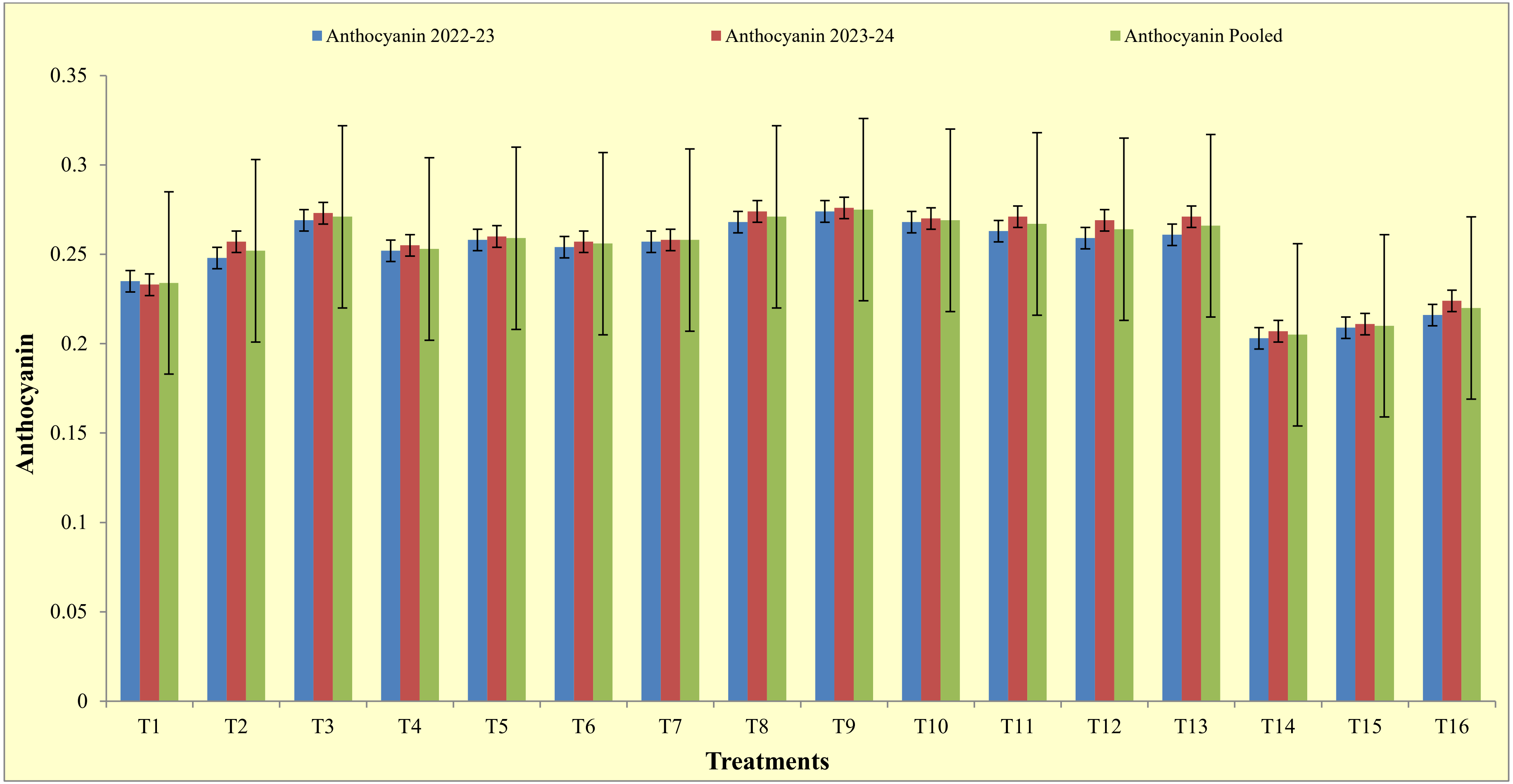

Figure 4.19: Effect of nano urea in combination with *Azotobacter* on anthocyanin in strawberry cv. Winter Dawn.

role in promoting plant growth and health (Aasfar *et. al.* 2021). More importantly, *Azotobacter* can influence secondary metabolite pathways through its effect on the hormonal balance within plants (Mousavi *et. al.* 2022). It has been documented that such microbial interactions can enhance the levels of growth regulators, including auxins and cytokinins (EL Sabagh *et. al.* 2022), which have been linked to the regulation of genes involved in anthocyanin synthesis (Li *et. al.* 2021; Wang *et. al.* 2023). Furthermore, the presence of *Azotobacter* can stimulate the plant's defence mechanisms (Hindersah et. al, 2020), potentially leading to an induced systemic response that includes upregulation of antioxidant pathways, which are closely related to anthocyanin synthesis (Chen *et. al.* 2020).

Therefore, the synergistic use of nano urea and *Azotobacter* not only optimizes nitrogen efficiency but also potentially modifies physiological and metabolic pathways in strawberries, enhancing anthocyanin content. This hypothesis suggests a dual mechanism where improved nitrogen status enhances the precursor availability for anthocyanin synthesis, and microbial interaction modulates the regulatory and biochemical pathways favoring these phenolic compounds. Future empirical research should focus on delineating these interactions at a molecular level to establish a clear causal relationship and optimize application rates and conditions for maximum anthocyanin enhancement in strawberries. This knowledge would significantly contribute to the fields of agronomy and plant physiology, offering strategies to naturally improve the nutritional and aesthetic qualities of strawberries.

4.5 Nutrient Analysis

4.5.1 Plant Nutrient Analysis (NPK)

Data pertaining to plant nutrient analysis (NPK) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside of the Table 4.20 and visually unveiled inside of the Figure 4.20. A thorough examination with respect to the data indicates a noteworthy impact of nano urea on plant nutrient analysis (NPK) of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the plant nutrient analysis (NPK) of strawberry cv. Winter Dawn during both years of the research experiment.

The first-year trial (2022-23) showed the maximum presence of nitrogen (2.51 %) under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_{11} (50% RDF +N_2 + *Azotobacter*) and T_8 (25% RDF +N_1 + *Azotobacter*) having values of 2.46 per cent as well as

2.42 per cent, apiece. The treatment control T_1 recorded 1.56 per cent nitrogen while the least (0.99 %) was recorded under T_{14} (25% RDF + *Azotobacter*). During second year trial (2023-24), the maximum presence of nitrogen (2.47 %) was observed under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_{11} (50% RDF +N_2 + *Azotobacter*) and T_8 (25% RDF +N_1 + *Azotobacter*) having values 2.37 per cent as well as 2.36 per cent, apiece. The control treatment T_1 recorded 1.42 per cent nitrogen while the least nitrogen (0.96 per cent) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*). The pooled analysis of both the years (2022-23 and 2023-24) revealed the maximum nitrogen (2.49 %) under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) followed by T_{11} (50% RDF +N_2 + *Azotobacter*) and T_8 (25% RDF +N_1 + *Azotobacter*) having values 2.42 per cent as well as 2.39 per cent, apiece. The treatment control T_1 recorded 1.49 per cent nitrogen while the least (0.98 %) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*).

In the first-year experiment (2022-23), the maximum phosphorus (0.38 %) was recorded under the treatment T_9 (25% RDF +N_2 + *Azotobacter*) T_{10} (25% RDF +N_2 + *Azotobacter*) T_{11} (25% RDF +N_2 + *Azotobacter*) and T_{15} (25% RDF +N_2 + *Azotobacter*), each. The control treatment T_1 recorded 0.37 per cent phosphorus while the least (0.35 %) was recorded under the treatment T_{12} (75% RDF +N_1 + *Azotobacter*). During the second year trial (2023-24), maximum phosphorus (0.37) was recorded under treatment T_2 (25% RDF +N_2), T_4 (50% RDF +N_1), T_6 (75% RDF +N_1 and T_{15} (75% RDF +N_2), each. The control treatment T_1 was recorded with 0.36 phosphorus while the least (0.33 %) was recorded under the treatment T_5 (50% RDF +N_2) and T_7 (75% RDF +N_2), each. The pooled analysis for both the years (2023-23 and 2023-24) revealed the maximum phosphorus (0.37 %) under the treatment T_1 (control), T_2 (25% RDF +N_2), T_4 (50% RDF +N_1), T_6 (75% RDF +N_1), T_8 (25% RDF +N_1 + *Azotobacter*), T_9 (25% RDF +N_2 + *Azotobacter*), T_{10} (50% RDF +N_1 + *Azotobacter*), T_{11} (50% RDF +N_2 + *Azotobacter*) and T_{16} (75% RDF + *Azotobacter*), each. The least phosphorus (0.34 %) was recorded under the treatment T_5 (50% RDF +N_2).

In the first-year trial (2022-23), the potassium (K) was recorded maximum (2.73 %) under the treatment T_2 (25% RDF +N_1 + *Azotobacter*) followed by T_{15} (25% RDF +N_2 + *Azotobacter*) having a value of 2.70 per cent. The control treatment T_1 recorded 2.66 per cent potassium while the least was recorded under the treatment T_6 (75% RDF +N_1 + *Azotobacter*). The second-year trial (2023-24) recorded the maximum potassium (2.78 %) under the treatment T_2 (25% RDF +N_1) followed by T_1 (control) and T_{15} (50% RDF + *Azotobacter*) having values of 2.66 per cent and 2.65 per cent, respectively. The least potassium (2.49 %) was recorded under the treatment T_7 (75% RDF +N_2). The pooled analysis for both the years (2022-23 and 2023-24) revealed the maximum potassium under the treatment T_2 (25% RDF +N_1) followed by T_{15} (50% RDF + *Azotobacter*) and T_1 (control) having values 2.67 and 2.66, respectively. The least value (2.59 %) was recorded the treatment T_7 (75% RDF +N_2).

The foliate application having the nano urea combined with a basal dose consisting the *Azotobacter* is a novel approach that potentially enhances nitrogen availability in strawberry plants, particularly within the leaves where photosynthesis and growth processes are highly concentrated. Nano urea, characterized by its nano-scale particles, provides a distinct advantage over conventional urea through more efficient and rapid absorption by the leaf surface (Dimkpa *et. al.* 2022). This method bypasses the soil-plant interface, reducing nitrogen losses commonly associated with leaching, volatilization, or immobilization in the soil (Yadav *et. al.* 2023). The direct availability of nitrogen to the photosynthetic tissues ensures immediate utilization for amino acid synthesis and other nitrogen-demanding metabolic processes, which are crucial for plant growth and productivity (Ji *et. al.* 2023).

Azotobacter, applied as a basal soil treatment, complements this approach by enhancing soil nitrogen levels through biological nitrogen fixation (Raza *et. al.* 2020). This bacterium not only contributes fixed nitrogen to the soil but also promotes increased root health and development, improving the plant's overall nutrient uptake capacity (Aasfar *et. al.* 2021; Sumbul *et. al.* 2020). The presence of *Azotobacter* in the soil can lead to improved soil structure and fertility over time, facilitating better absorption and translocation of nitrogen and other nutrients from the soil to the plant (Sharma *et. al.* 2020; Dellagi *et. al.* 2020; Etesami *et. al.* 2020).

The integrated use of foliar-applied nano urea and soil-applied *Azotobacter* creates a dual-enhancement mechanism of nitrogen availability in strawberry leaves. While nano urea directly supplies nitrogen to leaf tissues, enhancing immediate nitrogen assimilation for critical processes such as chlorophyll synthesis and photosynthesis, *Azotobacter* indirectly supports this by enriching the soil nitrogen pool and root uptake efficiency. This synergistic application ensures that nitrogen is available in a sustained manner throughout different plant parts, optimizing growth and productivity. This might have been the reason of increased or levelled up nitrogen present in the strawberry plant leaves while there was no significant

Table 4.20: Effect of nano urea in combination with *Azotobacter* on plant nutrient status (NPK) in strawberry cv. Winter Dawn.

Treatments	Plant nutrient analysis (NPK) %								
	Nitrogen			Phosphorus			Potassium		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	1.56^{d}	1.42^{d}	1.49^{d}	0.37^{a}	0.36^{a}	0.37^{a}	2.66^{a}	2.66^{bc}	2.66^{ab}
T_2	2.00^{g}	2.06^{g}	2.03^{g}	0.37^{a}	0.37^{a}	0.37^{a}	2.73^{a}	2.78^{c}	2.75^{b}
T_3	2.14^{h}	2.16^{h}	2.15^{h}	0.36^{a}	0.34^{a}	0.35^{a}	2.67^{a}	2.64^{b}	2.65^{ab}
T_4	1.89^{e}	1.93^{e}	1.91^{e}	0.36^{a}	0.37^{a}	0.37^{a}	2.66^{a}	2.58^{ab}	2.62^{ab}
T_5	2.00^{g}	2.02^{fg}	2.01^{fg}	0.35^{a}	0.33^{a}	0.34^{a}	2.64^{a}	2.60^{ab}	2.62^{ab}
T_6	1.88^{e}	1.91^{e}	1.90^{e}	0.37^{a}	0.37^{a}	0.37^{a}	2.62^{a}	2.62^{ab}	2.62^{ab}
T_7	1.93^{f}	1.97^{ef}	1.95^{f}	0.37^{a}	0.33^{a}	0.35^{a}	2.69^{a}	2.49^{a}	2.59^{a}
T_8	2.42^{j}	2.36^{j}	2.39^{j}	0.37^{a}	0.36^{a}	0.37^{a}	2.69^{a}	2.52^{ab}	2.60^{a}
T_9	2.51^{l}	2.47^{k}	2.49^{k}	0.38^{a}	0.36^{a}	0.37^{a}	2.63^{a}	2.57^{ab}	2.60^{ab}
T_{10}	2.33^{i}	2.28^{i}	2.30^{i}	0.38^{a}	0.35^{a}	0.37^{a}	2.70^{a}	2.60^{ab}	2.65^{ab}
T_{11}	2.46^{k}	2.37^{j}	2.42^{j}	0.38^{a}	0.35^{a}	0.37^{a}	2.62^{a}	2.58^{ab}	2.60^{a}
T_{12}	2.31^{i}	2.28^{i}	2.29^{i}	0.35^{a}	0.34^{a}	0.35^{a}	2.66^{a}	2.63^{b}	2.65^{ab}
T_{13}	2.17^{h}	2.14^{h}	2.16^{h}	0.37^{a}	0.35^{a}	0.36^{a}	2.69^{a}	2.61^{ab}	2.65^{ab}
T_{14}	0.99^{a}	0.96^{a}	0.98^{a}	0.37^{a}	0.36^{a}	0.36^{a}	2.68^{a}	2.61^{ab}	2.65^{ab}
T_{15}	1.11^{b}	1.05^{b}	1.08^{b}	0.38^{a}	0.34^{a}	0.36^{a}	2.70^{a}	2.65^{b}	2.67^{ab}
T_{16}	1.21^{c}	1.16^{c}	1.19^{c}	0.37^{a}	0.37^{a}	0.37^{a}	2.67^{a}	2.63^{b}	2.65^{ab}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

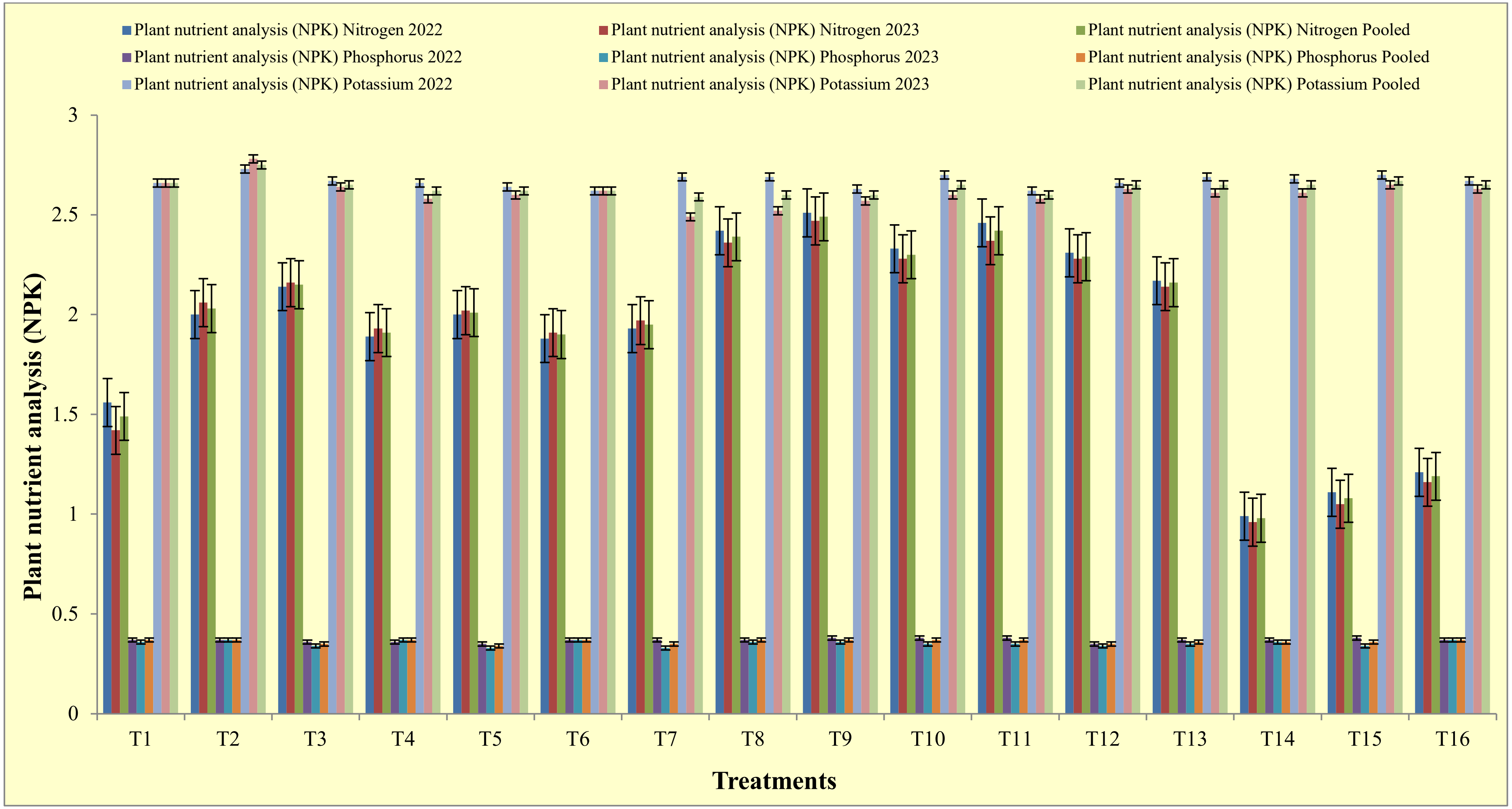

Figure 4.20: Effect of nano urea in combination with *Azotobacter* on plant nutrient status (NPK) in strawberry cv. Winter Dawn.

variation was observed in the phosphorus and potassium availability in strawberry plant as the provided dose was constant.

4.5.2 Soil nutrient analysis (NPK)

Data allied to soil nutrient analysis (NPK) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside of the Table 4.21 also visually unveild inside the Figure 4.21. A thorough examination of the data indicates a noteworthy impact of nano urea on soil nutrient analysis (NPK) of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the soil nutrient analysis (NPK) of strawberry cv. Winter Dawn during both years of the research experiment.

The initial trial (2022-23) recorded 151.56 kg/ha of nitrogen in the soil, 16.23 kg/ ha of phosphorus, 198.43 kg/ha of potassium, 3.7 $g^{-1}kg$ organic carbon and 3 CFU 10^6 *Azotobacter* count. Whereas, second year research trial (2023-24) observed 150.23 kg/ha of nitrogen, 15.51 kg/ha of phosphorus, 196.38 kg/ha of potassium, 3.4 g/kg of organic carbon, and 2 CFU 10^6 of *Azotobacter* colonies.

The soil NPK analysis was observed with significant variation among the treatments of nano urea application. The first-year trial (2022-23) recorded maximum nitrogen (234.65 kg/ha) under the treatment T_1 (control) followed by T_7 (75% RDF +N_2) and T_6 (75% RDF +N_1) having values 227.86 kg/ha and 221.34 $kg^{-1}ha$, apiece. The minimal soil nitrogen (169.00 kg^{-1} ha) was recorded by treatment T_9 (25% RDF +N_2 + *Azotobacter*). During the second-year trial (2023-24), the soil nitrogen was observed highest (222.10 kh/ha) under the treatment T_1 (control) followed by T_7 (75% RDF +N_2) and T_6 (75% RDF +N_1) having values of 218.18 kg/ha and 217.04 kg^{-1} ha, apiece. The minimal soil nitrogen (151.28 kg^{-1} ha) was listed by treatment T_3 (25% RDF +N_2). The pooled analysis for both the years (2022-23 and 2023-24) revealed the maximum soil nitrogen (228.38 kg/ha) under the treatment T_1 (control) followed by T_7 (75% RDF +N_2) and T_{16} (75% RDF + *Azotobacter*) with the values of 223.02 kg/ha and 220.44 kg/ha, respectively.

The initial research trial (2022-23 and 2023-24) recorded the maximum phosphorus (28.53 kg/ha) under the treatment T_{13} (75% RDF +N_2 + *Azotobacter*) followed by T_{16} (75% RDF + *Azotobacter*) and T_{11} (50% RDF +N_2 + *Azotobacter*) having values of 27.39 kg/ha and

26.90 kg^{-1} ha, respectively. The least of the soil phosphorus (20.76 kg^{-1} ha) was recorded by treatment T_1 (control). The second-year trial (2023-24) revealed the maximum observance of soil phosphorus (23.25 kg/ha) under the treatment T_{12} (75% RDF +N_1 + *Azotobacter*) followed by T_6 (75% RDF +N_1) and T_3 (25% RDF +N_2) having values 22.93 kg/ha and 22.89 kg/ha, respectively. The control treatment T_1 recorded 22.61 kg/ha soil phosphorus while the minimum (22.15 kg/ha) was observed under the treatment T_4 (50% RDF +N_1). The combined analysis for both years (2022-23 and 2023-24) showed the maximum soil phosphorus (25.71 kg/ha) under T_{13} (75% RDF +N_2 + *Azotobacter*) followed by T_{12} (75% RDF +N_1 + *Azotobacter*) and T_{16} (75% RDF + *Azotobacter*) having values 24.85 kg/ha and 24.74 kg/ha, respectively.

The first-year trial (2022-23) recorded the maximum potassium (215.71 kg/ ha) under the treatment T_{13} (75% RDF +N_2 + *Azotobacter*) followed by T_{15} (50% RDF + *Azotobacter*) and T_{12} (75% RDF +N_1 + *Azotobacter*). The control treatment T_1 recorded a minimum potassium value of 204.45 kg/ha which the minimum value recorded. The second year (2023-24) showed the maximum presence of potassium (208.01 kg/ha) under the treatment T_3 (25% RDF +N_2) followed by T_7 (75% RDF +N_2) and T_{13} (75% RDF +N_2 + *Azotobacter*) having values of 206.67 kg/ha and 205.26 kg/ha, respectively. The control treatment T_1 recorded 201.16 kg/ha of potassium while the minimum (200.34 kg/ha) was recorded under the treatment T_5 (50% RDF +N_2). The pooled analysis for both the years (2022-23 and 2023-24) revealed the maximum presence of potassium (210.49 kg/ ha) under the treatment T_{13} (75% RDF +N_2 + *Azotobacter*) followed by T_7 (75% RDF +N_2) and T_3 (25% RDF +N_2) having values of 209.72 kg/ ha and 208.77 kg/ ha, respectively. The control treatment T_1 was recorded with 205.01 kg/ ha of potassium while the minimum (204.65 kg/ ha) was recorded under the treatment T_4 (50% RDF +N_2).

The basal application of nitrogen (N) is a critical agricultural practice aimed at enhancing the availability of nitrogen in soil (Yadav *et. al.* 2017), thereby optimizing crop growth and yield (Hammad *et. al.* 2018). This technique employs applying nitrogen fertilizers at or near the plant, targeting the root zone of the crops (Sharma and Bali, 2017). Through this method, nitrogen is strategically placed in the soil where it can be readily accessed by the developing root system of the plants (Gutschick, 1981; Lynch, 2013). One of the key mechanisms through which basal application enhances nitrogen availability in soil is its dilution in the soil (Zhang *et. al.* 2012). When nitrogen fertilizers are applied at the basal level, they are in closer proximity to the root zone, minimizing the distance nitrogen must

Table 4.21: Effect of nano urea in combination with *Azotobacter* on soil nutrient status (NPK) in strawberry cv. Winter Dawn.

Treatments	Soil nutrient analysis (NPK) kg/ha								
	Nitrogen			Phosphorus			Potassium		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
T_1	234.65^{j}	222.10^{h}	228.38^{k}	20.76^{a}	22.61^{a}	21.69^{a}	204.45^{a}	205.56^{ab}	205.01^{a}
T_2	178.39^{ab}	162.32^{ab}	170.36^{ab}	22.89^{bc}	22.52^{a}	22.70^{abcd}	207.96^{ab}	203.61^{ab}	205.79^{a}
T_3	173.87^{a}	151.28^{a}	162.58^{a}	21.90^{ab}	22.89^{a}	22.40^{ef}	209.54^{ab}	208.01^{b}	208.77^{a}
T_4	195.65^{de}	180.16^{cd}	187.90^{cd}	22.28^{b}	22.15^{a}	22.22^{ab}	208.32^{ab}	200.97^{a}	204.65^{a}
T_5	209.56^{fg}	199.61^{efg}	204.59^{fg}	25.87^{ef}	21.91^{a}	23.89^{de}	210.98^{ab}	200.34^{a}	205.66^{a}
T_6	221.34^{hi}	217.04^{gh}	219.19^{ij}	24.87^{de}	22.93^{a}	23.90^{de}	213.87^{ab}	201.95^{ab}	207.91^{a}
T_7	227.86^{ij}	218.18^{h}	223.02^{jk}	23.87^{cd}	22.54^{a}	23.21^{bcd}	212.76^{ab}	206.67^{ab}	209.72^{a}
T_8	183.98^{bc}	178.00^{bcd}	180.99^{c}	22.67^{bc}	22.58^{a}	22.62^{abc}	210.65^{ab}	204.85^{ab}	207.75^{a}
T_9	169.00^{a}	173.08^{bcd}	171.04^{b}	23.67^{cd}	22.63^{a}	23.15^{bcd}	209.45^{ab}	203.42^{ab}	206.44^{a}
T_{10}	190.45^{cd}	199.48^{efg}	194.97^{de}	24.87^{de}	22.53^{a}	23.70^{cde}	213.75^{ab}	202.09^{ab}	207.92^{a}
T_{11}	187.76^{bcd}	197.91^{ef}	192.84^{de}	26.90^{fg}	22.53^{a}	24.72^{ef}	210.91^{ab}	204.00^{ab}	207.46^{a}
T_{12}	213.67gh	213.52^{fgh}	213.60^{hi}	26.45^{fg}	23.25^{a}	24.85^{ef}	214.30^{ab}	201.91^{ab}	208.11^{a}
T_{13}	202.75^{ef}	213.87^{fgh}	208.31^{gh}	28.53^{h}	22.88^{a}	25.71^{f}	215.71^{b}	205.26^{ab}	210.49^{a}
T_{14}	172.21^{a}	165.26^{abc}	168.74^{ab}	24.87^{de}	22.48^{a}	23.68^{cde}	212.76^{ab}	202.28^{ab}	207.52^{a}
T_{15}	211.78^{fgh}	184.00^{de}	197.89^{ef}	23.98^{cd}	22.55^{a}	23.27^{bcd}	214.72^{ab}	202.79^{ab}	208.75^{a}
T_{16}	218.45^{ghi}	222.43^{h}	220.44^{ijk}	27.39^{gh}	22.09^{a}	24.74^{bcd}	213.36^{ab}	202.55^{ab}	207.96^{a}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

***Note:** N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

Figure 4.21: Effect of nano urea in combination with *Azotobacter* on soil nutrient status (NPK) in strawberry cv. Winter Dawn.

travel through the soil profile before being taken up by plants (Whetton *et. al.* 2022). This reduces the risk of nitrogen being lost through leaching, where it is washed deeper into the soil beyond the reach of plant roots, or through volatilization, where nitrogen is lost to the atmosphere as gaseous ammonia.

Furthermore, basal application facilitates the incorporation of nitrogen into the soil matrix, promoting interactions with soil particles and organic matter (Plaza *et. al.* 2016). This helps to stabilize nitrogen compounds and reduce their susceptibility to loss mechanisms such as denitrification (Mahmud *et. al.* 2021), wherein nitrogen is converted into gaseous forms and lost to the atmosphere (Robertson, and Groffman, 2024).

Overall, the basal application of nitrogen plays a crucial role in enhancing nitrogen availability in soil by optimizing the placement of nitrogen fertilizers, minimizing losses, and promoting its uptake by plants. The dosages of nano urea were found with no result in terms of soil nitrogen availability.

4.5.3 Soil Nutrient Analysis (Organic Carbon)

Data pertaining to soil nutrient analysis (available OC) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside of the Table 4.22 and visually depicted inside the Figure 4.22. A thorough examination of the data displayed a noteworthy impact of nano urea on soil nutrient analysis (available OC) of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the soil nutrient analysis (available OC) of strawberry cv. Winter Dawn during both years of the research experiment.

The initial year trial (2022-23) revealed the maximum presence of available soil carbon (3.90 g/ kg) under the treatment T_3 (25% RDF +N_2), T_9 (25% RDF +N_2 + *Azotobacter*) and T_{14} (25% RDF + *Azotobacter*) followed by T_2 (25% RDF +N_1), T_8 (25% RDF +N_1 + *Azotobacter*), T_{10} (50% RDF +N_1 + *Azotobacter*) and T_{11} (50% RDF +N_2 + *Azotobacter*) having a value of 3.80 g/ kg, each. The control treatment T_1 recorded 3.50 g/ kg soil organic carbon which remained the minimum value, the same observance was recorded under the treatment T_7 (75% RDF +N_2) and T_{16} (75% RDF + *Azotobacter*).

During the second-year trial (2023-24), the maximum presence of soil organic carbon (3.76 g kg^{-1}) was listed by the treatment T_8 (25% RDF +N_1 + *Azotobacter*) followed by T_3

(25% RDF +N_2) and T_9 (25% RDF +N_2 + *Azotobacter*). The control treatment T_1 was recorded minimum with 3.38 g/ kg followed by T_7 (75% RDF +N_2) and T_{16} (75% RDF + *Azotobacter*) having values of 3.39 g/ kg and 3.40 g/ kg, respectively.

The pooled analysis of both the trials (2022-23 and 2023-24) showed the utmost soil organic carbon (3.83 g^{-1} kg) by the treatment T_3 (25% RDF +N_2) and T_9 (25% RDF +N_2 + *Azotobacter*), each. This was followed by T_8 (25% RDF +N_1 + *Azotobacter*) and T_2 (25% RDF +N_1) having values of 3.78 and 3.74, respectively. The control treatment T_1 recorded the minimum (3.44 g/ kg) soil organic carbon.

The basal application of conventional nitrogen fertilizers has been observed to have adverse effects on the available organic carbon content in soil (Li *et. al.* 2017), a phenomenon that underscores the intricate interplay between nutrient management practices and soil carbon dynamics. This decrease in available organic carbon can be attributed to several underlying mechanisms. Firstly, the application of nitrogen fertilizers at the basal level often leads to an accelerated rate of microbial activity in the soil (Ge *et. al.* 2010). Microorganisms, particularly those involved in nitrogen cycling processes, respond positively to the sudden influx of nitrogen, which in turn stimulates their metabolic activities (Hutchins *et. al.* 2022). As a consequence, these microbial communities increasingly utilize organic carbon as a substrate for energy and growth (Garcia-Pausas, and Paterson, 2011), thereby depleting the pool of available organic carbon in the soil.

Moreover, the basal application of conventional nitrogen fertilizers can disrupt the balance of microbial communities responsible for organic carbon turnover in soil (Condron *et. al.* 2010). Certain microbial taxa, favoured by the elevated nitrogen availability (Fierer *et. al.* 2012), may exhibit enhanced competitiveness over others, leading to shifts in community composition and function (Herren and McMahon, 2018). This alteration in microbial diversity and activity can result in the preferential decomposition of organic carbon compounds, further reducing their availability in the soil matrix.

Furthermore, the increased nitrogen availability resulting from basal application can indirectly impact the dynamics of soil organic carbon through its influence on plant-microbe interactions (Murphy *et. al.* 2017; Meng *et. al.* 2024)). Elevated nitrogen levels can stimulate plant growth and alter root exudation patterns (Yin *et. al.* 2013), which in turn can influence the quantity and quality of organic carbon inputs to the soil (Lei *et. al.* 2023). Changes in plant physiology and root architecture may lead to decreased carbon allocation belowground

Table 4.22: Effect of nano urea in combination with *Azotobacter* on soil (organic carbon) in strawberry cv. Winter Dawn.

Treatments	Soil (Organic carbon) g/ kg		
	2022-23	2023-24	Pooled
T_1	3.50^{a}	3.38^{a}	3.44^{a}
T_2	3.80^{cd}	3.69^{ghi}	3.74^{ef}
T_3	3.90^{d}	3.75^{i}	3.82^{f}
T_4	3.70^{bc}	3.62^{efg}	3.66^{cde}
T_5	3.60^{sb}	3.53^{cd}	3.56^{bc}
T_6	3.60^{ab}	3.47^{bc}	3.53^{ab}
T_7	3.50^{a}	3.39^{ab}	3.45^{a}
T_8	3.80^{cd}	3.76^{i}	3.78^{f}
T_9	3.90^{d}	3.74^{hi}	3.82^{f}
T_{10}	3.80^{cd}	3.66^{fgh}	3.73^{def}
T_{11}	3.80^{cd}	3.66^{gh}	3.73^{def}
T_{12}	3.70^{bc}	3.58^{def}	3.64^{cd}
T_{13}	3.60^{ab}	3.54^{cde}	3.57^{bc}
T_{14}	3.90^{d}	3.69^{ghi}	3.79^{f}
T_{15}	3.70^{bc}	3.54^{cde}	3.62^{bc}
T_{16}	3.50^{a}	3.40^{ab}	3.45^{a}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

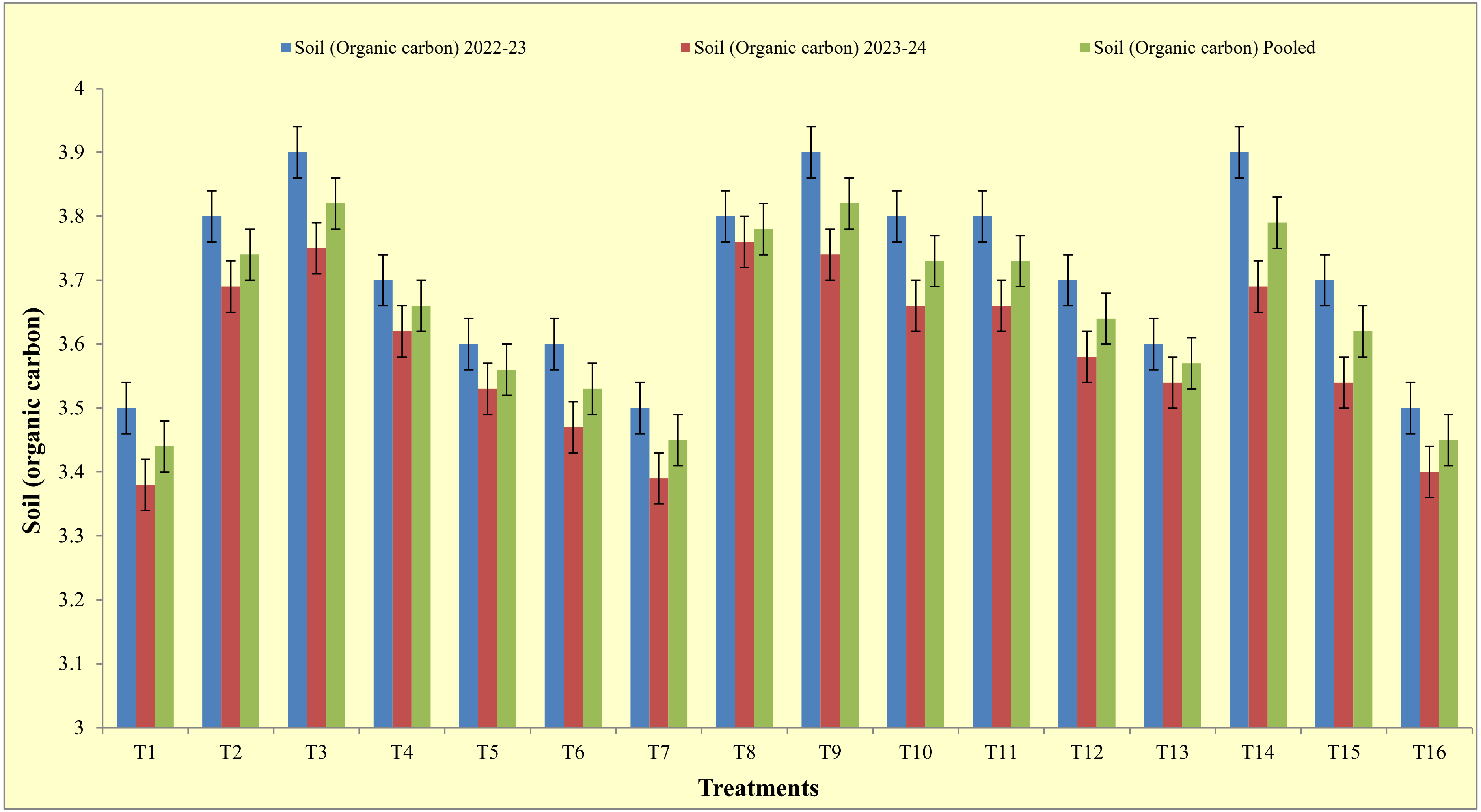

Figure 4.22: Effect of nano urea in combination with *Azotobacter* on soil (oranic carbon) in strawberry cv. Winter Dawn.

(Savage *et. al.* 2016), diminishing the input in case of the organic carbon into soil, and consequently reducing pool regarding available carbon for microbial utilization (Gross, and Harrison, 2019).

Overall, the basal application of conventional nitrogen fertilizers exerts a complex and multifaceted influence on the available organic carbon content in soil, driven by alterations in microbial activity, community composition, and plant-soil interactions. Understanding these mechanisms is crucial for devising sustainable nutrient management strategies that optimize both nutrient availability and soil carbon sequestration, thereby ensuring the long-term productivity and resilience of agro ecosystems.

4.5.4 ***Azotobacter*** **count (CFU 10^6)**

Data pertaining to *Azotobacter* count (CFU 10^6) and its variation over the two experimental years (2022-23 and 2023-24) is provided inside of the Table 4.23 and visually depicted inside the Figure 4.23. A thorough examination with respect to the data indicates a noteworthy impact of nano urea on *Azotobacter* count (CFU 10^6) of strawberry cultivar Winter Dawn throughout the two years of the research experiment. It is noteworthy that the data reveals a statistically significant influence of nano urea on the *Azotobacter* count (CFU 10^6) of strawberry cv. Winter Dawn during both years of the research experiment.

The initial year trial (2023-24) recorded the maximum *Azotobacter* count (11.33 CFU 10^6) under the treatment T_{14} (25% RDF + *Azotobacter*) followed by T_8 (25% RDF +N_1 + *Azotobacter*) and T_9 (25% RDF +N_2 + *Azotobacter*) having values of 11.33 CFU 10^6 and 11.00 CFU 10^6, respectively. The minimum *Azotobacter* count (2.63 CFU 10^6) was recorded under the treatment T_1 (control) followed by T_6 (75% RDF +N_1) and T_7 (75% RDF +N_2) having values of 3.00 CFU 10^6, each.

The second-year research trial (2023-24) the maximum *Azotobacter* count (11.83 CFU 10^6) was recorded under the treatment T_8 (25% RDF +N_1 + *Azotobacter*) followed by T_{14} (25% RDF + *Azotobacter*) and T_9 (25% RDF +N_2 + *Azotobacter*) having values of 11.50 CFU 10^6 and 11.17 CFU 10^6, each. The minimum value of *Azotobacter* count (2.67 CFU 10^6)was recorded under the treatment T_1 (control) followed by T_6 (75% RDF +N_1) and T_7 (75% RDF +N_2) having values of 3.67 CFU 10^6, each.

Pooling the data of both the research trials (2022-23 and 2023-24) revealed the maximum presence of *Azotobacter* count (11.75 CFU 10^6) under the treatment T_{14} (25% RDF + *Azotobacter*) followed by T_8 (25% RDF +N_1 + *Azotobacter*) and T_9 (25% RDF +N_2 + *Azotobacter*) with the values 11.58 CFU 10^6 and 11.08 CFU 10^6, each. The minimum *Azotobacter* count (2.65 CFU 10^6) was observed under the treatment T_1 (control) followed by T_6 (75% RDF +N_1) and T_7 (75% RDF +N_2) having values of 3.33 CFU 10^6, each.

In the study of soil microbiology and fertility, the application of conventional nitrogenous fertilizers has been noted to impact various microbial populations, including the diazotrophic (nitrogen-fixing) bacteria such as *Azotobacter* (Aasfar *et. al.* 2021). Notably, basal application of these nitrogen fertilizers appears to decrease the population of *Azotobacter* in soil, a phenomenon that can be attributed to several interconnected factors (Jnawali, *et. al.* 2015).

Azotobacter species are free-living (Aasfar *et. al.* 2021), nitrogen-fixing bacteria that contribute to the nitrogen economy of soils (Reis, and Teixeira, 2015). They are known for their ability to fix atmospheric nitrogen under aerobic conditions (Ouyang *et. al.* 2024), converting it into forms usable by plants (Al-Baldawy *et. al.* 2023). However, when synthetic nitrogen fertilizers are applied to the soil, particularly as a basal dose, it provides plants with readily available inorganic nitrogen. This abundant supply of nitrogen reduces the ecological niche and the competitive advantage for *Azotobacter*, whose nitrogen-fixing capability becomes redundant in the presence of high nitrogen levels. The decrease in *Azotobacter* count following nitrogen application is also linked to the metabolic burden that nitrogen fixation imposes on bacteria (Han *et. al.* 2024); when nitrogen is readily available, the energy-intensive process of nitrogen fixation is unnecessary, leading to a competitive disadvantage for nitrogen-fixers.

Furthermore, the physiological and biochemical impacts of high nitrogen concentrations on soil micro-environments may directly inhibit the growth of *Azotobacter* (Gauri *et. al.* 2012). These bacteria are sensitive to the ionic forms of nitrogen, such as ammonium and nitrate, which can affect cellular processes and inhibit growth (Jensen, 1954). Also, nitrogen applications can lead to soil acidification over time (Barak *et. al.* 1997), altering pH levels to a range that is unfavourable for *Azotobacter* (Dar *et. al.* 2021), which prefers neutral to slightly alkaline conditions (Kozieł, *et. al.* 2021). This alteration in soil pH as a consequence of nitrogen fertilizer usage further explains the suppressive effect on *Azotobacter* populations (Dar *et. al.* 2021).

Thus, the basal application of nitrogen fertilizers can be seen as a double-edged sword; while enhancing plant growth by providing essential nutrients directly, it concurrently diminishes the population of beneficial nitrogen-fixing bacteria such as *Azotobacter* through mechanisms involving direct inhibition and ecological displacement. This aspect of soil dynamics is crucial for understanding the broader implications of agricultural practices on microbial biodiversity and soil health, emphasizing the need for integrated nutrient management strategies that consider both crop yield and microbial ecology.

The foliar application of nano urea presents a novel approach in agricultural practices, with significant implications for soil microbial populations (Upadhyay *et. al.* 2023), notably the *Azotobacter* species. Unlike conventional soil-applied fertilizers, nano urea is primarily absorbed through plant leaves, minimizing the direct contact and saturation of soil with excess nitrogen (Avila *et. al.* 2022). This targeted application method allows for efficient uptake of nitrogen by plants, potentially reducing nitrogen loss to the environment through leaching or runoff and hence lessening the direct negative impacts on soil microbial communities that are commonly associated with traditional nitrogen applications (Uscola *et. al.* 2014).

For nitrogen-fixing bacteria such as *Azotobacter*, the reduced soil nitrogen levels following foliar nano urea application can be beneficial (Gangaiah, and Yadav, 2024). *Azotobacter* species thrive in environments where nitrogen is not excessively available, as their ecological role of fixing atmospheric nitrogen becomes crucial in such circumstances. By avoiding significant alterations to the soil nitrogen balance, foliar nano urea application supports the maintenance of a niche for *Azotobacter*. Furthermore, because these bacteria also stimulate plant growth by producing phytohormones and enhancing nutrient availability, their increased activity in response to appropriate soil nitrogen levels can lead to improved soil health and structure.

Thus, the strategic use of nano urea via foliar application not only aims at enhancing plant nitrogen use efficiency but also supports the conservation and potentially the proliferation of beneficial microbial communities such as *Azotobacter*. This relationship underscores the importance of adopting innovative fertilization techniques that are sensitive

Table 4.23: Effect of nano urea in combination with *Azotobacter* on *Azotobacter* count in strawberry cv. Winter Dawn.

Treatments	*Azotobacter* count (CFU 10^6)		
	2022-23	2023-24	Pooled
T_1	2.63^{a}	2.67^{a}	2.65^{a}
T_2	4.35^{b}	4.83^{c}	4.59^{c}
T_3	4.33^{b}	4.67^{bc}	4.50^{c}
T_4	3.34^{ab}	4.00^{bc}	3.67^{b}
T_5	3.66^{ab}	4.00^{bc}	3.83^{bc}
T_6	3.00^{a}	3.67^{b}	3.33^{ab}
T_7	3.00^{a}	3.67^{b}	3.33^{ab}
T_8	11.33^{ef}	11.83^{f}	11.58^{g}
T_9	11.00^{ef}	11.17^{f}	11.08^{g}
T_{10}	8.67^{d}	9.83^{e}	9.25^{e}
T_{11}	8.33^{cd}	9.17^{e}	8.75^{e}
T_{12}	7.67^{cd}	8.17^{d}	7.92^{d}
T_{13}	7.33^{c}	8.00^{d}	7.67^{d}
T_{14}	12.00^{f}	11.50^{f}	11.75^{g}
T_{15}	10.33^{e}	10.00^{e}	10.17^{f}
T_{16}	7.67^{cd}	8.17^{d}	7.92^{d}

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea*

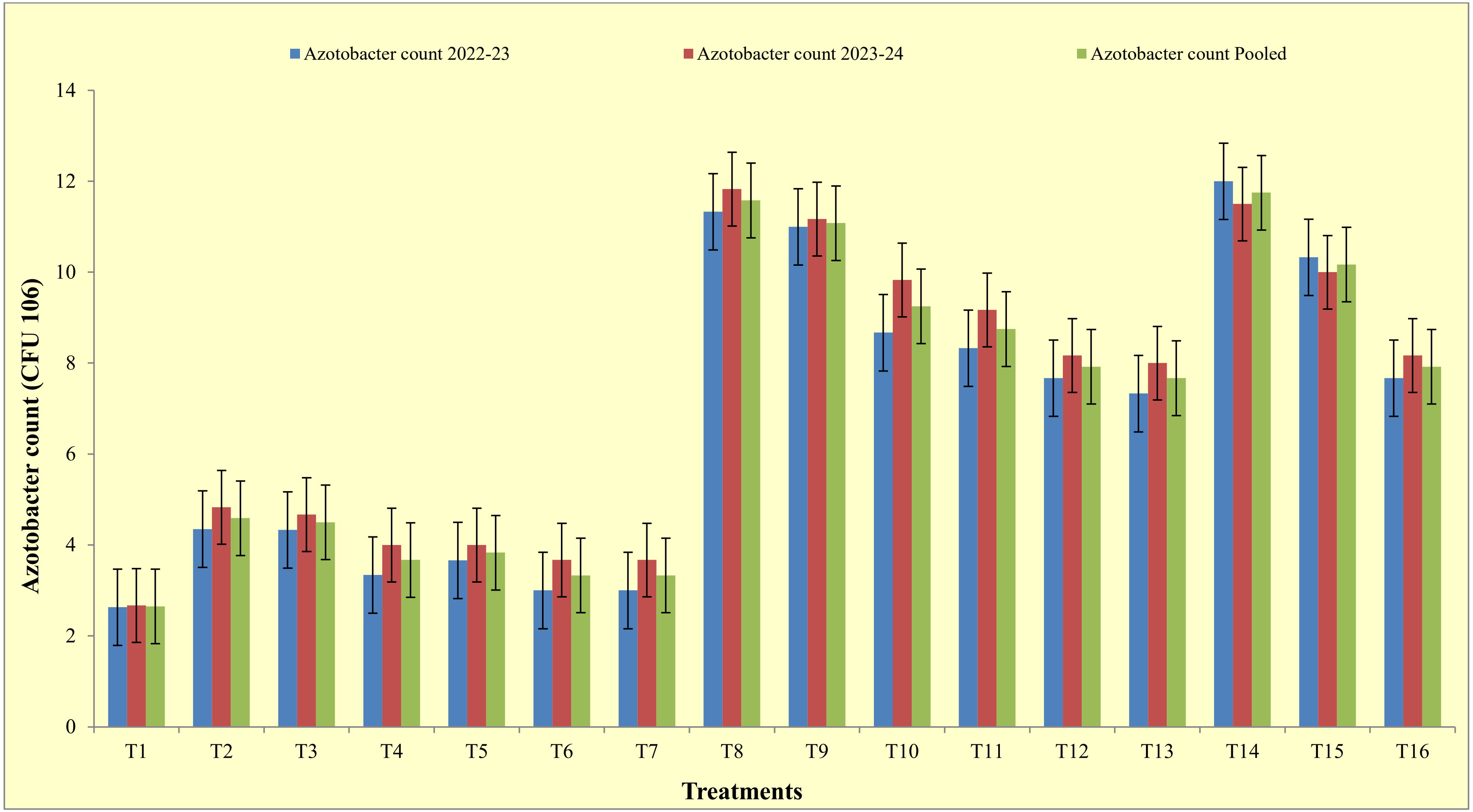

Figure 4.23: Effect of nano urea in combination with *Azotobacter* on *Azotobacter* count in strawberry cv. Winter Dawn.

to both plant needs and microbial ecological dynamics, aligning with sustainable agricultural goals that promote productivity while preserving soil microbial biodiversity and function.

4.6 Economic parameters

4.6.1 Total cost of cultivation

All treatments were evaluated of the economics aspects of cultivation, shown in Table 4.24, 4.25 and figure 4.24. Prevailing industrial price served as the basis for determining the conclusive benefit-cost ratios. The interpretation of results employed common cost concepts rooted in agricultural economics. The effect of various treatments had various results on strawberry cv. Winter Dawn.

During the first year trial (2022-23), the maximum cost of cultivation (987985.43 rupees) was noticed under the treatment T_{13} (75% RDF + N_2 + *Azotobacter*) followed by T_{12} (75% RDF + N_1 + *Azotobacter*) and T_{11} (50% RDF + N_2 + *Azotobacter*) having cost 987835.43 rupees and 986178.22 rupees, respectively. The control (T_1) was recorded with 970322.65 rupees for cost of cultivation while the minimum (965351.01 rupees) was noticed under the treatment T_2 (25% RDF + N_1). In the second year experiment (2023-24), the maximum cost of cultivation (1005485.43 rupees) was noticed under the treatment T_{13} (75% RDF + N_2 + *Azotobacter*) followed by T_{12} (75% RDF + N_1 + *Azotobacter*) and T_{11} (50% RDF + N_2 + *Azotobacter*) having cost 1005335.43 rupees and 1003678.22 rupees, respectively. The control (T_1) was recorded with 987822.65 rupees for cost of cultivation while the minimum (982851.01 rupees) was noticed under the treatment T_2 (25% RDF + N_1).

4.6.2 Gross income

During the first-year trial (2022-23), the maximum gross income (4587079.66 rupees) was noticed under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and T_{10} (50% RDF + N_1 + *Azotobacter*) having gross income 3195929.57 rupees and 3005046.02 rupees, respectively. The control (T_1) was recorded with 1403430.72 rupees of gross income while the minimum (307100 rupees) was noticed under the treatment T_{14} (25% RDF + *Azotobacter*). In the second-year experiment (2023-24), the maximum gross income (3865885.8 rupees) was noticed under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and T_{10} (50% RDF + N_1 +

Azotobacter) having gross income 3255537.50 rupees and 3163282.93 rupees, respectively. The control (T_1) was recorded with 1338600.8 rupees of gross income while the minimum (335042.4 rupees) was noticed under the treatment T_{14} (25% RDF + *Azotobacter*).

4.6.3 Net returns

During the first-year trial (2022-23), the maximum net returns (3602708.65 rupees) was noticed under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*) having gross income 26,39,166.467 rupeesand 2209751.35 rupees, respectively. The control (T_1) was recorded with 4,33,108.07 rupees of net returns while the loss of 676671.01 rupees was noticed under the treatment T_{14} (25% RDF + *Azotobacter*). In the second-year experiment (2023-24), the maximum net returns (28,64,014.79 rupees) were noticed under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and T_8 (25% RDF + N_1 + *Azotobacter*) having gross income 2251859.28 rupees and 2161561.923 rupees, respectively. The control (T_1) was recorded with 350778.15 rupees of net returns while the loss of 666228.61 rupees was noticed under the treatment T_{14} (25% RDF + *Azotobacter*).

4.6.4 B: C ratio

During the first-year trial (2022-23), the maximum benefit: cost ratio (3.66) was noticed under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_3 (25% RDF + N_2) and T_{11} (50% RDF + N_2 + *Azotobacter*) having benefit cost ratio 2.73 and 2.24, respectively. The control (T_1) was recorded with 0.45 rupees of net returns while the negative B: C ratio -0.69 was noticed under the treatment T_{14} (25% RDF + *Azotobacter*). In the second-year experiment (2023-24), the utmost benefit: cost ratio (2.86) was noticed by treatment T_9 (25% RDF + N_2 + *Azotobacter*) followed by T_{11} (50% RDF + N_2 + *Azotobacter*) and T_8 (25% RDF + N_1 + *Azotobacter*) having B: C ratio 2.24 and 2.16, respectively. The control (T_1) was recorded with 0.36 of benefit cost ratio while the negative B: C ratio -0.67 was noticed under the treatment T_{14} (25% RDF + *Azotobacter*).

In the realm of strawberry cultivation, the integration of nano urea in conjunction with *Azotobacter* presents a multifaceted boon to economic sustainability (Pirzadah *et. al.* 2019; Thirugnanasambandan 2018), underpinned by its profound implications for yield enhancement and resource efficiency alongside *Azotobacter* in strawberry cultivation represents a ground-breaking frontier in agricultural science, promising multifaceted economic advantages (Viscardi *et. al.* 2016). Nano urea, distinguished by its nano-scale dimensions and heightened solubility (Lakshman *et. al.* 2016), stands poised to revolutionize nutrient management strategies in strawberry farming (Shaifali *et. al.* 2023). Its nanostructure facilitates efficient nutrient delivery (Guo *et. al.* 2018), ensuring enhanced uptake by strawberry plants and minimizing nutrient losses through leaching and volatilization (Rana *et. al.* 2021).

Concomitantly, the introduction of *Azotobacter* into the agricultural milieu augments the nitrogen supply through biological nitrogen fixation, circumventing the need for additional nitrogen fertilizers (Mukherjee, 2017). This symbiotic association not only bolsters nitrogen availability but also fosters soil health and fertility, thereby fostering a conducive growth environment for strawberries. By reducing dependency on synthetic fertilizers, farmers stand to gain substantial economic savings while mitigating environmental repercussions stemming from chemical fertilizer usage.

Furthermore, the synergistic interaction between nano urea and *Azotobacter* instigates a cascade of positive agronomic effects (Kannoj *et. al.* 2022), culminating in augmented strawberry yields and improved fruit quality. The enhanced nutrient availability facilitated by nano urea primes plants for optimal growth (Kumar *et. al.* 2021), while *Azotobacter*'s role in nitrogen fixation ensures sustained nutrient provisioning throughout the crop cycle (Rashid *et. al.* 2015). This integrated approach not only amplifies productivity but also fortifies the resilience of strawberry crops against environmental stressors, thereby mitigating yield losses and safeguarding economic returns for farmers.

Beyond immediate economic gains, the adoption of nano urea and *Azotobacter* holds promise for long-term sustainability in strawberry cultivation. By fostering soil health, minimizing environmental impacts, and enhancing resource use efficiency, this innovative approach aligns with the principles of agro ecological resilience, ensuring the continued viability of strawberry farming amidst evolving climatic and economic challenges. Consequently, the economic benefits derived from nano urea and *Azotobacter* both transcends mere cost savings, heralding a transformative trajectory towards sustainable and profitable strawberry production systems.

Table 4.24: Effect of nano urea in combination with *Azotobacter* on economics in strawberry cv. Winter Dawn.

Parameters	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16
Fixed cost (rupees)																
Ploughing	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Cloud crushing	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
Bed preparation	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
Rent of land	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000
Interest @ 12%	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000
Labour charges	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800
Variable cost (rupees)																
Drip Irrigation	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000
Planting material	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000
Manures and fertilizers	62522.65	57551.01	57701.01	59358.22	59508.22	61165.43	61315.43	76421.01	76571.01	78228.22	78378.22	80035.43	80185.43	75971.01	77778.22	79585.43
Mulcing	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000
Cost of Cultivation	970322.7	965351	965501	967158.2	967308.2	968965.4	969115.4	984221	984371	986028.2	986178.2	987835.4	987985.4	983771	985578.2	987385.4
Returns (rupees)																
Yield per plant (kg)	0.316	0.458	0.609	0.444	0.458	0.417	0.413	0.465	0.689	0.541	0.576	0.447	0.486	0.138	0.152	0.170
Yield hectare^{-1}	23390.51	33896.44	45058.34	32859.11	33910.1	30867.29	30557.98	34431.62	50967.55	40067.28	42612.39	33073.31	35995.63	10236.67	11241.99	12607.89
Sale price	60	80	80	70	70	65	65	85	90	75	75	70	65	30	35	35
Gross Income	1403431	2711715	3604667	2300138	2373707	2006374	1986269	2926688	4587080	3005046	3195930	2315131	2339716	307100	393469.5	441276
Net Income	433108.1	1746364	2639166	1332980	1406399	1037409	1017154	1942467	3602709	2019018	2209751	1327296	1351730	-676671	-592109	-546109
B:C	0.45	1.81	2.73	1.38	1.45	1.07	1.05	1.97	3.66	2.05	2.24	1.34	1.37	-0.69	-0.60	-0.55

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*.

Note: *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea.*

Table 4.25: Effect of nano urea in combination with *Azotobacter* on economics in strawberry cv. Winter Dawn.

Parameters	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16
Fixed cost																
Ploughing	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Cloud crushing	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
Bed preparation	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500	7500
Rent of land	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000
Interest @ 12%	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000	9000
Labour charges	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800	155800
Variable cost																
Drip Irrigation	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000	75000
Planting material	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000	518000
Manures and fertilizers	62522.65	57551.01	57701.01	59358.22	59508.22	61165.43	61315.43	76421.01	76571.01	78228.22	78378.22	80035.43	80185.43	75971.01	77778.22	79585.43
Mulcing	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000	50000
Cost of Cultivation	970322.7	965351	965501	967158.2	967308.2	968965.4	969115.4	984221	984371	986028.2	986178.2	987835.4	987985.4	983771	985578.2	987385.4
Returns																
Yield per plant (kg)	0.316	0.458	0.609	0.444	0.458	0.417	0.413	0.465	0.689	0.541	0.576	0.447	0.486	0.138	0.152	0.170
Yield hectare^{-1}	23390.51	33896.44	45058.34	32859.11	33910.1	30867.29	30557.98	34431.62	50967.55	40067.28	42612.39	33073.31	35995.63	10236.67	11241.99	12607.89
Sale price	60	80	80	70	70	65	65	85	90	75	75	70	65	30	35	35
Gross Income	1403431	2711715	3604667	2300138	2373707	2006374	1986269	2926688	4587080	3005046	3195930	2315131	2339716	307100	393469.5	441276
Net Income	433108.1	1746364	2639166	1332980	1406399	1037409	1017154	1942467	3602709	2019018	2209751	1327296	1351730	-676671	-592109	-546109
B:C	0.45	1.81	2.73	1.38	1.45	1.07	1.05	1.97	3.66	2.05	2.24	1.34	1.37	-0.69	-0.60	-0.55

T_1: RDF (PAU recommendation), T_2: 25% RDF + N_1, T_3: 25% RDF + N_2, T_4: 50% RDF + N_1, T_5: 50% RDF + N_2, T_6: 75% RDF + N_1, T_7: 75% RDF + N_2, T_8: 25% RDF + N_1+ *Azotobacter*, T_9: 25% RDF + N_2+ *Azotobacter*, T_{10}: 50% RDF + N_1+ *Azotobacter*, T_{11}: 50% RDF + N_2+ *Azotobacter*, T_{12}: 75% RDF + N_1+ *Azotobacter*, T_{13}: 75% RDF + N_2+ *Azotobacter*, T_{14}: 25% RDF + *Azotobacter*, T_{15}: 50% RDF + *Azotobacter*, T_{16}: 75% RDF + *Azotobacter*. ***Note:*** *N_1: 300 ppm Nano Urea, N_2: 400 ppm Nano Urea.*

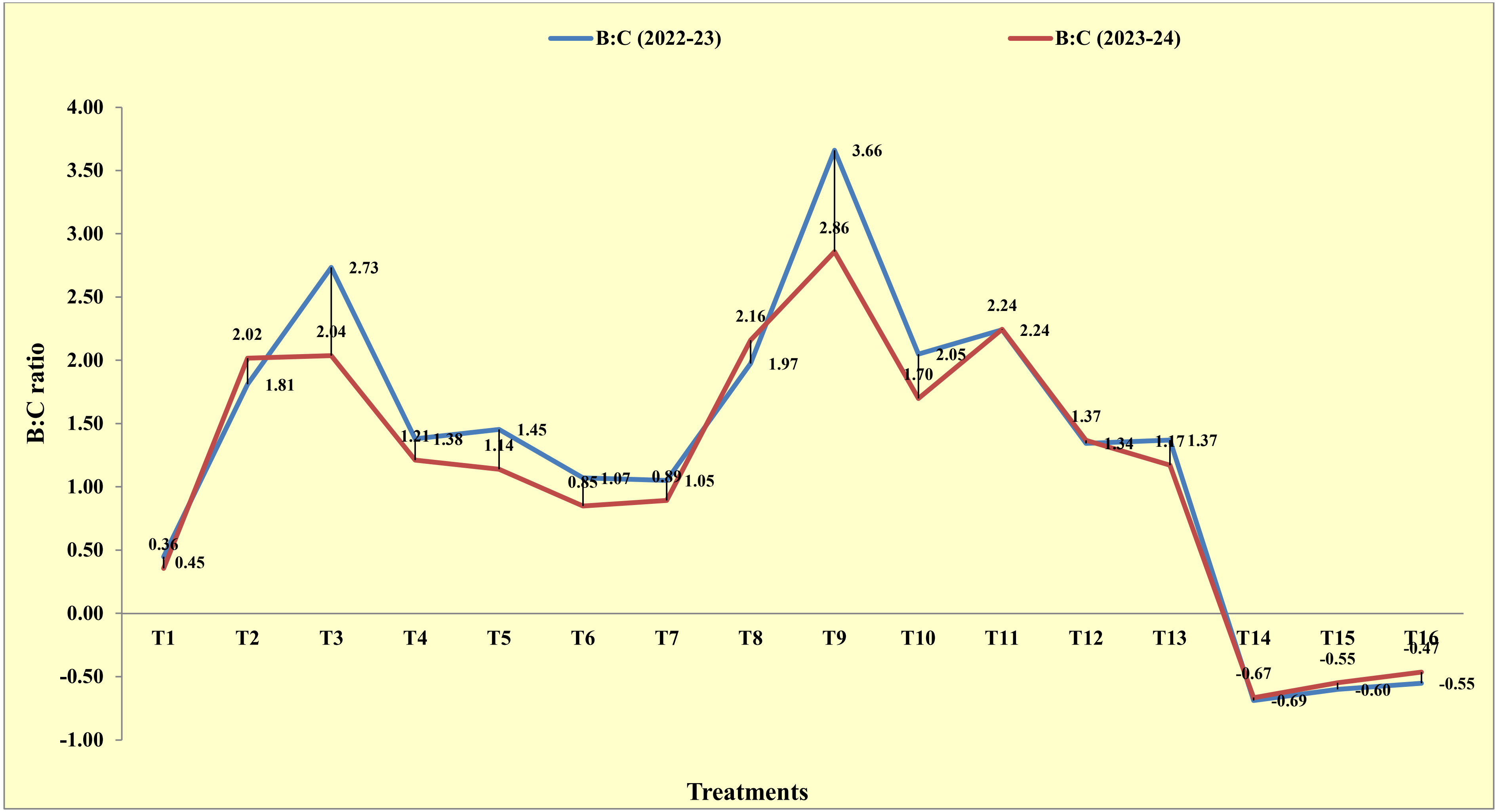

Figure 4.24: Effect of nano urea in combination with *Azotobacter* on economics in strawberry cv. Winter Dawn.

Chapter V

Summary and Conclusion

The investigation titled "Effect of nano urea in combination with *Azotobacter* on growth, yield and quality of strawberry (*Fragaria x ananassa* Dutch.) cv. Winter Dawn" was carried out during 2022 and 2024 within the polyhouse facilities of Lovely Professional University, Punjab. The research elucidated the efficacy of *Azotobacter* in conjunction with nano urea application in enhancing various parameters of strawberry cultivation, including growth, yield, and quality. Notably, the experimental results unequivocally demonstrated the beneficial effects of nano urea and *Azotobacter* combination on these aspects. Moreover, a notable enhancement in leaf nutrient content was observed across treatments incorporating nano urea and *Azotobacter*. This chapter encapsulates the outcomes derived from the two-year experimentation (2022 and 2023), alongside the aggregated data analysis.

5.1.1 Growth parameters

5.1.2 Plant height (cm)

- During the first-year experimental year (2022-23), the maximum plant height (12.44cm) at 120^{th} was recorded in T_9 (25% RDF + N_2 + *Azotobacter*).
- The second-year trial (2023-24) recorded the maximum plant height (12.87 cm) at120^{th} under T_9 (25% RDF + N_2 + *Azotobacter*).
- The pooled analysis recorded the same trend with 12.66 cm of plant height at 120^{th} day under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

5.1.3 Plant spread NS (cm)

- During first year experimental trial (2023-24), the maximum plant spread NS (22.4 cm) was observed at 120^{th} day under T_9 (25% RDF + N_2 + *Azotobacter*).
- The second-year experiment (2023-24) recorded maximum plant spread NS (22.76 cm) at 120^{th} day under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The pooled data revealed the maximum plant spread NS (22.58 cm) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

5.1.3. Plant spread EW (cm)

- The maximum plant spread EW (22.53 cm) during first year trial (2022-23) at 120th day was observed under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- During second year (2023-24), the maximum plant spread EW (22.00 cm) at 120th day was recorded under T_9 (25% RDF + N_2 + *Azotobacter*).
- Pooled analysis elucidated maximum plant spread EW (22.26 cm) under T_9 (25% RDF + N_2 + *Azotobacter*).

5.1.4 Chlorophyll index (Spad value)

- In the first-year trial (2022-23), the maximum chlorophyll index (55.97) was observed at 120th day under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- During second year research trial (2023-24), the maximum chlorophyll index (55.80) was recorded under the treatment T_3 (25% RDF + N_2).
- The pooled analysis revealed the maximum presence of chlorophyll index (55.41) at 120th day under the treatment T_3 (25% RDF + N_2) for both the years research trials (2022-23 and 2023-24)

5.1.5 Number of flowers (plant^{-1})

- The maximum number of flowers per plant (22.33) during first year trial (2022-23) at 120th day was found under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The second-year research trial (2023-24) recorded the maximum number of flowers per plant (21.67) at 120th day under the treatment T_2 (25% RDF + N_1).
- The combined data elucidated the maximum number of flowers (21.50) at 120th day under the treatment T_3 (25% RDF + N_2), T_9 (25% RDF + N_2 + *Azotobacter*) and T_9 (50% RDF + N_2 + *Azotobacter*) for both the years research trials (2022-23 and 2023-24).

5.1.6 Number of leaves (plant^{-1})

- The maximum number of leaves (17.3), during the first-year trial (2022-23), at 120th day, was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The second-year trial (2023-24) at 120th day recorded maximum number of leaves (18.3) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

- Combined data for both years (2022-23 and 2023-24) revealed the presence of maximum number of leaves (17.78) was observed under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

5.2 Physical fruit parameters

5.2.1 Number of fruits (plant^{-1})

- During the first-year research trial (2022-23), the maximum number of fruits (20.67)were recorded under the treatment T_3 (25% RDF + N_2) at 120th day.
- The second-year trial (2023-24) recorded maximum number of fruits (23.16) underthe treatments T_2 (25% RDF + N_1) at 120th day.
- The pooled data for both the years (2022-23 and 2023-24) analysed the maximum number of fruits (21.75) under the treatment T_2 (25% RDF + N_1).

5.2.2 Average fruit weight (g plant^1)

- The first-year trial (2022-23) revealed the maximum average fruit weight (21.87 gm)under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The second-year trial (2023-24) revealed the maximum average fruit weight (19.62gm) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The pooled analysis for both the years (2022-23 and 2023-24) showed the maximum average fruit weigh was found under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

5.2.3 Average fruit volume (cc)

- The first-year trial (2022-23) revealed the maximum fruit volume (21.95 cc) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The second-year treatment (2023-24) showed the maximum fruit volume (19.65 cc) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The pooled analysis for both the years (2022-23 and 2023-24) revealed the maximum average fruit volume (20.82 cc) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

5.2.4 Fruit yield per plant (kg plant^{-1})

- During the first-year research trial (2022-23) the maximum fruit yield (6.88.75 gm or 0.688 kg plant^{-1}) was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The second-year research trial (2023-24) recorded the maximum average fruit yield (580.46 gm or 0.580 kg plant^{-1}) was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The pooled analysis of data for both the years (2022-23 and 2023-24) revealed the maximum fruit yield (634.61 gm or 0.634 kg plant^{-1}) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

5.3 Qualitative parameters

5.3.1 Titratable acidity (%)

- The first-year trial (2022-23) recorded the minimum titratable acidity (0.42%) remained under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The second-year trial (2023-24) observed the minimum titratable acidity (0.44%) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The pooled analysis for both the years (2022-23 and 2023-34) revealed the minimum titratable acidity (0.43%) remained under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

5.3.2 Total soluble solids (TSS °brix)

- The first- year trial (2022-23) recorded the maximum TSS (9.10 ^{0}brix) under thetreatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The second-year trial (2023-24) showed the maximum presence of TSS (8.80 ^{0}brix)under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The combined data for both the years (2022-23 and 2023-24) revealed the maximum TSS (8.95 ^{0}brix) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

5.3.3 TSS: acid ratio

- The maximum TSS: acid ration (21.73) was observed under the treatment T_9 (25% RDF + N_2 + *Azotobacter*) for first year research trial (2022-23).

- The second-year research year trial (2023-24) recorded the maximum TSS: acid ratio (20.710 under the treatment T_{11} (50% RDF + N_2 + *Azotobacter*).
- The pooled analysis for both the years (2022-23 and 2023-24) revealed the maximum presence of TSS: acid ration (20.94) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

5.3.4 Ascorbic acid (mg 100 gm^{-1})

- The first-year trial (2022-23) recorded the maximum ascorbic acid (55.7 mg 100 gm^{-1})was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- During the second-year research trial (2023-24) the maximum ascorbic acid (55.7)was recorded by the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The pooled data revealed the maximum presence of ascorbic acid (55.72) was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

5.3.5 Total sugar (%)

- The first-year trial (2022-23) recorded the maximum total sugar (8.77 per cent) underthe treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The second-year trial (2023-24) recorded the maximum total sugar (9.03 per cent)under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The pooled analysis of both the years (2022-23 and 2023-24) revealed the maximum presence of total sugar (8.90 %) was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

5.3.6 Reducing sugar (%)

- During first year trial (2022-23), the maximum reducing sugar (7.17 per cent) was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The second-year trial (2023-24) recorded the maximum reducing sugar (7.30 per cent) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The pooled analysis of both the years (2022-23 and 2023-24) revealed the maximum presence of reducing sugar (7.23 per cent) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

5.4.7 Non reducing sugar (%)

- The first-year trial (2022-23) revealed the maximum non reducing sugar (1.52 per cent) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The second-year trial (2023-24) recorded the maximum non reducing sugar (1.84 per cent) T_2 (25% RDF + N_1).
- The polled analysis of both the years (2022-23 and 2023-24) revealed the maximum presence of non-reducing sugar (1.65 per cent) under the treatment T_2 (25% RDF + N_1).

5.5 Biochemical parameters

5.5.1 Antioxidant (µ mol TE/g FW)

- The first-year trial (2022-23) revealed the maximum antioxidant (1.90 µ mol TE/g FW) under the treatment T_{11} (50% RDF + N_2 + *Azotobacter*).
- The second-year trial (2023-24) recorded the maximum antioxidant (1.87 µ mol TE/g FW) under the treatment T_{11} (50% RDF + N_2 + *Azotobacter*).
- The pooled analysis of both the years (2022-23 and 2023-24) revealed that the maximum antioxidant (1.89 µ mol TE/g FW) was recorded under the treatment T_{11} (50% RDF + N_2 + *Azotobacter*).

5.5.2 Anthocyanin (mg per 100 g)

- The first-year trial (2022-23) revealed the maximum anthocyanin (0.274 mg per 100 g) was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The second-year trial (2023-24) recorded the maximum anthocyanin (0.276 mg per 100 gm) under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).
- The pooled analysis of both the years (2022-23 and 2023-24) revealed the maximum anthocyanin (0.275 mf per 100 gm) was recorded under the treatment T_9 (25% RDF + N_2 + *Azotobacter*).

5.6 Nutrient analysis parameters

5.6.1 Plant nutrient analysis (NPK %)

- The first- year trial (2022-23) recorded the maximum plant nitrogen (2.51 per cent) was observed under T_9 (25% RDF + N_2 + *Azotobacter*), maximum phosphorus (0.38

%) T_9 (25% RDF +N_2 + *Azotobacter*) T_{10} (25% RDF +N_2 + *Azotobacter*) T_{11} (25% RDF +N_2 + *Azotobacter*) and T_{15} (25% RDF +N_2 + *Azotobacter*), each and potassium (2.73 %) under the treatment T_2 (25% RDF + N_1).

- The second-year trial (2023-24) recorded the maximum plant nitrogen (2.47 per cent) was observed under T_9 (25% RDF + N_2 + *Azotobacter*), maximum phosphorus (0.37 %) under T, potassium (2.78 %) under the treatment T_2 (25% RDF + N_1).
- The pooled analysis of both the years (2022-23 and 2023-24) revealed the maximum plant nitrogen (2.49 per cent) was observed under T_9 (25% RDF + N_2 + *Azotobacter*), maximum phosphorus (0.37 %) under T, potassium (2.75 %) under the treatment T_2 (25% RDF + N_1).

5.6.2 Soil nutrient analysis (NPK kg ha^{-1})

- During the first-year trial (2022-23), the recorded maximum soil nitrogen (234.65 kg ha^{-1}) was observed under the treatment T_1 (control), maximum phosphorus (28.45 kg/ha) under T_{13} (75% RDF + N_2 + *Azotobacter*), maximum potassium (215.71 kg/ ha) under the treatment T_{13} (75% RDF + N_2 + *Azotobacter*).
- In the first-year trial (2023-24), the recorded maximum soil nitrogen (222.10 kg ha^{-1}) was observed under the treatment T_1 (control), maximum phosphorus (23.25 kg/ha) under T_{12} (75% RDF + N_1 + *Azotobacter*), maximum potassium (208.01 kg/ ha) under the treatment T_3 (25% RDF + N_2).
- The pooled analysis of both years (2022-23 and 2023-24), the recorded maximum soil nitrogen (228.38 kg ha^{-1}) was observed under the treatment T_1 (control), maximum phosphorus (27.71 kg/ha) under T_{13} (75% RDF + N_2 + *Azotobacter*), maximum potassium (210.49 kg/ ha) under the treatment T_{13} (75% RDF + N_2 + *Azotobacter*).

5.6.3 Soil organic carbon (g/ kg)

- The first-year trial (2022-23) recorded the maximum soil organic carbon (3.90 g/ kg) under the treatment T_3 (25% RDF + N_2), T_9 (25% RDF + N_2 + *Azotobacter*) and T_{14} (25% RDF + *Azotobacter*).
- The second-year trial (2023-24) revealed the maximum soil organic carbon (3.76 g/ kg) under the treatment T_8 (25% RDF + N_1 + *Azotobacter*).

- The pooled analysis of both the years (2022-23 and 2023-24) the maximum soil organic carbon (3.82 g/ kg) was recorded under the treatment T_3 (25% RDF + N_2) and T_9 (25% RDF + N_2 + *Azotobacter*).

5.6.4 *Azotobacter* count (CFU 10^6)

- The maximum *Azotobacter* count (12.00 CFU $10^{6)}$ for first year trial (2022-23) was recorded under the treatment T_{14} (25% RDF + *Azotobacter*).
- In second-year trial (2023-24), the maximum *Azotobacter* count (11.83 CFU 10^6) was observed under the treatment T_8 (25% RDF + N_1 + *Azotobacter*).
- The combined data for both the years (2022-23 and 2023-24) revealed the maximum presence of *Azotobacter* count (11.75 CFU 10^6) under the treatment T_{14} (25% RDF + *Azotobacter*).

5.7 Economics parameters

5.7.1 Cost of cultivation (rupees)

- The maximum cost of cultivation (987985.43 rupees) in the first year (2022-23) was noticed under the treatment T_{13} (75% RDF +N_2 + *Azotobacter*).
- The maximum cost of cultivation (1005485.43 rupees) in the second year (2023-24) was noticed under the treatment T_{13} (75% RDF +N_2 + *Azotobacter*).

5.7.2 Gross Income (rupees)

- Maximum gross income (4587079.66 rupees) during first year of experiment was noticed under the treatment T_9 (25% RDF +N_2 + *Azotobacter*).
- In the second-year experiment (2023-24), the maximum gross income (3865885.8 rupees) was noticed under the treatment T_9 (25% RDF +N_2 + *Azotobacter*).

5.7.3 Net returns (rupees)

- First year (2022-23) trial recorded the maximum (3602708.65 rupees) was noticed under the treatment T_9 (25% RDF +N_2 + *Azotobacter*).
- In the second-year experiment (2023-24), the maximum net return (2864014.79 rupees) was noticed under the treatment T_9 (25% RDF +N_2 + *Azotobacter*).

5.7.4 B:C ratio

- First year of experiment, maximum benefit cost ratio (3.66) was noticed under thetreatment T_9 (25% RDF +N_2 + *Azotobacter*).
- In the second- year experiment (2023-24), the maximum benefit cost ratio (2.86) wasnoticed under the treatment T_9 (25% RDF +N_2 + *Azotobacter*).

Conclusion

In conclusion, the present study successfully addressed the objectives outlined for evaluating the combined application of nano urea and *Azotobacter* on strawberry plants (cv. Winter Dawn) in terms of growth, yield, fruit quality, nutrient status, soil fertility, and economic feasibility.

1. Effect on Growth and Yield: The application of nano urea in conjunction with *Azotobacter* significantly enhanced the vegetative growth and yield attributes of strawberry plants. Among the various treatments, the combination of 25% recommended dose of fertilizers (RDF) augmented with 400 ppm nano urea and *Azotobacter* (designated as T_9) demonstrated superior performance in terms of vegetative growth indices. This treatment also led to a marked increase in yield-related parameters, including the number of fruits per plant, average fruit weight, fruit volume, and total fruit yield, underscoring the beneficial impact of these treatments on strawberry productivity.

2. Effect on Fruit Quality: The biochemical analysis of fruit quality revealed that the combined treatment of nano urea and *Azotobacter* (particularly in T_9 and T_{11}) significantly improved several key quality indicators. These included increased titratable acidity, total soluble solids (TSS), TSS: acid ratio, ascorbic acid content, total sugars, reducing sugars, non-reducing sugars, anthocyanin levels, and antioxidant capacity. The results suggest that these treatments not only improve the growth and yield of strawberries but also enhance the nutritional quality of the fruit, making them a promising strategy for producing high-quality strawberry crops.

3. Effect on Nutrient Status of the Plant: The incorporation of nano urea and *Azotobacter* had a positive effect on the nutrient uptake in strawberry plants, as evidenced by the higher nutrient content (NPK) in the leaves. This was particularly evident in treatment T_9, which demonstrated an efficient utilization of nitrogen, phosphorus, and potassium, thereby supporting optimal plant growth and fruit development.

4. Effect on Soil Fertility: The application of nano urea and *Azotobacter* also resulted in improvements in soil fertility status. The treatments contributed to a more favorable nutrient profile in the soil, particularly with respect to nitrogen availability, which can lead to long-term benefits in soil health and sustainability. This is particularly important in sustainable agricultural practices where maintaining soil fertility is crucial for sustained productivity.

5. **Economic Feasibility:** An economic analysis of the treatments revealed that the use of nano urea in combination with *Azotobacter* is a cost-effective approach for improving strawberry yield and quality. The optimized use of fertilizers (such as in treatment T_9) significantly reduced the overall input costs, leading to higher returns on investment without compromising productivity or quality.

References

Aasfar, A., Bargaz, A., Yaakoubi, K., Hilali, A., Bennis, I., Zeroual, Y., & Meftah Kadmiri, I. (2021). Nitrogen fixing Azotobacter species as potential soil biological enhancers for crop nutrition and yield stability. *Frontiers in microbiology*, *12*, 628379.

Abd El-Rhman, I. E., & Shadia, A. A. (2012). Effect of foliar sprays of urea and zinc on yield and physico chemical composition on jujube (*Ziziphus mauritiana*). *Middle East Journal of Agriculture Research*, *1*(1), 52-57.

Abd-Allah, A. S. E. (2006). Effect of spraying some macro and micro nutrients on fruit set, yield and fruit quality of Washington Navel orange trees. *Journal of Applied Sciences Research*, *2*(11), 1059-1063.

Abdelaziz, F. H., Akl, A. M. M. A., Mohamed, A. Y., & Zakier, M. A. (2019). Response of keitte mango trees to spray boron prepared by nanotechnology technique. *NY Sci. J*, *12*,48-55.

Abdollahi, M., Eshghi, S., & Tafazoli, E. (2010). Interaction of paclobutrazol, boron and zinc on vegetative growth, yield and fruit quality of strawberry (*Fragaria× Ananassa* Duch. cv. Selva). *Journal of Biological and Environmental Sciences*, *4*(11).

Adhikari, T., Kundu, S., Biswas, A. K., Tarafdar, J. C., & Subba Rao, A. (2015). Characterization of zinc oxide nano particles and their effect on growth of maize (*Zea mays* L.) plant. *Journal of Plant Nutrition*, *38*(10), 1505-1515.

Ahmad, M. F., Saxena, S. K., Sharma, R. R., & Singh, S. K. (2004). Effect of *Azotobacter chroococcum* on nutrient uptake in Amrapali mango under high density planting. *Indian Journal of Horticulture*, *61*(4), 348-349.

Aktaş, H., ABAK, K., Öztürk, L., & Çakmak, İ. (2006). The effect of zinc on growth and shoot concentrations of sodium and potassium in pepper plants under salinity stress. *Turkish journal of agriculture and forestry*, *30*(6), 407-412.

Akula, V., Delvadia, D. V., Sharma, L. K., Gardwal, P. C., & Makhmale, S. (2014). Effect of micronutrient application on flowering, fruiting and yield of acid lime

(*Citrus aurantifolia* L.)". cv. Kagzi Lime. *International Journal of Tropical Agriculture*, *32*(3/4), 331-334. 151.

Alarcón-Zayas, A., Hernández-Montiel, L. G., Medina-Hernández, D., Rueda-Puente, E. O., Ceiro-Catasú, W. G., & Holguín-Peña, R. J. (2024). Effects of Glomus fasciculatum, Azotobacter chroococcum and Vermicompost Leachate on the Production and Quality of Tomato Fruit. Microbiology Research, 15(1), 187-195.

Al-Baldawy, M. S. M., Matloob, A. A., & Almammory, M. K. (2023, November). The Importance of Nitrogen-Fixing Bacteria Azotobacter chroococcum in Biological Control to Root Rot Pathogens. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1259, No. 1, p. 012110). IOP Publishing.

Albureikan, M. O. I. (2024). Enhancement of Plant Growth with Plant-Based Compost and the Heterotrophic Azotobacter and Streptomyces Inoculation under Greenhouse Conditions. Journal of Pure & Applied Microbiology, 18(3).

Alloway, B. J. (2008). Zinc in Soils and Crop Nutrition. International Zinc Association and International Fertilizer Industry Association.

Alloway, B. J. (2008). Zinc in soils and crop nutrition. published by IZA and IFA. *Brussels, Belgium and Paris, France*, *139*.

Alloway, B. J. (Ed.). (2008). *Micronutrient deficiencies in global crop production*. Springer Science & Business Media.

Almohammedi, O., Sekhi, Y., & Ismail, M. (2023). A Review of Nano fertilization and its role on growth, yield and quality characteristics of fruit trees. *Tikrit Journal for Agricultural Sciences*, *23*(1), 158-167.

Al-Qadi, R. A., & Ameen Alimam, N. M. (2023). Response of three varieties of strawberry to the nano-NPK fertilizer, humic acid. *International Journal of Agricultural & StatisticalSciences*, *19*(1).

Amrish, S., Singh, J. K., & Singh, H. K. (2014). Integrated nutrient management (INM) on growth, yield and quality of papaya (*Carica papaya* L.) cv. CO-7. *Asian Journal of Horticulture*, *9*(2), 390-395.

Anees, M. (2012). Effect of foliar application of micronutrients on the quality of mango (*Mangifera indica* L.) cv. Dusehri fruit. *Mycopath*, *9*(1).

Anees, M., Tahir, F. M., Shahzad, J., and Mahmood, N. (2011). Effect of foliar application of micronutrients on the quality of mango (*Mangifera indica* L.) cv. Dusehri fruit. *Mycopath*, *9*(1): 25-28.

Anonymous (2017). Citrus cultivation in Punjab. P:6-7.

Anonymous (2021). Department of Horticulture, Punjab (Retrieved from http://horticulture.punjab.gov.in/?p=crops)

AOAC, A. (1995). Official methods of analysis 16th Ed. Association of official analytical chemists. Washington DC, USA. Sci. Educ. aromatic plants. *Journal of Applied Research on Medicinal and Aromatic Plants*, *18*, 100255.

Arvind, B., Mishra, N. K., Mishra, D. S., & Singh, C. P. (2012). Foliar application of potassium, calcium, zinc and boron enhanced yield, quality and shelf life of mango. *HortFlora Research Spectrum*, *1*(4), 300-305.

AS, A., Kumar, G. S., Sritharan, N., Radhamani, S., & Maragatham, S. (2023). Studies on the Effect of Nano-Urea on Growth, Yield and Nutrient Use Efficiency in Transplanted Rice. *International Journal of Environment and Climate Change*, *13*(10), 1547-1554.

Asad, A., Blamey, F. P. C., & Edwards, D. G. (2003). Effects of boron foliar applications on vegetative and reproductive growth of sunflower. *Annals of botany*, *92*(4), 565-570.

Ashraf, M. Y., Ashraf, M., Akhtar, M., Mahmood, K., & Saleem, M. (2013). Improvement in yield, quality and reduction in fruit drop in kinnow (*Citrus reticulata* Blanco) by 152.

Ashraf, M. Y., Gul, A., Ashraf, M., Hussain, F., & Ebert, G. (2010). Improvement in yield and quality of Kinnow (*Citrus deliciosa* x *Citrus nobilis*) by potassium fertilization. *Journal of Plant Nutrition*, *33*(11), 1625-1637.

Ashraf, M. Y., Hussain, F., Ashraf, M., Akhter, J., & Ebert, G. (2013). Modulation in yield and juice quality characteristics of citrus fruit from trees supplied with zinc andpotassium foliarly. *Journal of plant nutrition*, *36*(13), 1996-2012.

Ashraf, M. Y., Yaqub, M., Akhtar, J., Khan, M. A., Ali-Khan, M., & Ebert, G. (2012).

Control of excessive fruit drop and improvement in yield and juice quality of Kinnow (*Citrus deliciosa* x *Citrus nobilis*) through nutrient management. *Pak. J. Bot*, *44*, 259- 265. *Asian J. Hort*, *5*(2), 326-329.

Avila-Quezada, G. D., Ingle, A. P., Golińska, P., & Rai, M. (2022). Strategic applications of nano-fertilizers for sustainable agriculture: Benefits and bottlenecks. *Nanotechnology Reviews*, *11*(1), 2123-2140.

Babu, K. D., & Yadav, D. S. (2005). Foliar spray of micronutrients for yield and quality improvement in Khasi mandarin (*Citrus reticulata* Blanco.). *Indian Journal of Horticulture*, *62*(3), 280-281.

Bagal, P. K., Patil, P. L., & Jadhav, S. W. (1985). Effects of *Azotobacter* culture with urea onyield of paddy. *Journal of Maharashtra Agricultural University*, *10*(2), 141-142.

Bakshi, P., Jasrotia, A., Wali, V. K., Sharma, A., & Bakshi, M. (2013). Influence of pre-harvest application of calcium and micro-nutrients on growth, yield, quality and shelf- life of strawberry cv. Chandler. *Indian Journal of Agricultural Sciences*, *83*(8), 831- 835.

Balaji, T., Pandiyan, M., Veeramani, P., & Ramasamy, M. (2016). Effect of foliar spray of micronutrient on plant growth character and yield of banana. *Advance Research Journal of Crop Improvement*, *7*(1), 68-71.

Balesini, Y. M., Imani, A., & Piri, S. (2013). Effects of some of nutritional materials on fruit set and its characteristics in apple. *J. Basic Appl. Sci. Res*, *3*(1), 281-285. 153.

Barak, P., Jobe, B. O., Krueger, A. R., Peterson, L. A., & Laird, D. A. (1997). Effects of long-term soil acidification due to nitrogen fertilizer inputs in Wisconsin. *Plant and soil*, *197*, 61-69.

Barne V. G. (2011). Integrated nutrient management studies in guava. M.Sc. Thesis submitted to Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.

Barne, V. G., Bharad, S. G., Dod, V. N., & Baviskar, M. N. (2011). Effect of integrated nutrient management on yield and quality of guava. *Asian Journal of Horticulture*, *6*(2),546-548.

Barrios, A. C., Rico, C. M., Trujillo-Reyes, J., Medina-Velo, I. A., Peralta-Videa, J. R., & Gardea-Torresdey, J. L. (2016). Effects of uncoated and citric acid coated cerium oxide nanoparticles, bulk cerium oxide, cerium acetate, and citric acid on tomato plants. *Science of the total environment*, *563*, 956-964.

Baviskar, M. N. (2011). Effect of integrated nutrient management on yield and quality of sapota. M.Sc. Thesis submitted to Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola.

Behl, R. K., Sharma, H., Kumar, V., & Narula, N. (2003). Interactions amongst mycorrhiza, *Azotobacter chroococcum* and root characteristics of wheat varieties. *Journal of agronomy and crop science*, *189*(3), 151-155.

Beijerinck, M. W. (1901). Uber oligonitrophile mikroben. *Zentralbl. Bakterol.*

Beijerinck, M. W. (1901). Nitrogen fixing bacteria. *Centbl. f. Bakt*, *2*.

Benjamin, G., Tietel, Z., & Porat, R. (2013). Effects of rootstock/scion combinations on the flavor of citrus fruit. *Journal of Agricultural and Food chemistry*, *61*(47), 1128611294.

Bezerra, M., Ribeiro, M., Cosme, F., & Nunes, F. M. (2024). Overview of the distinctive characteristics of strawberry, raspberry, and blueberry in berries, berry wines, and berry.

Bhatia, S. K., Ahlawat, V. P., Gupta, A. K., & Rana, G. S. (2001). Physico-chemical attributes of guava as affected by nitrogen application. *Haryana Journal of Horticultural Sciences*, *30*(1/2), 65-66.

Bhattacharyya, A., Pablo, C. H., Mavrodi, O. V., Weller, D. M., Thomashow, L. S., & Mavrodi, D. V. (2021). Rhizosphere plant-microbe interactions under water stress. In *Advances in applied microbiology* (Vol. 115, pp. 65-113). Academic Press.

Bhatti, D., Varu, D. K., & Dudhat, M. (2023). Effect of different doses of urea and nano-ureaon growth and yield of guava (*Psidium guajava* L.) Cv. Lucknow-49.

Bhoyar, M. G., & Ramdevputra, M. V. (2016). Effect of foliar spray of zinc, iron and boron on the growth, yield and sensory characters of guava (*Psidium guajava* L.) cv. Sardar L-49. *Journal of Applied and Natural Science*, *8*(2), 701-704. 154.

Bingham, F. T. (1983). Boron. *Methods of Soil Analysis: Part 2 Chemical and Microbiological Properties*, *9*, 431-447.

Biswas, P., & Wu, C. Y. (2005). Nanoparticles and the environment. *Journal of the air & waste management association*, *55*(6), 708-746.

Borah, P., Gogoi, N., Asad, S. A., Rabha, A. J., & Farooq, M. (2023). An insight into plant growth-promoting rhizobacteria-mediated mitigation of stresses in plant. *Journal of Plant Growth Regulation*, *42*(5), 3229-3256.

Bowler, C., Van Camp, W., Van Montagu, M., Inzé, D., & Asada, K. (1994). Superoxide dismutase in plants. *Critical Reviews in Plant Sciences*, *13*(3), 199- 218.

Brooks, A. M. (2022). Petals plucked from sunny climes. DigiCat.

Burgess, Alexandra J., Céline Masclaux-Daubresse, Günter Strittmatter, Andreas PM Weber, Samuel Harry Taylor, Jeremy Harbinson, Xinyou Yin *et. al.* "Improving crop yield potential: Underlying biological processes and future prospects." *Food and Energy Security* 12, no. 1 (2023): e435.

Cao, H., Jian, X., Zhang, D., Ling, W., Zhang, G., Zhang, Y., ... & Liu, F. (2024). Amphiphilicity-driven octaphenyl polyoxyethylenes regulate soft microcapsules flexibility for better foliar adhesion and pesticide utilization. *Advanced Agrochem*.

Carlesso, L. C., Luz, G. L. D., Lajus, C. R., Silva, L. L., Fiori, M., Rossoni, C., & Riella, H. (2018). Physical-Chemical Properties of Strawberry Pseudo fruits Submitted to Applications of Zinc Oxide Nanoparticles. *International Journal of Advanced Engineering Research and Science*, *5*(7), 264208.

Cassán, F., Vanderleyden, J., & Spaepen, S. (2014). Physiological and agronomical aspects of phytohormone production by model plant-growth-promoting rhizobacteria (PGPR) belonging to the genus Azospirillum. *Journal of Plant Growth Regulation*, *33*, 440-459.

Chahill, B. S., Dhatt, A. S., & Singh, R. (1988). Standardization of foliar sampling techniquein Kinnow mandarin. *Punjab Hort. J*, 28(3-4), 118-124.

Chakraborty, T., & Akhtar, N. (2021). Biofertilizers: Characteristic features and applications. *Biofertilizers: Study and Impact*, 429-489.

Chander, S., Jain, M. C., Pareek, P. K., Bola, P. K., Meena, R. R., & Sharma, Y. K. (2017). Effect of Foliar Feeding of Borax, Zinc sulphate and Urea on Fruiting and Yield of Guava (*Psidium guajava* L.) Cvs. Lalit and Shweta under high density planting system.*Chem. Sci. Rev. Lett*, *6*(22), 874-883.

Chandra, R., & Singh, K. K. (2015). Foliar application of zinc sulphate, magnesium sulphate and copper sulphate on the yield and quality of aonla (*Emblica officinallis* Gaerth L.) cv.–NA-7‖ under Garhwal Himalaya. *Himalaya Journal of Medicinal Plants Studies*, *3*(5), 42-45.

Chandra, S., Yadav, A. L., Singh, H. K., & Singh, M. K. (2010). Influence of micronutrients on plant growth, yield and quality of papaya fruit (*Carica papaya* L.) cv. Washington. *Asian Journal of Horticulture*, *5*(2), 326-329.

Chapman, H. D. (1964). Suggested Foliar Sampling and Handling Techniques for Determining the Nutrient Status of Some Field, Horticultural and Plantation Crops1. *Indian Journal of Horticulture*, *21*(2), 97-119. 155.

Chapman, H. D., & Pratt, F. P. (1961). Ammonium vandate-molybdate method for determination of phosphorus. *Methods of analysis for soils, plants and water*, *1*, 184- 203.

Chaudhary, I. J., Neeraj, A., Siddiqui, M. A., & Singh, V. (2020). Nutrient management technologies and the role of organic matrix-based slow-release biofertilizers for agricultural sustainability: A review. *Agricultural reviews*, *41*(1), 1-13.

Chauhan, A. (2008). Studies on integrated nutrient management in plum (*Prunus salicina* L.)cv. Santa Rosa (Doctoral dissertation, Ph. D. Thesis, Dr. YS Parmar University of Horticulture and Forestry, Nauni, Solan, India).

Chen, J. Y., Du, J., Li, M. L., & Li, C. M. (2020). Degradation kinetics and pathways of red raspberry anthocyanins in model and juice systems and their correlation with color and antioxidant changes during storage. *Lwt*, *128*, 109448.

Codoñer-Franch, P., & Valls-Bellés, V. (2010). Citrus as functional foods. *Current Topics in Nutraceutical Research*, *8*(4).

Condron, L., Stark, C., O'Callaghan, M., Clinton, P., & Huang, Z. (2010). The role of microbial communities in the formation and decomposition of soil organic matter. *Soil microbiology and sustainable crop production*, 81-118.

Dar, S. A., Bhat, R. A., Dervash, M. A., Dar, Z. A., & Dar, G. H. (2021). Azotobacter as biofertilizer for sustainable soil and plant health under saline environmental conditions. *Microbiota and Biofertilizers: A Sustainable Continuum for Plant and Soil Health*, 231-254.

Das, H. K. (2019). *Azotobacters* as biofertilizer. *Advances in applied microbiology*, *108*, 1- 43.

Davarpanah, S., Tehranifar, A., Davarynejad, G., Abadía, J., & Khorasani, R. (2016). Effects of foliar applications of zinc and boron nano-fertilizers on pomegranate (*Punica granatum* cv. Ardestani) fruit yield and quality. *Scientia horticulturae*, *210*, 57-64.

Davarpanah, S., Tehranifar, A., Davarynejad, G., Aran, M., Abadía, J., & Khorassani, R. (2017). Effects of foliar nano-nitrogen and urea fertilizers on the physical and chemical properties of pomegranate (Punica granatum cv. Ardestani) fruits. *HortScience*, *52*(2), 288-294.

Davarpanah, S., Tehranifar, A., Davarynejad, G., Aran, M., Abadía, J., & Khorassani, R. (2017). Effects of foliar nano-nitrogen and urea fertilizers on the physical and chemical properties of pomegranate (Punica granatum cv. Ardestani) fruits. *HortScience*, *52*(2), 288-294.

Dawood, S. A., Meligy, M. S., & El-Hamady, M. M. (2001). Influence of zinc sulfate application on tree leaf and fruit characters of three young citrus varieties grown on slightly alkaline soil. *Annals of Agriculture Science*, *39*, 433-447.

Dayal, H., Lal, G., Singh, Y. V., Kumar, P., & Singh, D. (2010). Effect of nitrogen, phosphorus and zinc on growth and yield of ber cv. Gola under arid and semi-arid conditions. *Indian Journal of Horticulture*, *67*(2), 277-280.

De Moraes Barros, H. R., de Castro Ferreira, T. A. P., & Genovese, M. I. (2012). Antioxidant capacity and mineral content of pulp and peel from commercial cultivars of citrus fromBrazil. *Food chemistry*, *134*(4), 1892-1898.

De Volder, M. F., Tawfick, S. H., Baughman, R. H., & Hart, A. J. (2013). Carbon nanotubes: present and future commercial applications. *science*, *339*(6119), 535-539.

Dellagi, A., Quillere, I., & Hirel, B. (2020). Beneficial soil-borne bacteria and fungi: a promising way to improve plant nitrogen acquisition. *Journal of Experimental Botany*, *71*(15), 4469-4479.

Devi, H. L., Mitra, S. K., & Poi, S. C. (2012, April). Effect of different organic and biofertilizer sources on guava (*Psidium guajava* L.)'Sardar'. In *III International Symposium on Guava and other Myrtaceae 959* (pp. 201-208). 156.

Dhurve, M. K., Sharma, T. R., Bhooriya, M. S., & Lodha, G. (2018). Effect of foliarapplication of zinc and boron on growth, reproductive and yield of pomegranate cv. Ganesh in hast bahar. *International Journal of Chemical Studies*, *6*(5), 499-503.

Dickenson, V. (2020). Berries. Reaktion Books.

Dimkpa, C. O., Campos, M. G., Fugice, J., Glass, K., Ozcan, A., Huang, Z., ... & Santra, S. (2022). Synthesis and characterization of novel dual-capped Zn–urea nanofertilizers and application in nutrient delivery in wheat. *Environmental Science: Advances*, *1*(1), 47-58.

Dimkpa, C. O., Fugice, J., Singh, U., & Lewis, T. D. (2020). Development of fertilizers for enhanced nitrogen use efficiency–Trends and perspectives. *Science of the Total Environment*, *731*, 139113.

Do, E., Kim, M., Ko, D. Y., Lee, M., Lee, C., & Ku, K. M. (2024). Machine learning for storage duration based on volatile organic compounds emitted from'Jukhyang'and'Merry Queen'strawberries during post-harvest storage. Postharvest Biology and Technology, 211, 112808.

Durán-Soria, S., Pott, D. M., Osorio, S., & Vallarino, J. G. (2020). Sugar signaling during fruit ripening. *Frontiers in Plant Science*, *11*, 564917.

Dutta, P., Kundu, S., & Chatterjee, S. (2008, December). Effect of bio-fertilizers on homestead fruit production of papaya cv. Ranchi. In *II International Symposium on Papaya 851* (pp. 385-388).

Dutta, P., Kundu, S., Bauri, F. K., Talang, H., & Majumder, D. (2014). Effect of bio-fertilizers on physico-chemical qualities and leaf mineral composition of guava grown in alluvial zone of West Bengal. *Journal of Crop and Weed*, *10*(2), 268-271.

Dwivedi, D. H., Lata, R., Ram, R. B., & Babu, M. (2010, August). Effect of bio-fertilizer and organic manures on yield and quality of' Red Fleshed guava. In *XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on 933* (pp. 239-244).

EL Sabagh, A., Islam, M. S., Hossain, A., Iqbal, M. A., Mubeen, M., Waleed, M., ... & Abdelhamid, M. T. (2022). Phytohormones as growth regulators during abiotic stress tolerance in plants. *Frontiers in Agronomy*, *4*, 765068.

El-Hak El, R. E. S. A., El-Aty El, S. A., El-Gazzar, A. A. E. F., Shaaban, E. A. E. A., & Saleh, M. M. S. (2019). Efficiency of nano-zinc foliar spray on growth, yield and fruit quality of flame seedless grape. *Journal of Applied Sciences*, *19*(6), 612-617.

Elsheery, N. I., Helaly, M. N., El-Hoseiny, H. M., & Alam-Eldein, S. M. (2020). Zinc oxide and silicone nanoparticles to improve the resistance mechanism and annual productivityof salt-stressed mango trees. *Agronomy, 10(4)*, 558.

Eman, A. A., El-Moneim, A., El-Migeed, M. A., Omayma, A. M. M. I., & Ismail, M. M. (2007). GA3 and zinc sprays for improving yield and fruit quality of Washington Navel orange trees grown under sandy soil conditions. *Research Journal of Agriculture and Biological Sciences*, *3*(5), 498-503.

Erel, R., Dag, A., Ben-Gal, A., Schwartz, A., & Yermiyahu, U. (2008). Flowering and fruit set of olive trees in response to nitrogen, phosphorus, and potassium. *Journal of the American Society for Horticultural Science*, *133*(5), 639-647.

Etesami, H., & Adl, S. M. (2020). Plant growth-promoting rhizobacteria (PGPR) and their action mechanisms in availability of nutrients to plants. *Phyto-Microbiome in* *stress regulation*, 147-203.

Etienne, A., Génard, M., Lobit, P., Mbeguié-A-Mbéguié, D., & Bugaud, C. (2013). What controls fleshy fruit acidity? A review of malate and citrate accumulation in fruit cells. *Journal of experimental botany*, *64*(6), 1451-1469.

exogenous application of plant growth regulators, potassium and zinc. *Pak. J. Bot*, *45*(S1), 433-440.

Famiani, F., Battistelli, A., Moscatello, S., Cruz-Castillo, J. G., & Walker, R. P. (2015). The organic acids that are accumulated in the flesh of fruits: occurrence, metabolism and factors affecting their contents-a review. *Revista Chapingo. Serie horticultura*, *21*(2), 97-128.
Famiani, F., Battistelli, A., Moscatello, S., Cruz-Castillo, J. G., & Walker, R. P. (2015). The organic acids that are accumulated in the flesh of fruits: occurrence, metabolism and factors affecting their contents-a review. *Revista Chapingo. Serie horticultura*, *21*(2), 97-128.
Famiani, F., Bonghi, C., Chen, Z. H., Drincovich, M. F., Farinelli, D., Lara, M. V., ... & Walker, R. P. (2020). Stone fruits: Growth and nitrogen and organic acid metabolism in the fruits and seeds—A review. *Frontiers in Plant Science*, *11*, 572601.

Fan, Z., & Whitaker, V. M. (2024). Genomic signatures of strawberry domestication and diversification. The Plant Cell, 36(5), 1622-1636.

Ferrarezi, R. S., Lin, X., Gonzalez Neira, A. C., Tabay Zambon, F., Hu, H., Wang, X., ... & Fan, G. (2022). Substrate pH influences the nutrient absorption and rhizosphere microbiome of Huanglongbing-affected grapefruit plants. *Frontiers in plant science*, *13*, 856937.

Fierer, N., Lauber, C. L., Ramirez, K. S., Zaneveld, J., Bradford, M. A., & Knight, R. (2012). Comparative metagenomic, phylogenetic and physiological analyses of soil microbial communities across nitrogen gradients. *The ISME journal*, *6*(5), 1007-1017.

Food and Agriculture Organization of the United Nations (FAO) (1986). *6th Report of* *the Joint FAO/OIE Expert Committee on Brucellosis*, *12*. 157.

Gangaiah, B., & Yadav, A. K. (2024). Modern Crop Management Practices for Pearl Millet Cultivation in Asia. In *Pearl Millet in the 21st Century: Food-Nutrition-Climate resilience-Improved livelihoods* (pp. 479-511). Singapore: Springer Nature Singapore.

Garcia-Pausas, J., & Paterson, E. (2011). Microbial community abunda

Gaur, B., Beer, K., Hada, T. S., Kanth, N., & Syamal, M. M. (2014). Studies on the effect of foliar application of nutrients and GA3 on fruit yield and quality of winter season guava. *The Ecoscan*, *6*, 479-483.

Gauri, S. S., Mandal, S. M., & Pati, B. R. (2012). Impact of Azotobacter exopolysaccharides on sustainable agriculture. *Applied microbiology and biotechnology*, *95*, 331-338.

Ge, G., Li, Z., Fan, F., Chu, G., Hou, Z., & Liang, Y. (2010). Soil biological activity and their seasonal variations in response to long-term application of organic and inorganicfertilizers. *Plant and Soil*, *326*, 31-44.

Ghadirnezhad Shiade, S. R., Fathi, A., Kardoni, F., Pandey, R., & Pessarakli, M. (2024). Nitrogen contribution in plants: recent agronomic approaches to improve nitrogen use efficiency. *Journal of Plant Nutrition*, *47*(2), 314-331.

Ghosh, D., *et. al.* (2017). Nano-urea fertilizer improves growth and yield of strawberry (Fragaria × ananassa Duch.). Journal of Plant Nutrition, 40(15), 2194-2202.

Ghosh, S. K., & Bera, T. (2021). Molecular mechanism of nano-fertilizer in plant growth and development: A recent account. In *Advances in nano-fertilizers and nano-pesticides in agriculture* (pp. 535-560). Woodhead Publishing.

Ghosh, S. N., Bera, B., Roy, S., Kundu, A., & Roy, S. D. (2009). Effect of nutrients and plantgrowth regulators on fruit retention, yield and physico-chemical characteristics in aonlacv. NA-10. *Journal of Horticultural Sciences*, *4*(2), 164-166.

Giesecke, A. (Ed.). (2023). A cultural history of plants in antiquity. Bloomsbury Publishing.

Godage, S. S. (2012). Influence of bio-fertilizers in combination with chemical fertilizers on growth, yield and quality of guava (*Psidium guajava* L.) cv. Allahabad Safeda. M.Sc. Thesis submitted to Anand Agricultural University, Anand.

Godage, S. S., Parekh, N. S., Nehete, D. S., & Jagtap, V. M. (2013). Influence of chemical and bio-fertilizers on growth, flowering, fruit yield and quality of guava (*Psidium guajava* L.) cv. Allahabad Safeda. *BIOINFOLET-A Quarterly Journal of Life Sciences*,*10*(2a), 480-485.

Goldenberg, L., Yaniv, Y., Kaplunov, T., Doron-Faigenboim, A., Porat, R., & Carmi, N. (2014). Genetic diversity among mandarins in fruit-quality traits. *Journal of Agricultural and Food Chemistry*, *62*(21), 4938-4946.

Goren, R., Huberman, M., & Zhong, G. Y. (2000). Basics aspects of hormonal control of abscission. In *Proceedings International Society of Citriculture* (Vol. 9, pp. 591-594).

Goswami, A. K., Lal, S., & Misra, K. K. (2012). Integrated nutrient management improves growth and leaf nutrient status of guava cv. Pant Prabhat. *Indian Journal of Horticulture*, *69*(2), 168-172.

Goswami, A. K., Lal, S., Thakare, M., Mishra, D. S., & Kumar, R. (2015). Studies on integrated nutrient management on yield and quality of guava cv. Pant Prabhat. *Indian Journal of Horticulture*, *72*(1), 139-142.

Goswami, A. K., Shukla, H. S., & Mishra, D. S. (2014). Influence of pre-harvest nutrients application on the physico-chemical quality and storage behaviour of guava (*Psidium guajava* L.) fruit cv. L-49. *Progressive Horticulture*, *46*(1), 54-57. 158.

Goswami, A. K., Shukla, H. S., Prabhat, K., & Mishra, D. S. (2012). Effect of pre-harvest application of micro-nutrients on quality of guava (*Psidium guajava* L.) cv. Sardar. *HortFlora Research Spectrum*, *1*(1), 60-63.

Gross, C. D., & Harrison, R. B. (2019). The case for digging deeper: soil organic carbon storage, dynamics, and controls in our changing world. *Soil Systems*, *3*(2), 28.

Gu, J., Li, Z., Mao, Y., Struik, P. C., Zhang, H., Liu, L., ... & Yang, J. (2018). Roles of nitrogen and cytokinin signals in root and shoot communications in maximizing of plant productivity and their agronomic applications. *Plant Science*, *274*, 320-331.

Guo, H., White, J. C., Wang, Z., & Xing, B. (2018). Nano-enabled fertilizers to control the release and use efficiency of nutrients. *Current Opinion in Environmental Science & Health*, *6*, 77-83.

Guo, H., White, J. C., Wang, Z., & Xing, B. (2018). Nano-enabled fertilizers to control the release and use efficiency of nutrients. Current Opinion in Environmental Science & Health, 6, 77-83.

Gupta, A. K., & Tripathi, V. K. (2012). Efficacy of *Azotobacter* and vermicompost alone andin combination on vegetative growth, flowering and yield of strawberry (*Fragaria* x *ananassa* Duch.) cv. Chandler. *Progressive Horticulture*, *44*(2), 256-261.

Gupta, A., Tripathy, D. B., Kumar, G., Agarwal, P., & Ghosal, A. Nanopesticides, Nanoherbicides, and Nanofertilizers.

Gupta, S., *et. al.* (2019). Nano-urea improves soil health and productivity in paddyfields.

Gupta, S., *et. al.* (2020). Effect of nano-urea on fruit quality attributes of peach (Prunuspersica L.). Journal of Applied Horticulture, 22(1), 43-48.

Gupta, S., *et. al.* (2021). Economic and environmental benefits of nano urea in wheat cultivation. Journal of Sustainable Agriculture, 39(4), 390-405.

Gupta, S., *et. al.* (2021). Economic and environmental benefits of nano urea in strawberrycultivation. Journal of Sustainable Agriculture, 39(4), 390-405.

Gurjar, M. K., Kaushik, R. A., & Baraily, P. (2015). Effect of zinc and boron on the growth and yield of Kinnow mandarin. *Int J Scientific Res*, *4*(1).

Gurjar, P. S., & Rana, G. S. (2014). Influence of foliar application of nutrients and growth regulator on fruit drop, yield and fruit size and quality in Kinnow mandarin. *Indian Journal of Horticulture*, *71*(1), 109-111.

Gurjar, T. D., Patel, N. L., Panchal, B., & Chaudhari, D. (2015). Effect of foliar spray of micronutrients on flowering and fruiting of Alphonso mango (*Mangifera indica* L.). *The bioscan*, *10*(3), 1053-1056.

Gurung, S., Mahato, S. K., Suresh, C. P., & Chetrri, B. (2016). Impact of foliar application of growth regulators and micronutrients on the performance of Darjeeling mandarin. *American Journal of experimental agriculture*, *12*(4), 1-7.

Gutierrez, L., Gomez, L., Irusta, S., Arruebo, M., & Santamaria, J. (2011). Comparative studyof the synthesis of silica nanoparticles in micromixer–microreactor and batch reactor systems. *Chemical Engineering Journal*, *171*(2), 674-683.

Gutschick, V. P. (1981). Evolved strategies in nitrogen acquisition by plants. *The American Naturalist*, *118*(5), 607-637.

Hafeez, B. M. K. Y., Khanif, Y. M., & Saleem, M. (2013). Role of zinc in plant nutrition-a review. *American journal of experimental Agriculture*, *3*(2), 374.

Hafez, O. M., & El-Metwally, I. M. (2007). Efficiency of zinc and potassium sprays alone or in combination with some weed control treatments on weeds growth, yield and fruit quality of Washington navel orange orchards. *Journal of Applied Sciences Research*, *3*(7), 613-621. 159.

Hamdi, Y. A. (1982). *Application of nitrogen-fixing systems in soil improvement and management* (No. 49). Food & Agriculture Org..

Hammad, H. M., Abbas, F., Ahmad, A., Farhad, W., Wilkerson, C. J., & Hoogenboom, G. (2018). Evaluation of timing and rates for nitrogen application for optimizing maize growth and development and maximizing yield. *Agronomy Journal*, *110*(2), 565-571.

Han, F., Li, H., Lyu, E., Zhang, Q., Gai, H., Xu, Y., ... & Wei, M. (2024). Soybean-mediated suppression of BjaI/BjaR1 quorum sensing in Bradyrhizobium diazoefficiens impacts symbiotic nitrogen fixation. *Applied and Environmental Microbiology*, *90*(2), e01374- 23.

Hasani, M., Zamani, Z., Savaghebi, G., & Fatahi, R. (2012). Effects of zinc and manganese as foliar spray on pomegranate yield, fruit quality and leaf minerals. *Journal of soil science and plant nutrition*, *12*(3), 471-480.

Hashemabadi, D., Namaki, M. H., & Saeeid Zade, F. (2019). The effect of bio-fertilizers andNano-nitrogen on strawberry quality and quantity under different levels of nitrogen. *Journal of Plant Environmental Physiology*, *13*(52), 67-80.

Herren, C. M., & McMahon, K. D. (2018). Keystone taxa predict compositional change in microbial communities. *Environmental Microbiology*, *20*(6), 2207-2217.

Hindersah, R., Kamaluddin, N. N., Samanta, S., Banerjee, S., & Sarkar, S. (2020). Role and perspective of Azotobacter in crops production. *SAINS TANAH-Journal of Soil Scienceand Agroclimatology*, *17*(2), 170-179.
Hindersah, R., Kamaluddin, N. N., Samanta, S., Banerjee, S., & Sarkar, S. (2020). Role and perspective of Azotobacter in crops production. *SAINS TANAH-Journal of Soil Scienceand Agroclimatology*, *17*(2), 170-179.
Hong, J., Wang, C., Wagner, D. C., Gardea-Torresdey, J. L., He, F., & Rico, C. M. (2021). Foliar application of nanoparticles: mechanisms of absorption, transfer, and multiple impacts. *Environmental Science: Nano*, *8*(5), 1196-1210.

Hu, J., & Xianyu, Y. (2021). When nano meets plants: A review on the interplay between nanoparticles and plants. Nano Today, 38, 101143.

Hurtado Pérez, G. A. (2024). Rain damage in strawberries: identifying the drivers and understanding the mechanisms.

Hutchins, D. A., & Capone, D. G. (2022). The marine nitrogen cycle: new developments andglobal change. *Nature Reviews Microbiology*, *20*(7), 401-414.

Iglesias, D. J., Cercós, M., Colmenero-Flores, J. M., Naranjo, M. A., Ríos, G., Carrera, E., & Talon, M. (2007). Physiology of citrus fruiting. *Brazilian Journal of Plant Physiology*, *19*, 333-362.

Iqbal, M. A. (2019). Nano-fertilizers for sustainable crop production under changing climate:a global perspective. *Sustainable crop production*, *8*, 1-13.

Iqbal, M., Umar, S., & Mahmooduzzafar. (2019). Nano-fertilization to enhance nutrient use efficiency and productivity of crop plants. *Nanomaterials and plant potential*, 473-505.

Ismail, A. I. (1994). Growth and productivity of Valencia orange trees as affected by micronutrients applications (Doctoral dissertation, Ph.D Thesis. Fac. Agri., Cairo University, Egypt).

J. C., & Pedraza, R. O. (2015). Physiological, structural and molecular traits activated in strawberry plants after inoculation with the plant growth-promoting bacterium Azospirillum brasilense REC 3. *Plant Biology*, *17*(3), 766-773.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi, 98p.

Jain, A., *et. al.* (2018). Impact of nano-urea on soil microbial population and activity in maize-wheat cropping system. Journal of Soil Science and Plant Nutrition, 18(3), 712- 725.

Jaiswal, S. K., Mohammed, M., Ibny, F. Y., & Dakora, F. D. (2021). Rhizobia as a source of plant growth-promoting molecules: Potential applications and possible operational mechanisms. *Frontiers in Sustainable Food Systems*, *4*, 619676.

Jat, G., & Laxmidas, K. H. (2014). Response of guava to foliar application of urea and zinc on fruit set, yield and quality. *Journal of agrisearch*, *1*(2).

Javed, T., I, I., Singhal, R. K., Shabbir, R., Shah, A. N., Kumar, P., ... & Siuta, D. (2022). Recent advances in agronomic and physio-molecular approaches for improving nitrogen use efficiency in crop plants. *Frontiers in Plant Science*, *13*, 877544.

Jayaprakasha, G. K., Brodbelt, J. S., Bhat, N. G., & Patil, B. S. (2006). Methods for the separation of limonoids from citrus.

Jensen, H. (1954). The azotobacteriaceae. *Bacteriological Reviews*, *18*(4), 195-214.

Jeyabaskaran, K. J., & Pandey, S. D. (2008). Effect of foliar spray of micronutrients in banana under high soil pH condition. *Indian Journal of Horticulture*, *65*(1), 102-105.

Ji, Y., Yue, L., Cao, X., Chen, F., Li, J., Zhang, J., ... & Xing, B. (2023). Carbon dots promoted soybean photosynthesis and amino acid biosynthesis under drought stress: Reactive oxygen species scavenging and nitrogen metabolism. *Science of the Total Environment*, *856*, 159125.

Ji, Y., Yue, L., Cao, X., Chen, F., Li, J., Zhang, J., ... & Xing, B. (2023). Carbon dots promoted soybean photosynthesis and amino acid biosynthesis under drought stress: Reactive oxygen species scavenging and nitrogen metabolism. *Science of the Total Environment*, *856*, 159125.

Jnawali, A. D., Ojha, R. B., & Marahatta, S. (2015). Role of Azotobacter in soil fertility and sustainability–a review. *Adv. Plants Agric. Res*, *2*(6), 1-5.

Journal of Agricultural Science, 44(8), 1165-1173.

Kalil, A. T., & Al-Aareji, J. M. (2022). ROLE OF FOLIAR SPRAY WITH SELENIUM AND UREA ON Growth, FLOWERING, AND YIELD OF STRAWBERRY (Fragaria x ananassa Duch.) CV. ALBION. *British Journal of Global Ecology and SustainableDevelopment*, *5*, 1-11.
Kalil, A. T., & Al-Aareji, J. M. (2022). ROLE OF FOLIAR SPRAY WITH SELENIUM AND UREA ON Growth, FLOWERING, AND YIELD OF STRAWBERRY (Fragaria x ananassa Duch.) CV. ALBION. *British Journal of Global Ecology and SustainableDevelopment*, *5*, 1-11.
Kamel, F., Sabir, S., Mahal, A., & Wei, X. (2022). In vitro Antibacterial Activity of Orange Peel Oil Extract from *Citrus sinensis* Fruit in Erbil. *Egyptian Journal of Chemistry*, *65*(4), 157-160.

Kamiloglu, S., Tomas, M., Ozdal, T., & Capanoglu, E. (2021). Effect of food matrix on the content and bioavailability of flavonoids. *Trends in Food Science & Technology*, *117*, 15-33. 160.

Kannoj, J., Jain, D., Tomar, M., Patidar, R., & Choudhary, R. (2022). Effect of Nano Urea vs Conventional Urea on the Nutrient Content, Uptake and Economics of Black Wheat (Triticum aestivum L.) along with Biofertilizers. In *Biological Forum–An InternationalJournal* (Vol. 14, No. 2a, pp. 499-504).
Kannoj, J., Jain, D., Tomar, M., Patidar, R., & Choudhary, R. (2022). Effect of Nano Urea vs Conventional Urea on the Nutrient Content, Uptake and Economics of Black Wheat (Triticum aestivum L.) along with Biofertilizers. In *Biological Forum–An InternationalJournal* (Vol. 14, No. 2a, pp. 499-504).

Kannoj, J., Jain, D., Tomar, M., Patidar, R., & Choudhary, R. (2022). Effect of Nano Urea vs Conventional Urea on the Nutrient Content, Uptake and Economics of Black Wheat (Triticum aestivum L.) along with Biofertilizers. In Biological Forum–An InternationalJournal (Vol. 14, No. 2a, pp. 499-504).
Karmakar, A., Giri, A., Bahadur, R., & Kumar, N. PLANT GROWTH AND

DEVELOPMENT: PHASES AND REGULATION. *SYSTEMS IN AGRI-HORTI.*

Kaur, N., Monga, P. K., Arora, P. K., & Kumar, K. (2015). Effect of micronutrients on leaf composition, fruit quality and yield of Kinnow mandarin. *Journal of Applied and Natural Science*, *7*(2), 639-643.

Kazemi, M. (2014). Influence of foliar application of iron, calcium and zinc sulfate on vegetative growth and reproductive characteristics of Strawberry cv.‗Pajaro'. *Trakia Journal of Sciences*, *12*(1), 21-26.

Kazi, S. S., Ismail, S., & Joshi, K. G. (2012). Effect of multi-micronutrient on yield and quality attributes of the sweet orange. *African Journal of Agricultural Research*, *7*(29), 4118-4123.

Khan, A. S., Nasir, M., Malik, A. U., Basra, S. M. A., & Jaskani, M. J. (2015). Combined application of boron and zinc influence the leaf mineral status, growth, productivity and fruit quality of ‗Kinnow'mandarin (*Citrus nobilis* Lour× *Citrus deliciosa* Tenora). *Journal of Plant Nutrition*, *38*(6), 821-838.

Khan, A. S., Ullah, W., Malik, A. U., Ahmad, R., Saleem, B. A., & Rajwana, I. A. (2012). Exogenous applications of boron and zinc influence leaf nutrient status, tree growth andfruit quality of Feutrell's early (*Citrus reticulata* Blanco). *Pak. J. Agri. Sci*, *49*(2), 113- 119.

Khan, A., Ding, Z., Ishaq, M., Khan, I., Ahmed, A. A., Khan, A. Q., & Guo, X. (2020). Applications of beneficial plant growth promoting rhizobacteria and mycorrhizae in rhizosphere and plant growth: A review. *International Journal of Agricultural and Biological Engineering*, *13*(5), 199-208.

Khan, M. S., *et. al.* (2019). Economic feasibility of nano urea over conventional urea in rice cultivation. Journal of Agricultural Economics, 35(2), 210-225.

Khan, S., Singh, H. K., & Pratap, B. (2009). Impact of foliar application of micro-nutrients and thiourea on growth, fruit yield and quality of aonla (*Emblica officinalis* Gaertn) cv.Narendra Aonla-6. *Annals of Horticulture*, *2*(1), 83-85.

Kiran, S., Furtana, G. B., & Ellialtioglu, Ş. Ş. (2022). Physiological and biochemical assay of drought stress responses in eggplant (Solanum melongena L.) inoculated with commercial inoculant of Azotobacter chroococum and Azotobacter vinelandii.

ScientiaHorticulturae, *305*, 111394.

Kishorekumar, R., Bulle, M., Wany, A., & Gupta, K. J. (2020). An overview of important enzymes involved in nitrogen assimilation of plants. *Nitrogen metabolism in plants: methods and protocols*, 1-13.

Kizilkaya, R. (2009). Nitrogen fixation capacity of Azotobacter spp. strains isolated from soils in different ecosystems and relationship between them and the microbiological properties of soils. *J. Environ. Biol*, *30*(1), 73-82.

Korwar, G. R., Pratibha, G., Ravi, V., & Palanikumar, D. (2006). Influence of organics and inorganics on growth, yield of aonla (*Emblica officinalis*) and soil quality in semi arid tropics. *Indian J Agric Sci*, *76*(8), 457-461. 161.

Kozieł, M., Martyniuk, S., & Siebielec, G. (2021). Occurrence of Azotobacter spp. in cultivated soils in Poland. *Polish Journal of Agronomy*, (44), 3-8.

Kráľová, K., & Jampílek, J. (2022). Metal-and metalloid-based nanofertilizers and nanopesticides for advanced agriculture. In *Inorganic Nanopesticides and Nanofertilizers: A View from the Mechanisms of Action to Field Applications* (pp. 295- 361). Cham: Springer International Publishing.

Kukreja, K., Suneja, S., Goyal, S., & Narula, N. (2004). Phytohormone production by Azotobacter–a review. *Agricultural Reviews*, *25*(1), 70-75.

Kulkarni, N. H. (2004). Effect of growth regulators and micronutrients on fruit drop, yield and quality in sweet orange (*Citrus sinensis* Osbeck). *Unpublished Ph. D. Thesis, Marathwada Agricultural University, Parbhani, India*.

Kumar, A., & Kumar, P. (2020). Chemical control measures adopted by kinnow growers in Punjab. *Indian Journal of Economics and Development*, *16*(2s), 246-252.

Kumar, A., *et. al.* (2020). Nano-urea promotes physiological growth and fruit yield of strawberry (*Fragaria × ananassa* Duch.). Journal of Plant Nutrition, 43(11), 1685-1694.

Kumar, A., *et. al.* (2021). Nano-urea promotes physiological growth and fruit yield of mango(Mangifera indica L.). Journal of Plant Nutrition, 44(11), 1685-1694.

Kumar, A., Maurya, B. R., & Raghuwanshi, R. (2014). Isolation and characterization of PGPR and their effect on growth, yield and nutrient content in wheat (*Triticum aestivum* L.). *Biocatalysis and Agricultural Biotechnology*, *3*(4), 121-128.

Kumar, A., Ram, H., Kumar, S., Kumar, R., Yadav, A., Gairola, A., ... & Sharma, T. (2023). A Comprehensive Review of Nano-Urea vs. Conventional Urea. *International Journal of Plant & Soil Science*, *35*(23), 32-40.

Kumar, A., Ram, H., Kumar, S., Kumar, R., Yadav, A., Gairola, A., ... & Sharma, T. (2023). A Comprehensive Review of Nano-Urea vs. Conventional Urea. *International Journal of Plant & Soil Science*, *35*(23), 32-40.

Kumar, A., Ram, H., Kumar, S., Kumar, R., Yadav, A., Gairola, A., ... & Sharma, T. (2023). A Comprehensive Review of Nano-Urea vs. Conventional Urea. *International Journal of Plant & Soil Science*, *35*(23), 32-40.

Kumar, G. K., Vani, V. S., Rao, A. D., Subbaramamma, P., & Sujatha, R. V. (2017). Effect of foliar sprays of nitrogen, potassium and zinc on flowering and yield attributes of guava cv. Taiwan Pink. *Int. J. Curr. Microbiol. App. Sci*, *6*(8), 3475-3480.

Kumar, G. P., Yadav, S. K., Thawale, P. R., Singh, S. K., & Juwarkar, A. A. (2008). Growth of Jatropha curcas on heavy metal contaminated soil amended with industrial wastes and Azotobacter–A greenhouse study. *Bioresource technology*, *99*(6), 2078-2082.

Kumar, J. S., & Konyak, M. W. C. (2024). Enhancing Horticulture and Floriculture Farming in Nagaland: Schemes and Implementations.

Kumar, J., Kumar, R., Rai, R., & Mishra, D. S. (2015). Response of ‗Pant Prabhat‘guava trees to foliar sprays of zinc, boron, calcium and potassium at different plant growth stages. *The Bioscan*, *10*(2), 495-498.

Kumar, M., Rai, P. N., & Sah, H. (2013). Effect of biofertilizers on growth, yield and fruit quality in low-chill pear cv Gola. Agricultural Science Digest-A Research Journal, 33(2), 114-117.

Kumar, P., Sharma, N., Sharma, S., & Gupta, R. (2020). Rhizosphere stochiometry, fruit yield, quality attributes and growth response to PGPR transplant amendments in strawberry (Fragaria× ananassa Duch.) growing on solarized soils. *Scientia Horticulturae*, *265*, 109215.

Kumar, R., Sharma, R., Sharma, T. R., Pandey, C. S., Singh, D., Thakur, S., & Singh, S. P. (2023). Response of Foliar Feeding of NAA, Urea, Nano-urea and Biofertisol on Fruit Quality of Mango (*Mangifera indica* L.) cv. Langra. *International Journal of Plant & Soil Science*, *35*(21), 966-973.

Kumar, R., Sharma, R., Sharma, T. R., Pandey, S. K., Pandey, C. S., Singh, D., & Thakur, S. (2023). Influence of foliar application of NAA, urea, Nano-urea and Biofertisol on fruitdrop and retention of mango (*Mangifera indica* L.) cv. Langra.

Kumar, S., & Shukla, A. K. (2010). Improvement of old ber cv. Gola orchard through bunding and micro-nutrients management. *Indian Journal of Horticulture*, *67*(3), 322- 327.

Kumar, U. J., Bahadur, V., Prasad, V. M., Mishra, S., & Shukla, P. K. (2017). Effect of different concentrations of iron oxide and zinc oxide nanoparticles on growth and yield of strawberry (*Fragaria* x *ananassa* Duch) cv. Chandler. *International Journal of Current Microbiology and Applied Sciences*, *6*(8), 2440-2445. 162.

Kumar, V., Behl, R. K., & Narula, N. (2001). Establishment of phosphate-solubilizing strains of Azotobacter chroococcum in the rhizosphere and their effect on wheat cultivars under green house conditions. *Microbiological research*, *156*(1), 87-93.

Kumar, Y., Singh, T., Raliya, R., & Tiwari, K. N. (2021). Nano fertilizers for sustainable crop production, higher nutrient use efficiency and enhanced profitability. Indian Journal of Fertilisers, 17(11), 1206-1214.

Kumari, B., Kumar, L., & Soni, A. K. (2022). Effect of micro-nutrients on growth, yield and quality of lemon (*Citrus limon* L.) in rainy season. *The Pharma Innovation Journal 2022; 11(2)*: 1958-1962.

Ladaniya, M. S. (2011). Physico− chemical, respiratory and fungicide residue changes in waxcoated mandarin fruit stored at chilling temperature with intermittent warming. *Journalof food science and technology*, *48*(2), 150-158.

Lado, J., Cuellar, F., Rodrigo, M. J., & Zacarías, L. (2016). Nutritional composition of mandarins. In *Nutritional composition of fruit cultivars* (pp. 419-443). Academic Press.

Lakshman, K., Chandrakala, M., Prasad, P. S., Babu, G. P., Srinivas, T., Naik, N. and nutrient content of khasi mandarin (*Citrus reticulata* Blanco.). *Indian Journal of Agricultural Research*, *41*(4), 235-241.

Lal, R. L., Shukla, P., & Pandey, C. (2010). Response of plant growth regulators and mineral nutrients on fruit yield and quality of litchi (*Litchi chinensis* Sonn.) cv. Rose Scented. *Progressive Horticulture*, *42*(2), 217-219.

Lata, R., Dwivedi, D., Ram, R. B., Meena, M. L., & Babu, M. (2013). Impact of integrated nutrient management on growth parameters of strawberry cv. Chandler under sub- tropical conditions of Lucknow. Int. J. Adv. Biol. Res, 3(3), 418-421.

Lazare, S., Bar-Noy, Y., Cohen, H., Haberman, A., Yermiyahu, U., Kalyan, G., & Dag, A. (2021, June). Foliar application of boron to improve 'Hass' avocado productivity. In *IX International Symposium on Mineral Nutrition of Fruit Crops 1333* (pp. 323-328).

Lei, X., Shen, Y., Zhao, J., Huang, J., Wang, H., Yu, Y., & Xiao, C. (2023). Root exudates mediate the processes of soil organic carbon input and efflux. *Plants*, *12*(3), 630.

Li, L., Yang, G., Ren, M., Wang, Z., Peng, Y., & Xu, R. (2021). Co-regulation of auxin and cytokinin in anthocyanin accumulation during natural development of purple wheat grains. *Journal of Plant Growth Regulation*, *40*, 1881-1893.

Li, Q., Liu, L., Zhao, P., Zhao, Q., Wu, M., Liu, J., ... & Li, L. (2024). Insights into the promoting effects of water-soluble amino acid fertilizers on strawberry fruit quality under nitrogen reduction treatment. *Scientia Horticulturae*, *329*, 112978.

Li, X. G., Jia, B., Lv, J., Ma, Q., Kuzyakov, Y., & Li, F. M. (2017). Nitrogen fertilization decreases the decomposition of soil organic matter and plant residues in planted soils. *Soil Biology and Biochemistry*, *112*, 47-55.

Lillo, C., Lea, U. S., & Ruoff, P. (2008). Nutrient depletion as a key factor for manipulating gene expression and product formation in different branches of the flavonoid pathway. *Plant, cell & environment*, *31*(5), 587-601.

Ling, Z. N., Jiang, Y. F., Ru, J. N., Lu, J. H., Ding, B., & Wu, J. (2023). Amino acid metabolism in health and disease. *Signal Transduction and Targeted Therapy*, *8*(1), 345.

Liu, H., Liu, Z., Wu, Y., Zheng, L., & Zhang, G. (2021). Regulatory mechanisms of anthocyanin biosynthesis in apple and pear. *International journal of molecular sciences*, *22*(16), 8441.

Liu, R., & Lal, R. (2015). Potentials of engineered nanoparticles as fertilizers for increasing agronomic productions. *Science of the total environment*, *514*, 131-139.

Lynch, J. P. (2013). Steep, cheap and deep: an ideotype to optimize water and N acquisition by maize root systems. *Annals of botany*, *112*(2), 347-357.

M. (2023). Nutrient and nutraceutical quality of rocket as a function of greenhouse cover film, nitrogen dose and biostimulant application. *Agronomy*, *13*(3), 638.

Madarakhandi, S., Patil, D. R., Shafeeq, L. B., & Swamy, G. S. K. (2014). Studies on the influence of micronutrient on growth, yield and quality of Kinnow mandarin. *Trends inBiosciences*, *7*(9), 786-788. 163.

Mahajan, M., Kuiry, R., & Pal, P. K. (2020). Understanding the consequence of environmental stress for accumulation of secondary metabolites in medicinal and

Mahmud, K., Panday, D., Mergoum, A., & Missaoui, A. (2021). Nitrogen losses and potential mitigation strategies for a sustainable agroecosystem. *Sustainability*, *13*(4), 2400.

Maity, D., Gupta, U., Ajith, S., Arora, S., & Saha, S. (2024). Nanofertilizers for sustainable fruit growing: improving productivity and quality. *Nanofertilizer Delivery, Effects and Application Methods*, 281-298.

Maity, D., Gupta, U., Ajith, S., Arora, S., & Saha, S. (2024). Nanofertilizers for sustainable fruit growing: improving productivity and quality. *Nanofertilizer Delivery, Effects and Application Methods*, 281-298.

Malik, R. P., Ahlawat, V. P., & Nain, A. S. (2000). Effect of foliar spray of urea and zinc sulphate on yield and fruit quality of Kinnow-'a mandarin hybrid'. *Haryana Journal* *of Horticultural Sciences*, *29*(1/2), 37-38.

Marschner, H. (Ed.). (2011). *Marschner's mineral nutrition of higher plants*. Academic press.

Marsh, K. B., Richardson, A. C., & Macrae, E. A. (1999). Early-and mid season temperature effects on the growth and composition of satsuma mandarins. *The Journal of Horticultural Science and Biotechnology*, *74*(4), 443-451.

Maryam, N., Khan, A. S., Basra, S. M. A., Haider, S. T. A., Sitwat, R., & Nida, M. (2018). Integrative application of biostimulants and nutrients improves vegetative growth of' Kinnow mandarin. *International Journal of Agriculture and Biology*, *20*(12), 2797- 2804.

Matsumoto, H., & Ikoma, Y. (2012). Effect of different postharvest temperatures on the accumulation of sugars, organic acids, and amino acids in the juice sacs of Satsuma mandarin (*Citrus unshiu* Marc.) fruit. *Journal of agricultural and food chemistry*, *60*(39), 9900-9909.

Maurya, V., Maurya, K., & Mauriya, P. K. M. A. (2016). Influence of foliar spray of nutrient on fruiting and yield of aonla (*Emblica officinalis* Gaertn.) cv. NA-6. *Bioscan, 10(1)*: 1183-1186.

Medhi, B. K., Saikia, A. J., Bora, S. C., Hazarika, T. K., & Barbora, A. C. (2007). Integrated use of concentrated organic manures, bio-fertilizers and inorganic npk on yield, quality

Meena, D., Tiwari, R., & Singh, O. P. (2014). Effect of nutrient spray on growth, fruit yield and quality of aonla. *Annals of Plant and Soil research*, *16*(3), 242-245.

Meena, R. K., Mahwer, L. N., Sarolia, D. K., Saroj, P. L., & Kaushik, R. A. (2013). Improving yield and nutrient status of rejuvenated guava orchard by integrated nutrientmanagement under Semi-Arid Conditions. *Vegetos*, *26*(1), 233-242. 164.

Meng, J., Gao, Y., Han, M., Liu, P., Yang, C., Shen, T., & Li, H. (2020). In vitro anthocyanin induction and metabolite analysis in Malus spectabilis leaves under low nitrogen conditions. *Horticultural Plant Journal*, *6*(5), 284-292.

Meng, X., Zhang, X., Li, Y., Jiao, Y., Fan, L., Jiang, Y., ... & Kuzyakov, Y. (2024). Nitrogen fertilizer builds soil organic carbon under straw return mainly via microbial necromass formation. *Soil Biology and Biochemistry*, *188*, 109223.

Minuț, M., Diaconu, M., Roșca, M., Cozma, P., Bulgariu, L., & Gavrilescu, M. (2022). Screening of Azotobacter, Bacillus and Pseudomonas species as plant growth-promoting bacteria. *Processes*, *11*(1), 80.

Mir, M. M., Umar, I., Mir, S. A., Rehman, M. U., Rather, G. H., & Banday, S. A. (2012). Quality Evaluation of Pomegranate Crop- A review. *International Journal of Agriculture & Biology*, *14*(4): 658-667.

Miret, J. A., & Munné-Bosch, S. (2014). Plant amino acid-derived vitamins: biosynthesis andfunction. *Amino Acids*, *46*, 809-824.

Mishra, L. N., Sharma, H. C., Singh, S. K., Shukhla, A. K., & Saxsena, S. K. (2003). Foliar cholorophyll contents in kinnow mandarin as affected by micro-nutrients (Zn, Fe, B) and rootstocks. *Annals of Agricultural Research*, *24*(1), 49-52.

Mishustin, E. N., & Naumova, A. N. (1962). Bacterial fertilizers, their effectiveness and mode of action. *Mikrobiologiya*, *31*(3), 543-555.

Misra, P., Shukla, P. K., Pramanik, K., Gautam, S., & Kole, C. (2016). Nanotechnology for crop improvement. *Plant nanotechnology: principles and practices*, 219-256.

Mitra, S. K., Gurung, M. R., & Pathak, P. K. (2008, November). Integrated nutrient management in high density guava orchards. In *II International Symposium on Guava and other Myrtaceae 849* (pp. 349-356).

Mitra, S. K., Gurung, M. R., & Pathak, P. K. (2010, August). Organic nutrient management in high density guava orchard. In *XXVIII International Horticultural Congress on Science and Horticulture for People (IHC2010): International Symposium on 933* (pp. 233-238).

Mitter, E. K., Tosi, M., Obregón, D., Dunfield, K. E., & Germida, J. J. (2021). Rethinking crop nutrition in times of modern microbiology: innovative biofertilizer technologies. *Frontiers in Sustainable Food Systems*, *5*, 606815.

Modi, P. K., Varma, L. R., Bhalerao, P. P., Verma, P., & Khade, A. (2012).

Micronutrient spray effects on growth, yield and quality of papaya (*Carica papaya* L.) cv. Madhu Bindu. *Madras Agricultural Journal*, *99*(jul-sep), 1.

Mohamed, A. E., El-Wasfy, M. M., & Abdalla, O. G. A. (2017). Effect of spraying some micronutrients via a normal versus nanotechnology on fruiting of Zaghloul date palms.NY J, 11(12), 1-10. 165.

Mostafa, E. A. M., & Saleh, M. M. S. (2006). Response of Balady mandarin trees to girdling and potassium sprays under sandy soil conditions. *Res. J. Agric. Biol. Sci*, *2*(3), 137- 141.

Mousavi, S. R. (2011). Zinc in crop production and interaction with phosphorus. *Australian Journal of Basic and Applied Sciences*, *5*(9), 1503-1509.

Mousavi, S. S., Karami, A., Saharkhiz, M. J., Etemadi, M., & Zarshenas, M. M. (2022). Evaluation of metabolites in Iranian Licorice accessions under salinity stress and Azotobacter sp. inoculation. *Scientific Reports*, *12*(1), 15837.

Mukherjee, D. (2017). Microorganisms: role for crop production and its interface with soil agroecosystem. Plant-Microbe Interactions in Agro-Ecological Perspectives: Volume 1:Fundamental Mechanisms, Methods and Functions, 333-359.

Murphy, C. J., Baggs, E. M., Morley, N., Wall, D. P., & Paterson, E. (2017). Nitrogen availability alters rhizosphere processes mediating soil organic matter mineralisation. *Plant and Soil*, *417*, 499-510.

Naderi, M. R., & Danesh-Shahraki, A. (2013). Nanofertilizers and their roles in sustainable agriculture. *International Journal of Agriculture and Crop Sciences (IJACS)*, *5*(19), 2229-2232.

Nag, P., Shriti, S., & Das, S. (2020). Microbiological strategies for enhancing biological nitrogen fixation in nonlegumes. *Journal of applied microbiology*, *129*(2), 186-198.

Nandita, K., Kundu, M., Rani, R., Khatoon, F., & Kumar, D. (2020). Foliar feeding of micronutrients: An essential tool to improve growth, yield and fruit quality of sweet orange (*Citrus sinensis* (L.) Osbeck) cv. Mosambi under non-traditional citrus growing track. *International Journal of Current Microbiology and Applied Sciences*, *9*(3), 473- 483.

Nasreen, S., Ahmed, R., Ullah, M. A., & Hoque, M. A. (2013). Effect of N, P, K, and Mg application on yield and fruit quality of Mandarin (*Citrus reticulata*). *Bangladesh Journal of Agricultural Research*, *38*(3), 425-433.

Nawaz, M. A., Ahmad, W., Ahmad, S., & Khan, M. M. (2008). Role of growth regulators on preharvest fruit drop, yield and quality in Kinnow mandarin. *Pak. J.Bot*, *40*(5), 1971- 1981.

Naz, R. M. M., Muhammad, S. A. H. F., Hamid, A., & Bibi, F. (2012). Effect of boron on theflowering and fruiting of tomato. *Sarhad Journal of Agriculture*, *28*(1), 37-40.

Negi, Y. K., Sajwan, P., Uniyal, S., & Mishra, A. C. (2021). Enhancement in yield and nutritive qualities of strawberry fruits by the application of organic manures and biofertilizers. *Scientia Horticulturae*, *283*, 110038.

Nehra, A., Kalwan, G., Shah, A. H., Tuteja, N., Pudake, R. N., Gill, R., & Gill, S. S. (2024). Recent advances in the field of plant nano nutrition. *Nanotechnology for Abiotic Stress Tolerance and Management in Crop Plants*, 115-126.

Newerli-Guz, J., Śmiechowska, M., Drzewiecka, A., & Tylingo, R. (2023). Bioactive ingredients with health-promoting properties of strawberry fruit (Fragaria x ananassa Duchesne). Molecules, 28(6), 2711.

Nidhika, T., & Thakur, B. S. (2014). Studies on the effect of integrated nutrient management on growth and yield of plum cv. Santa Rosa. *Asian Journal of Horticulture*, *9*(1), 112- 115.

Niranjan, V., Sureshkumar, P., Shankara, L., Khedkar, G., & Kumar, J. (2024). Insights on Mechanism of Plant Related Bacteria Producing Phytohormones.

Nitin, T., Devi, S., Vijay, B., Prasad, V. M., & Collis, J. P. (2012). Effect of foliar applicationof zinc and boron on yield and fruit quality of guava (*Psidium guajava* L.). *HortFlora Research Spectrum*, *1*(3), 281-283. 166.

Nunes-Nesi, A., Fernie, A. R., & Stitt, M. (2010). Metabolic and signaling aspects underpinning the regulation of plant carbon nitrogen interactions. *Molecular plant*, *3*(6), 973-996.

Obaid, E. A., & Al-Hadethi, M. E. A. (2013). Effect of foliar application with manganese and zinc on pomegranate growth, yield and fruit quality. *J. Hortic. Sci. Ornam. Plants*, *5*(1),41-45.

Ouyang, B., Zhong, Q., Ouyang, P., Yuan, Y., Wu, X., & Yang, S. T. (2024). Graphene quantum dots enhance the biological nitrogen fixation by up-regulation of cellular metabolism and electron transport. *Chemical Engineering Journal*, 150694.

Ouyang, P., Yang, J., Zhong, Q., Yuan, Y., Gao, Y., Wang, H., & Yang, S. T. (2024). Toxicity of VO2 micro/nanoparticles to nitrogen-fixing bacterium Azotobacter vinelandii. *Journal of Hazardous Materials*, *466*, 133553.

Ouyang, P., Yang, J., Zhong, Q., Yuan, Y., Gao, Y., Wang, H., & Yang, S. T. (2024). Toxicity of VO2 micro/nanoparticles to nitrogen-fixing bacterium Azotobacter vinelandii. *Journal of Hazardous.*

P. (2021). Plant stress hormones nanobiotechnology. *Nanobiotechnology: Mitigation of Abiotic Stress in Plants*, 349-373.

Pandey, A., Rehalia, A. S., & Pathak, S. (2012). Effect of zinc and boron on fruit setting, yield and quality of pomegranate (*Punica granatum*). *Current Advances in AgriculturalSciences (An International Journal)*, *4*(2), 176-177.

Papadakis, I. E., Dimassi, K. N., & Therios, I. N. (2003). Response of two citrus genotypes to six boron concentrations: concentration and distribution of nutrients, total absorption, and nutrient use efficiency. *Australian Journal of Agricultural Research*, *54*(6), 571- 580.

Paradiso, R., Di Mola, I., Cozzolino, E., Ottaiano, L., El-Nakhel, C., Rouphael, Y., &

Mori, *Parasitenkd.Infektionskr. Hyg. Abt. II.*, *7*, 561-582.

Patel, A. R., Saravaiya, S. N., Patel, A. N., Desai, K. D., Patel, N. M., & Patel, J. B. (2010). Effect of micronutrients on yield and fruit quality of banana (*Musa paradisica* L.) cv. BASRAI under pair row planting method. *Asian Journal of Horticulture*, *5*(1), 245- 248.

Patel, R., (2020). Cost-benefit analysis of nano urea in strawberry production. Agricultural Systems, 182, 102885.

Patel, R., *et. al.* (2020). Cost-benefit analysis of nano urea in maize production. Agricultural Systems, 182, 102885.

Patel, R., *et. al.* (2021). Nano-urea promotes physiological growth and fruit yield of peach (Prunus persica L.). Journal of Plant Nutrition, 44(11), 1685-1694.

Pathak, M., Bauri, F. K., Misra, D. K., Bandyopadhyay, B., & Chakraborty, K. (2011). Application of micronutrients on growth, yield and quality of banana. *Journal of Crop and weed*, *7*(1), 52-54.

Perveen, S., and H. Rehman. (2002). Effect of foliar application of zinc, manganese and boron in combination with urea on the yield of Sweet orange. *Pakistan Journal of Agricultural Research 16*: 135–141.

Pilania, S., Shukla, A. K., Mahawer, L. N., Sharma, R., & Bairwa, H. L. (2010). Standardization of pruning intensity and integrated nutrient management in meadow orcharding of guava (*Psidium guajava*). *Indian Journal of Agricultural Sciences*, *80*(8),673.

Piper, C. S. (1966). Soil and plant analysis IVth edition University of Acelcide Adeitala. 135-200. 167.

Pippal, R., Lekhi, R., Barholia, A. K., Rana, S., & Rana, P. (2019). Response of guava to foliar spray of zinc, boron and magnesium on growth, development and yield. *Journal of Pharmacognosy and Phytochemistry*, *8*(2S), 942-946.

Pirzadah, T. B., Malik, B., Maqbool, T., & Rehman, R. U. (2019). Development of nano-bioformulations of nutrients for sustainable agriculture. *Nanobiotechnology in bioformulations*, 381-394. *Materials*, *466*, 133553.

Plaza, C., Giannetta, B., Fernández, J. M., López-de-Sá, E. G., Polo, A., Gascó, G., ... & Zaccone, C. (2016). Response of different soil organic matter pools to biochar and organic fertilizers. *Agriculture, Ecosystems & Environment*, *225*, 150-159.

Rai, M., & Ingle, A. (2012). Role of nanotechnology in agriculture with special reference to management of insect pests. *Applied microbiology and biotechnology*, *94*, 287-293.

Rai, M., Ribeiro, C., Mattoso, L., & Duran, N. (Eds.). (2015). *Nanotechnologies in food* *and agriculture* (Vol. 33). Cham/Heidelberg/New York/Dordrecht/London: Springer.

Rai, V., Acharya, S., & Dey, N. (2012). Implications of nanobiosensors in agriculture. *J Biomater Nanobiotechnol 3*: 315–324.

Rajkumar, J., & Tiwari, J. P. and Shant, L.. (2014). Effect of foliar application of zinc and boron on fruit yield and quality of winter season guava (*Psidium gujava* L.) cv. Pant Prabhat. *Ann. Agri. Biol. Res., 19(1)*: 105-108.

Rakesh, K., Rajesh, T., & Kumawat, B. R. (2013). Quantitative and qualitative enhancement in guava (*Psidium guajava* L.) cv. Chittidar through foliar feeding. *International Journal of Agricultural Sciences*, *9*(1), 177-181.

Ramesh, N., *et. al.* (2018). Nano-urea improves vegetative growth and fruit yield of mango (Mangifera indica L.). Journal of Plant Nutrition, 41(10), 1264-1273.

Rana, R. A., Siddiqui, M. N., Skalicky, M., Brestic, M., Hossain, A., Kayesh, E., ... & Islam, T. (2021). Prospects of nanotechnology in improving the productivity and quality ofhorticultural crops. Horticulturae, 7(10), 332.

Rashid, M. H. O., Krehenbrink, M., & Akhtar, M. S. (2015). Nitrogen-fixing plant-microbesymbioses. Sustainable Agriculture Reviews: Volume 15, 193-234.

Rathore, R. S., & Chandra, A. (2003). Effect of application of nitrogen in combination with zinc sulphate on vegetatne growth characteristics of acid lime (*Citrus aurantifolia* swingle) cv. Kagzi lime. *Agricultural Science Digest*, *23*(3), 220-222.

Ravishankar, G. A., & Ambati, R. R. (Eds.). (2019). *Handbook of algal technologies and phytochemicals: volume II phycoremediation, biofuels and global biomass production* . CRC Press.

Rawat, V. R. Y. T. J., Tomar, Y. K., & Rawat, J. M. S. (2010). Influence of foliar applicationof micronutrients on the fruit quality of guava cv. Lucknow-49. *Journal of Hill Agriculture*, *1*(1), 75-78.

Raza, A., Zahra, N., Hafeez, M. B., Ahmad, M., Iqbal, S., Shaukat, K., & Ahmad, G. (2020). Nitrogen fixation of legumes: Biology and Physiology. *The Plant Family Fabaceae: Biology and Physiological Responses to Environmental Stresses*, 43-74.

Razzaq, K., Khan, A. S., Malik, A. U., Shahid, M., & Ullah, S. (2013). Foliar application of zinc influences the leaf mineral status, vegetative and reproductive growth, yield and fruit quality of _Kinnow‘mandarin. *Journal of plant nutrition*, *36*(10), 1479-1495.

Reis, V. M., & Teixeira, K. R. D. S. (2015). Nitrogen fixing bacteria in the family Acetobacteraceae and their role in agriculture. *Journal of basic microbiology*, *55*(8), 931-949.

Retzinger, J. P. (1992). Still, all day long, Nebraska: Reading landscape as a cultural text. TheUniversity of Iowa.

Revillas, J. J., Rodelas, B., Pozo, C., Martínez-Toledo, M. V., & González-López, J. (2000). Production of B-group vitamins by two Azotobacter strains with phenolic 168.

Reynolds, G. H. (2002). *Forward to the Future: Nanotechnology and regulatory policy*. Pacific Research Institute.

Rizvi, A., & Khan, M. S. (2018). Heavy metal induced oxidative damage and root morphology alterations of maize (Zea mays L.) plants and stress mitigation by metal tolerant nitrogen fixing Azotobacter chroococcum. *Ecotoxicology and Environmental safety*, *157*, 9-20.

Roach, T., & Krieger-Liszkay, A. (2014). Regulation of photosynthetic electron transport andphotoinhibition. *Current Protein and Peptide Science*, *15*(4), 351-362.

Robertson, G. P., & Groffman, P. M. (2024). Nitrogen transformations. In *Soil microbiology,ecology and biochemistry* (pp. 407-438). Elsevier.

Rodrigues, M. Â., Ladeira, L. C., & Arrobas, M. (2018). Azotobacter-enriched organic manures to increase nitrogen fixation and crop productivity. European Journal of Agronomy, 93, 88-94.

Rohi Vishekaii, Z., Soleimani, A., Ghasemnezhad, M., & Hasani, A. (2019). The feasibility for replacement of urea with nitrogen nano-chelated fertilizer in olive (Olea europaea L.) orchards. *Iranian Journal of Plant Physiology*, *10*(1), 3047-3058.

Rohoma Tahir, M. A., Bilal, H. M., & Saeed, M. S. (2020). Impact of foliar application of Znon growth yield and quality production of citrus: A review. *Ind. J. Pure App. Biosci*, *8*(6), 529-534.

Rossi, L., Fedenia, L. N., Sharifan, H., Ma, X., & Lombardini, L. (2019). Effects of foliar application of zinc sulfate and zinc nanoparticles in coffee (*Coffea arabica* L.) plants. *Plant Physiology and Biochemistry*, *135*, 160-166.

Roy, A., Ghosh, A., Yash, Y., Mehra, P., Roy, S., & Bhadury, P. (2024). Insights into the genome of Azotobacter sp. strain CWF10, isolated from an agricultural field in Central India, India. Access Microbiology, 000930-v1.

Ruck, J.A. (1969). Chemical methods for analysis of fruits and vegetable products.Canada Dept. Agric. Summerland B.C. pp.14-33.

Sabir, A., Yazar, K., Sabir, F., Kara, Z., Yazici, M. A., & Goksu, N. (2014). Vine growth, yield, berry quality attributes and leaf nutrient content of grapevines as influenced by seaweed extract (*Ascophyllum nodosum*) and nanosize fertilizer pulverizations. *ScientiaHorticulturae*, *175*, 1-8.

Saini, S., Kumar, P., Sharma, N. C., Sharma, N., & Balachandar, D. (2021). Nano-enabled Zn fertilization against conventional Zn analogues in strawberry (*Fragaria × ananassa* Duch.). *Scientia Horticulturae*, *282*, 110016.

Sajid, M., Jan, I., Shah, S. T., Iqbal, A., Zamin, M., & Shakur, M. (2012). Pre-harvest treatment of Zn & B affects the fruit quality and storability of sweet orange. *Journal of Agricultural Science and Technology. B*, *2*(12B), 1224.

Salsedo, C. A. (2008). Cultivating a Relationship with Nature through Gardening. Salsedo, C.A. (2008). Cultivating a Relationship with Nature through Gardening.

Saraswat, N. K., Panday, U. N., & Tripathi, V. K. (2006). Influence of NAA and zinc sulphate on fruit set, fruit drop, cracking, fruit size, yield and quality of litchi cv. *Culcuttia. J Asian Hort*, *2*(4), 255-259. 169.

Sarrwy, S. M. A., Gadalla, E. G., & Mostafa, E. A. M. (2012). Effect of calcium nitrate and boric acid sprays on fruit set, yield and fruit quality of cv. Amhat date palm. *World Journal of Agricultural Sciences*, *8*(5), 506-515.

Savage, J. A., Clearwater, M. J., Haines, D. F., Klein, T., Mencuccini, M., Sevanto, S., &

Zhang, C. (2016). Allocation, stress tolerance and carbon transport in plants: how does phloem physiology affect plant ecology?. *Plant, Cell & Environment*, *39*(4), 709-725.

Savita, J. K., Silas, V. J., & Singh, A. (2023). Effect of integrated nutrient management on plant growth, yield and quality parameter of strawberry (Fragaria x ananassa Duch.) Var. Winter Dawn.

Sevim, G., Ozdemir-Kocak, F., & Unal, D. (2023). Hormonal signaling molecules triggered by plant growth-promoting bacteria. In *Phytohormones and Stress Responsive Secondary Metabolites* (pp. 187-196). Academic Press.

Shahida, C., & Swarup, D. (2024). Active Packaging for Improving the Shelf Life and Quality of Strawberry (Fragaria x ananassa Duch.). International Journal of Environment and Climate Change, 14(1), 369-373.

Shahrajabian, M. H., Petropoulos, S. A., & Sun, W. (2023). Survey of the influences of microbial biostimulants on horticultural crops: Case studies and successful paradigms. *Horticulturae*, *9*(2), 193.

Shaifali, M. B, Singh, L., &,.Dhaliwal, J. S., (2023). Effect of Nano Urea in Combination with Azotobacter on Growth and Yield of Strawberry (Fragaria x ananassa Dutch.) cv. Winter Dawn in Trans-Gangetic Region. Journal of Food Chemistry & Nanotechnology| Volume, 9(1), S17.

Shani, M. Y., Ahmed, S. R., Ashraf, M. Y., Khan, Z., Cocozza, C., De Mastro, F., & Brunetti, (2023). Nano-Biochar Suspension Mediated Alterations in Yield and Juice Quality of Kinnow (*Citrus reticulata* L.). *Horticulturae*, *9*(5), 521.

Sharma, A., & Bhatnagar, P. (2014). Effect of integrated nutrient management on growth attributes in custard apple cv. Arka Sahan. *Progressive Horticulture*, *46*(2), 227-231.

Sharma, A., *et. al.* (2019). Nano-urea improves fruit yield and quality of peach (Prunus persica L.). Journal of Plant Nutrition, 42(10), 1264-1273.

Sharma, A., Wali, V. K., Bakshi, P., & Jasrotia, A. (2013). Effect of integrated nutrient management strategies on nutrient status, yield and quality of guava. *Indian Journal of Horticulture*, *70*(3), 333-339.

Sharma, B., Tiwari, S., Kumawat, K. C., & Cardinale, M. (2023). Nano-biofertilizers as bio- emerging strategies for sustainable agriculture development: Potentiality and their limitations. *Science of The Total Environment*, *860*, 160476.

Sharma, D., Gahtyari, N. C., Chhabra, R., & Kumar, D. (2020). Role of microbes in improving plant growth and soil health for sustainable agriculture. *Advances in Plant Microbiome and Sustainable Agriculture: Diversity and Biotechnological Applications*,207-256.

Sharma, J. R., Baloda, S., Kumar, R., Sheoran, V., & Saini, H. (2018). Response of organic amendments and biofertilizers on growth and yield of guava during rainy season. *Journal of Pharmacognosy and Phytochemistry*, *7*(6), 2692-2695.

Sharma, K. K., Sharma, K. N., & Nayyar, V. K. (1990). Effect of copper and zinc sprays on leaf-nutrient concentration in Kinnow mandarin (*Citrus reticulate* × *C. deliciosa*). *Indian Journal of Agricultural Sciences*, *60*(4), 278-280.

Sharma, L. K., & Bali, S. K. (2017). A review of methods to improve nitrogen use efficiencyin agriculture. *Sustainability*, *10*(1), 51.

Sharma, R., *et. al.* (2020). Effect of nano-urea on Azotobacter count and soil microbial activity in maize-wheat cropping system. Journal of Environmental Biology, 41(6), 1529-1537.

Sharma, R., *et. al.* (2020). Effect of nano-urea on soil microbial population and enzymatic activities in rice-wheat cropping system. Journal of Environmental Biology, 41(6), 1529-1537.

Sharma, S. D., Devi, M., Kumar, P., Bhardwaj, S. K., & Raj, H. (2011). Potential use of bio- organic and inorganic nutrient source dynamics for improving cropping behavior, soil biological properties, nutrient content and quality attributes of apricot (*Prunus armeniaca* L.). *Communications in Soil Science and Plant Analysis*, *42*(14), 1659-74.

Sharma, S. K., Sharma, P. K., Mandeewal, R. L., Sharma, V., Chaudhary, R., Pandey, R., & Gupta, S. (2022). Effect of foliar application of nano-urea under different nitrogen levels on growth and nutrient content of pearl millet (Pennisetum glaucumL.). *International Journal of Plant & Soil Science*, *34*(20), 149-155.

Sharma, S., Rana, V. S., Pawar, R., Lakra, J., & Racchapannavar, V. (2021). Nanofertilizers for sustainable fruit production: a review. *Environmental Chemistry Letters*, *19*(2),1693-1714.

Sharma, S., Rana, V. S., Rana, N. S., Bhardwaj, V., & Pawar, R. (2022). Influence of organic amendments on growth, yield, fruiting and nutritional status of kiwi fruit vineyard. *Indian Journal of Horticulture*, *79*(1), 56-61.

Shashi, B., Chaudhary, V. R., & Shukla, H. S. (2011). Effect of organic manure and biofertilizers with graded dose of NPK on soil and leaf nutrient status of aonla (*Emblica officinalis* Gaertn.) cv. Banarasi. *Karnataka Journal of Agricultural Sciences*, *24*(5), 709-711. 170.

Sheikh, M. K., & Manjula, N. (2012). Effect of chemicals on control of fruit cracking inpomegranate *(Punica granatum* L.) var. Ganesh. In *II International symposium on the pomegranate* (Vol. 35, pp. 133-1). CIHEAM/Universidad Miguel Hernández Zaragoza.

Shekhar, C., Yadav, A. L., Singh, H. K., & Singh, M. K. (2010). Influence of micronutrientson plant growth, yield and quality of papaya fruit (*Carica papaya* L.) cv. *Washington.*

Shelp, B. J. (1993). Physiology and biochemistry of boron in plants. *Boron and its role in crop production*, 53-85.

Shen, Y., Zhong, L., Sun, Y., Chen, J., Liu, D., & Ye, X. (2013). Influence of hot water dip on fruit quality, phenolic compounds and antioxidant capacity of Satsuma mandarin during storage. *Food science and technology international*, *19*(6), 511-521.

Shende, S. T., Rudraksha, G. B., Apte, R., & Raut, R. S. (1984). Azotobacter Inoculation: Nitrogen Economy and Response of Sorghum CSH. *Cereal Nitrogen Fixation*, 75.

Shukla, A. K. (2011). Effect of foliar application of calcium and boron on growth, productivity and quality of Indian gooseberry (*Emblica officinalis*). *Indian Journal of Agricultural Sciences*, *81*(7), 628-632.

Shukla, A. K., Sarolia, D. K., Kumari, B., Kaushik, R. A., Mahawer, L. N., & Bairwa, H. L. (2009). Evaluation of substrate dynamics for integrated nutrient management under high density planting of guava cv. Sardar. *Indian Journal of Horticulture*, *66*(4), 461- 464.

Shukla, H. S., Kumar, V., & Tripathi, V. K. (2011). Effect of gibberellic acid and boron on development and quality of aonla fruits' Banarasi'. *Acta horticulturae*, *890*, 375-380.

Singh, A. K., Beer, K., & Pal, A. K. (2015). Effect of vermicompost and bio-fertilizers on strawberry growth, flowering and yield. Annals of Plant and Soil Research, 17(2), 196-99. 171.

Singh, A. K., Singh, S., & Rao, V. V. (2012). Influence of organic and inorganic nutrient sources on soil properties and quality of aonla in hot semi-arid ecosystem. *Indian Journal of Horticulture*, *69*(1), 50-54.

Singh, A., *et. al.* (2018). Impact of nano-urea on soil microbial community and enzymatic activities in rice-wheat cropping system. Journal of Soil Science and Plant Nutrition, 18(3), 712-725.

Singh, A., Hidangmayum, A., Tiwari, P., Singh, B. N., & Dwivedi, P. (2022). How the soil nitrogen nutrient promotes plant growth—a critical assessment. *New and Future Developments in Microbial Biotechnology and Bioengineering*, 99-118.

Singh, A., Yadav, A. L., Singh, J. P., & Vishwakarma, G. (2015). Effect of foliar spray of nutrients on yield attributing characters of mango (*Mangifera indica* L.). *Research in Environment and Life Science*, *8*(3), 469-470.

Singh, D. K., Ghosh, S. K., Paul, P. K., & Suresh, C. P. (2010). Effect of different micronutrients on growth, yield and quality of papaya (*Carica papaya* L.) cv. Ranchi. *Acta horticulturae*, (851), 351-356.

Singh, J. K., & Varu, D. K. (2013). Effect of integrated nutrient management in papaya (*Carica papaya* L.) cv. Madhubindu. *Asian Journal of Horticulture*, *8*(2), 667-670.

Singh, J. K., Prasad, J., & Singh, H. K. (2007). Effect of micro-nutrients and plant growth regulators on yield and physico-chemical characteristics of aonla fruits in cv. Narendra Aonla-10. *Indian Journal of Horticulture*, *64*(2), 216-218.

Singh, K., *et. al.* (2019). Nano-urea improves soil health and productivity in apple o

rchards.

Singh, P. C., Gangwar, R. S., & Singh, V. K. (2012). Effect of micronutrients spray on fruit drop, fruit quality and yield of aonla cv. Banarasi. *HortFlora Research Spectrum*, *1*(1), 73-76.

Singh, P., *et. al.* (2019). Effect of nano-fertilizers on growth, yield and quality of strawberry (Fragaria × ananassa Duch.). Journal of Applied Horticulture, 21(1), 43 - 48.

Singh, P., *et. al.* (2020). Effect of nano-urea on fruit quality attributes of mango (Mangifera indica L.). Journal of Applied Horticulture, 22(1), 43-48.

Singh, S. D., Singh, Y. V., & Bhandari, R. C. (1989). Tomato yield as related to drip lateral spacing and fertilizer application on total and wetted area basis. *Canadian Journal of Plant Science*, *69*(3), 991-999.

Singh, S. R., Zargar, M. Y., Najar, G. R., Ishaq, M. I., & Hakeem, S. A. (2012). Effect of integrated nutrient supply on yield, fertility and quality of strawberry under rainfed temperate conditions. *Journal of the Indian Society of Soil Science*, *60*(1), 79-82.

Singh, S., Bhoi, T. K., Vyas, V., Khan, I., Rathi, A., & Singh, I. (2024). Microbial bioinoculants: boosting horticultural productivity. In Bio-Inoculants in Horticultural Crops (pp. 1-20). Woodhead Publishing.
Singh, S., Bhoi, T. K., Vyas, V., Khan, I., Rathi, A., & Singh, I. (2024). Microbial bioinoculants: boosting horticultural productivity. In Bio-Inoculants in Horticultural Crops (pp. 1-20). Woodhead Publishing.
Singh, V. J., Sharma, S. D., Kumar, P., & Bhardwaj, S. K. (2012). Effect of bio-organic and inorganic nutrient sources to improve leaf nutrient status in apricot. *Indian Journal of Horticulture*, *69*(1), 45-49. 172.

Singleton, V. L., & Rossi, J. A. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. American journal of Enology and Viticulture, 16(3), 144-158.

Sirijan, M., Pipattanawong, N., Saeng-On, B., & Chaiprasart, P. (2020). Anthocyanin content,bioactive compounds and physico-chemical characteristics of potential new strawberry cultivars rich in-anthocyanins. *Journal of Berry Research*, *10*(3), 397-410.

Smith, J. R., *et. al.* (2019). Economic feasibility of nano urea over conventional urea in strawberry cultivation. Journal of Agricultural Economics, 35(2), 210-225.

Smith, P. F. (1966). Leaf analysis of citrus. *Temperate to tropical fruit nutrition*, *2*, 208-228.Sonkar, S., Sharma, L., Singh, R. K., Pandey, B., Rathore, S. S., Singh, A. K., ... & Singh, S. spirits. Comprehensive Reviews in Food Science and Food Safety, 23(3), e13354.

Srivastava, A., Bishnoi, S., & Sarkar, P. (2014). Integrated nutrient management (INM) on growth, yield and quality of papaya (*Carica papaya* L.) cv. CO-7. *The Asian Journal ofHorticulture*, *9*(2), 390-395.

Stearns, P. N. Happiness and industrialization: Western society in the nineteenth century. In The Routledge History of Happiness (pp. 217-230). Routledge.

Subramani, T., Velmurugan, A., Bommayasamy, N., Swarnam, T. P., Ramakrishna, Y., Jaisankar, I., & Singh, L. (2023). Effect of Nano Urea on growth, yield and nutrient use efficiency of Okra under tropical island ecosystem. *International Journal of Agricultural Sciences*, *19*, 134-139.

Sumbul, A., Ansari, R. A., Rizvi, R., & Mahmood, I. (2020). Azotobacter: A potential bio- fertilizer for soil and plant health management. *Saudi journal of biological sciences*, *27*(12), 3634-3640.

Sumbul, A., Ansari, R. A., Rizvi, R., & Mahmood, I. (2020). Azotobacter: A potential bio- fertilizer for soil and plant health management. *Saudi journal of biological sciences*, *27*(12), 3634-3640.

Sumbul, A., Ansari, R. A., Rizvi, R., & Mahmood, I. (2020). Azotobacter: A potential bio- fertilizer for soil and plant health management. *Saudi journal of biological sciences*, *27*(12), 3634-3640.

Sutanu, M., Aniruddha, Y., & Meena, K. R. (2017). Effect of calcium and boron on growth, yield and quality of pomegranate (*Punica granatum* L.). *International Journal of Plant Sciences (Muzaffarnagar)*, *12*(2), 108-113.

Swietlik, D. (2001, September). Zinc nutrition of fruit trees by foliar sprays. In *International Symposium on Foliar Nutrition of Perennial Fruit Plants 594* (pp. 123-129).

Tang, D., Liu, M. Y., Zhang, Q., Ma, L., Shi, Y., & Ruan, J. (2020). Preferential assimilation of NH4+ over NO3− in tea plant associated with genes involved in nitrogen transportation, utilization and catechins biosynthesis. *Plant science*, *291*, 110369.

Tarafdar, J. C., Raliya, R., Mahawar, H., & Rathore, I. (2014). Development of zinc nanofertilizer to enhance crop production in pearl millet (*Pennisetum americanum*). *Agricultural Research*, *3*, 257-262.

Tariq, M., Sharif, M., Shah, Z., & Khan, R. (2007). Effect of foliar application of micronutrients on the yield and quality of sweet orange (*Citrus sinensis* L.). *Pak. J. Biol. Sci*, *10*(11), 1823-1828.

Thirugnanasambandan, T. (2018). Advances and trends in nano-biofertilizers. *Available at SSRN 3306998*.

Tripathi, M., Kumar, S., Kumar, A., Tripathi, P., & Kumar, S. (2018). Agro-nanotechnology: a future technology for sustainable agriculture. *Int J Curr Microbiol Appl Sci, 7*, 196- 200. 173

Tripathi, V. K., Kumar, S., Kumar, K., Kumar, S., & Dubey, V. (2016). Influence of Azotobacter, Azospirillum and PSB on vegetative growth, flowering, yield and quality of strawberry cv. Chandler. *Progressive Horticulture*, *48*(1), 48-52.

Tripathi, V. K., Mishra, A. N., Kumar, S., & Tiwari, B. (2014). Efficacy of *Azotobacter* and PSB on vegetative growth, flowering, yield and quality of strawberry cv. Chandler. *Progressive Horticulture*, *46*(1), 48-53.

Tsonev, T., & Cebola Lidon, F. J. (2012). Zinc in plants-an overview. *Emirates Journal of Food & Agriculture (EJFA)*, *24*(4).

Ullah, S., Khan, A. S., Malik, A. U., Afzal, I., Shahid, M., & Razzaq, K. (2012). Foliar application of boron influences the leaf mineral status, vegetative and reproductive growth, yield and fruit quality of _Kinnow'mandarin (*Citrus reticulata* Blanco.). *Journal of plant nutrition*, *35*(13), 2067-2079.

Umar, I., Mir, M. M., Rehman, M. U., Bisati, I., Rather, G. H., Mir, M. A., & Zubair, M. (2013). Impact of Integrated Nutrient Management on some Quantitative and Qualitative Characteristics of Strawberry cv. Chandler. *SKUAST Journal of Research*, *15*(1), 7-16.

Upadhyay, P. K., Dey, A., Singh, V. K., Dwivedi, B. S., Singh, T., GA, R., ... & Shukla, G. (2023). Conjoint application of nano-urea with conventional fertilizers: An energy efficient and environmentally robust approach for sustainable crop production. *Plos one*, *18*(7), e0284009.

Uscola, M., Villar-Salvador, P., Oliet, J., & Warren, C. R. (2014). Foliar absorption and root translocation of nitrogen from different chemical forms in seedlings of two Mediterranean trees. *Environmental and experimental botany*, *104*, 34-43.

USDA, F. (2020). Citrus: World markets and trade.

Uthman, Q. O., Kadyampakeni, D. M., Nkedi-Kizza, P., Kwakye, S., & Barlas, N. T. (2022). Boron, manganese, and zinc sorption and leaf uptake on citrus cultivated on a sandy soil. *Plants*, *11*(5), 638.

Vavilov's Early Explorations to Genebanks around the World. *Plants*, *12*(4), 814. 174

Vondracek, K., Altpeter, F., Liu, T., & Lee, S. (2024). Advances in genomics and genome editing for improving strawberry (Fragaria× ananassa). Frontiers in Genetics, 15, 1382445.

Verma, J., & Rao, V. K. (2013). Impact of INM on soil properties, plant growth and yield parameters of strawberry cv. Chandler. *Journal of Hill Agriculture*, *4*(2), 61-67.

Vessey, J. K. (2003). Plant growth promoting rhizobacteria as biofertilizers. *Plant and soil*, *255*, 571-586.

Vessey, J. K. (2003). Plant growth promoting rhizobacteria as biofertilizers. *Plant and soil*, *255*, 571-586.

Viscardi, S., Ventorino, V., Duran, P., Maggio, A., De Pascale, S., Mora, M. L., & Pepe, O. (2016). Assessment of plant growth promoting activities and abiotic stress tolerance of Azotobacter chroococcum strains for a potential use in sustainable agriculture. *Journal of soil science and plant nutrition*, *16*(3), 848-863.

Vishwakarma, G., Yadav, A. L., Kumar, A., Singh, A., & Kumar, S. (2017). Effect of Integrated Nutrient Management on Physico-Chemical Characters of Bael (*Aegle marmelos* Correa) cv. Narendra Bael-9. *Int. J. Curr. Microbiol. App. Sci*, *6*(6), 287 296.

Volk, G. M., Gmitter Jr, F. G., & Krueger, R. R. (2023). Conserving Citrus Diversity.

WA Al-juthery, H., & Hilal Obaid Al-Maamouri, E. (2020). Effect of urea and nano-nitrogen fertigation and foliar application of nano-boron and molybdenum on some growth and yield parameters of potato. *Al-Qadisiyah Journal For Agriculture Sciences*, *10*(1), 253- 263.

Wang, L., Yang, S., Ni, J., Teng, Y., & Bai, S. (2023). Advances of anthocyanin synthesis regulated by plant growth regulators in fruit trees. *Scientia Horticulturae*, *307*, 111476.

Wang, Q., Lu, L., Wu, X., Li, Y., & Lin, J. (2003). Boron influences pollen germination and pollen tube growth in Picea meyeri. *Tree physiology*, *23*(5), 345-351.

Waskela, R. S., Kanpure, R. N., Kumawat, B. R., & Kachouli, B. K. (2013). Effect of foliar spray of micronutrients on growth, yield and quality of guava (*Psidium guajava* L.) cv. Dharidar. *International Journal of Agricultural Sciences*, *9*(2), 551-556.

Wassel, A. H., El-Hameed, M. A., Gobara, A., & Attia, M. (2007). Effect of some micronutrients, gibberellic acid and ascorbic acid on growth, yield and quality of white Banaty seedless grapevines. In *8th African Crop Science Society Conference, El-Minia, Egypt, 27-31 October 2007* (pp. 547-553).

Weibel, F. P., & Alföldi, T. (2007). Improving the quality and shelf life of fruit from organic production systems. In *Handbook of organic food safety and quality* (pp. 330-352). Woodhead Publishing.

Whetton, R. L., Harty, M. A., & Holden, N. M. (2022). Communicating nitrogen loss mechanisms for improving nitrogen use efficiency management, focused on global wheat. *Nitrogen*, *3*(2), 213-246.

Woch, N., Laha, S., & Gudipalli, P. (2023). Salicylic acid and jasmonic acid induced enhanced production of total phenolics, flavonoids, and antioxidant metabolism in callus cultures of Givotia moluccana (L.) Sreem. *In Vitro Cellular & Developmental Biology-Plant*, *59*(2), 227-248.

Wu, M., Zhao, P., Liu, L., Zhao, Q., Li, Q., Li, L., & Xu, J. (2024). The organic manure-improved yield and quality in strawberries is attributed to metabolic reprogramming to increase amino acids, sugar/acid ratio, flavonoids and phenolic volatiles. *Plant and Soil*, 1-19.

Wu, W., Du, K., Kang, X., & Wei, H. (2021). The diverse roles of cytokinins in regulating leaf development. *Horticulture Research*, *8*.

Xu, G., Liu, D., Chen, J., Ye, X., Ma, Y., & Shi, J. (2008). Juice components and antioxidantcapacity of citrus varieties cultivated in China. *Food chemistry*, *106*(2), 545-551.

Yadav, A. K., Singh, J. K., & Singh, H. K. (2011). Studies on integrated nutrient management in flowering, fruiting, yield and quality of mango cv. Amrapali under highdensity orcharding. *Indian Journal of Horticulture*, *68*(4), 453-460.

Yadav, A., Upadhyay, A., Kumar, R., Prajapati, J., & Pal, S. (2023). Nanotechnology Based Nano Urea to Increase Agricultural Sustainability. *Just Agriculture*, *3*(12), 266-274.

Yadav, H. C., Yadav, A. L., Yadav, D. K., & Yadav, P. K. (2011). Effect of foliar applicationof micronutrients and GA3 on fruit yield and quality of rainy season guava (*Psidium guajava* L.) cv. L-49. *Plant Archives*, *11*(1), 147-149.

Yadav, M. R., Kumar, R., Parihar, C. M., Yadav, R. K., Jat, S. L., Ram, H., ... & Jat, M. L. (2017). Strategies for improving nitrogen use efficiency: A review. *Agricultural Reviews*, *38*(1), 29-40.

Yadav, M. R., Kumar, S., Lal, M. K., Kumar, D., Kumar, R., Yadav, R. K., & Rajput, V.

D. (2023). Mechanistic understanding of leakage and consequences and recent technological advances in improving nitrogen use efficiency in cereals. *Agronomy*, *13*(2), 527.

Yadav, V. K., Jain, M. C., Sharma, M. K., Gupta, N. K., & Singh, J. (2014). Effect of micronutrients foliar feeding on growth and yield of pomegranate (*Punica granatum* L.) cv. Sindhuri. *International Journal of Tropical Agriculture*, *32*(3/4), 469-473.

Yadav, V., Singh, P. N., & Yadav, P. (2013). Effect of foliar fertilization of boron, zinc and iron on fruit growth and yield of low-chill peach cv. Sharbati. *International Journal of Scientific and Research Publications*, *8*(3), 1-6.

Yin, H., Li, Y., Xiao, J., Xu, Z., Cheng, X., & Liu, Q. (2013). Enhanced root exudation stimulates soil nitrogen transformations in a subalpine coniferous forest under experimental warming. *Global change biology*, *19*(7), 2158-2167.

Yu, Z., Xu, X., Guo, L., Jin, R., & Lu, Y. (2024). Uptake and transport of micro/nanoplastics in terrestrial plants: Detection, mechanisms, and influencing factors. *Science of the Total Environment*, *907*, 168155.

Zalabák, D., Pospíšilová, H., Šmehilová, M., Mrízová, K., Frébort, I., & Galuszka, P. (2013). Genetic engineering of cytokinin metabolism: prospective way to improve agricultural traits of crop plants. *Biotechnology advances*, *31*(1), 97-117.

Zhang, J. B., Zhu, T. B., Cai, Z. C., Qin, S. W., & Müller, C. (2012). Effects of long-term repeated mineral and organic fertilizer applications on soil nitrogen transformations. *Euro*

Zheng, A., & Lv, J. (2023). Spatial patterns of bamboo expansion across scales: how does Moso bamboo interact with competing trees?. *Landscape Ecology*, *38*(12), 3925-3943.

Zheng, Y., Yang, Z., Luo, J., Zhang, Y., Jiang, N., & Khattak, W. A. (2023). Transcriptome analysis of sugar and acid metabolism in young tomato fruits under high temperature and nitrogen fertilizer influence. *Frontiers in Plant Science*, *14*, 1197553.

Zhou, L., Liu, W., Duan, H., Dong, H., Li, J., Zhang, S., & Guo, B. (2023). Improved effects of combined application of nitrogen-fixing bacteria Azotobacter beijerinckii andmicroalgae Chlorella pyrenoidosa on wheat growth and saline-alkali soil quality. *Chemosphere*, *313*, 137409.

Zhou, Y., Xiong, J., Shu, Z., Dong, C., Gu, T., Sun, P., & Cheng, Z. M. (2023). The telomere-to-telomere genome of Fragaria vesca reveals the genomic evolution of Fragaria and the origin of cultivated octoploid strawberry. *Horticulture Research*, 10(4),uhad027.

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

1. 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
1	Scopus	Published	Research	Journal of Food Chemistry & Nanotechnology	Effect of Nano Urea in Combination with *Azotobacter* on Growth and Yield of Strawberry (*Fragaria* x *ananassa* Dutch.) cv. Winter Dawn in Trans-Gangetic Region	Vol: 9, Issue: S1 (special issue) Page: S16-S20	2471-4291 SJR 0.22
2	Scopus	Published	Research	African Journal of Biological Sciences	Profitability Prospects: Assessing Nano Urea and *Azotobacter* Combined Application in Strawberry Farming	Vol: 6, Issue: 5 Page: 3090-3102	2663-2187 SJR 0.15
3	Scopus	Published	Research	Journal of Applied and	Comparative evaluation of strawberry cultivars under	Vol: 16, Issue: 1 Page: 282-	2231-5209

				Natural Science	Subhash Palekar natural farming and conven-tional farming regimes in Doaba region of Punjab conditions	288	SJR 0.18
4	Scopus	Published	Research	Russian Journal of Earth Sciences	Comparative evaluation of strawberry cultivars under Subhash Palekar natural farming and conven-tional farming regimes in Doaba region of Punjab conditions	Vol: 23, Issue: 5 Page: 0215	1681-1208 SJR 0.24
5	NAAS	Published	Research	Journal of Experimenta l Agriculture International	Evaluation of Bio-Stimulants for Active Growth, Yield and Shelf Life of Papaya Cv. Red Lady	Vol: 46, Issue: 7 Page: 686-94	2457-0591 SJR 0.24

2. **List of Conferences**

S. No.	Conference attended
1	JK Agri-Med Science Congress at Sher-e-Kashmir Agriculture University, Kashmir, Jammu & Kashmir (Feb 2024).
2	International conference on Recent Advances in Smart and Sustainable Agriculture for Food and Nutritional Security-2023 at School of Agriculture, Lovely Professional University, Punjab (Nov 2023).
3	5^{th} International Conference on Climate Change and Its Impact (CCI 2023) at Sher-e-Kashmir Agriculture University, Kashmir, Jammu & Kashmir (June 9-11, 2023).
4	International conference on Recent trends in Smart and Sustainable Agriculture for Food Security (SSAFS-2022) at School of Agriculture, Lovely Professional University, Punjab (Jan 2022).