INTERACTIVE EFFECTS OF NANO ZINC, AM FUNGI AND SELENOBACTERIA FOR SELENIUM BIOFORTIFICATION IN STRAWBERRY (*Fragaria* x *ananassa* Duch.)

Thesis

by

DIVYA PANDEY
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Dr Jitender K Chauhan
Major Advisor

Department of Fruit Science
Dr. Yashwant Singh Parmar University of
Horticulture & Forestry,
(Nauni) Solan (HP) -173 230 India

CERTIFICATE-I

This is to certify that the thesis titled**, "Interactive effects of nano zinc, AM fungi and selenobacteria for selenium biofortification in strawberry (*Fragaria* × *ananassa* Duch.)"** submitted in partial fulfilment of the requirements for the award of the degree of **Doctor of Philosophy Fruit Science** in the discipline of **Horticultural Sciences** to Dr. Yashwant Singh Parmar University of Horticulture & Forestry, (Nauni) Solan (HP)-173 230 is a bonafide research work carried out by **Ms. Divya Pandey (H-2019-18-D)** daughter of Shri Sudhir Pandey under my supervision and that no part of this thesis has been submitted for any other degree or diploma.

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

Place: Nauni-Solan
Dated:

Dr Jitender K Chauhan
(Major Advisor)

CERTIFICATE-II

This is to certify that the thesis titled, **"Interactive effects of nano zinc, AM fungi and selenobacteria for selenium biofortification in strawberry (*Fragaria* × *ananassa* Duch.)"** submitted by **Ms. Divya Pandey (H-2019-18-D)** daughter of Shri Sudhir Pandey to the Dr. Yashwant Singh Parmar University of Horticulture and Forestry, (Nauni) Solan (HP)-173 230 India in partial fulfilment of the requirements for the degree of **Doctor of Philosophy Fruit Science** in the discipline of **Horticultural Sciences** has been approved by the Advisory Committee after an oral examination of the student in collaboration with an External Examiner.

16.9.2023

Dr Jitender K Chauhan
Major Advisor

16/9/23

Dr Vikas Tandon
External Examiner

Members of Advisory Committee

1. **Dr N C Sharma**
   (Associate Professor)
   16/9/2023
2. **Dr Uday Sharma**
   (Principal Scientist)
   16/9/23
3. **Dr Nivedita Sharma**
   (Professor and Head)
   16/9/23

Dr Dharam Paul Sharma
Professor and Head
Department of Fruit Science

Countersigned

Dean
College of Horticulture
Dr. Yashwant Singh Parmar University of Horticulture & Forestry,
(Nauni)-173 230, Solan (HP)

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Date: **(Divya Pandey)**

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ABBREVIATIONS

ANOVA	:	Analysis of variance
@	:	At the rate
AMF	:	Arbuscular mycorrhizal fungi
cm	:	Centimetre
cm^2	:	Centimetre square
CD	:	Critical difference
cv./cvs.	:	Cultivar/ cultivars
df	:	Degrees of freedom
^{0}C	:	Degree celsius
^{0}B	:	Degree brix
dSm^{-1}	:	Deci siemen per meter
et al.	:	Etalia (Co-workers)
=	:	Equal to
Fig.	:	Figure
g	:	Gram
ha	:	Hectare
HP	:	Himachal Pradesh
i.e.,	:	id est (that is)
kg	:	Kilogram
nm	:	Nanometer
m	:	Meter
mg	:	Milligram
mm	:	Millimeter
ml	:	Millilitre
MSS	:	Mean sum of squares
NHB	:	National Horticulture Board
NS	:	Non-significant
N	:	Normality
OD	:	Optical density
%	:	Percentage
/	:	Per
ppm	:	Parts per million
RCBD	:	Randomized complete block design
TSS	:	Total soluble solids
µ	:	Microgram
viz.,	:	Videlicet (namely)

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Chapter-1

INTRODUCTION

The strawberry (*Fragaria* × *ananassa* Duch.) has gained prominence as a fruit of global importance (Zeist and Resende 2019). The garden strawberry (*Fragaria* × *ananassa*) is a cross between the wild strawberries *Fragaria virginiana* and *Fragaria chiloensis*. The ancestry of the current hybrid species can be traced back to the Americas. Nonetheless, the current hybrid species was cultivated in Europe using imported specimens and then introduced to the United States in the latter half of the 18th century (Hernández-Martnez et al. 2023). A strawberry is an aggregated fruit that develops from receptacular tissue. Multiple ovaries develop on a single receptacle to produce achenes, which are fruits with a single seed. According to Flachowsky et al. (2011) the enlarged receptacle containing achenes is considered a berry, but is commonly referred to as a 'fruit' in a horticultural sense. Strawberry plants are perennial, herbaceous and of low stature. Typically, strawberry flowers have five white petals. Strawberry plants are capable of vegetative propagation through the production of runners (stolons), which trail above-ground and can establish new, clonal daughter plants at their nodes (Davis et al. 2007).

There are day-neutral and short-day varieties of strawberries based on their photoperiodic response. Sweet Charlie, a cultivar with a day-neutral photoperiod, has dark red berries with dark green and semi-glossy leaves. It possesses specific characteristics in its composition that appeal to consumers, such as its intense bright red colour, characteristic odour, soft texture and slightly acidic flavour (Gabriel et al. 2019) which grant it desirable properties for a commodity that can be used in a variety of food products. It is widely utilised in frozen yoghurts, jams, squashes, syrups, confections, mocktails, smoothies and other sweets due to its delicious flavour and appealing appearance. The inclusion of this fruit in the diet on a daily basis, whether it be fresh, frozen or processed (such as juices, jams, yoghurts etc.) is a significant source of beneficial nutrients, including fibre, vitamins (particularly C and B9), minerals (primarily potassium and magnesium) and antioxidants (such as flavonoids, phenolic acids and ellagitannins) that can prevent or lessen certain types of cancer, cardiovascular diseases, obesity, type II diabetes and cellular damage induced by reactive oxygen species (ROS) (Olsson et al. 2004, Wang and Lewers 2007, He and Giusti 2010 and Giampieri et al. 2012). As a result, the strawberry is a highly valued fruit due to its nutritional qualities, the beneficial properties of its bioactive components (a heterogeneous group of biologically active non-nutrients, primarily represented by polyphenols) and a complex mixture of volatile organic compounds (Diamanti et al. 2012). The bright red colour of strawberries is a result of flavonoids, particularly anthocyanins in the form of pelargonidin and cyanidin derivatives (Todeschini et al. 2018).

It is a temperate-zone crop that can also be found in the subtropics and grows at an altitude of 3000 m above mean sea level. In India, 14,000 MT of strawberries are produced annually on an area of 3000 ha (NHB 2022). Maharashtra, Punjab, Haryana, the Himachal Pradesh hills, Jammu & Kashmir, Uttarakhand, Uttar Pradesh, Rajasthan, and West Bengal are the main strawberry-growing states in India. In Himachal Pradesh, it is cultivated in Sirmour, Kullu, Kangra, Solan and Shimla districts, covering a combined total of 40 ha and producing 210 MT annually (NHB 2022). The plants thrived at temperatures between 15 and 35 °C, with flowering occurring best at 14°C to 18 °C (Rani and Ahmad 2012). It thrives best in soil that ranges in pH from 5.7 to 6.5 and is sandy loam to loamy.

Zinc (Zn) is one of the important micronutrients essential for plants. It is an essential co-factor for many enzymes, serving in structural, regulatory, or functional capacities. Zn is necessary for the production of tryptophan, which is a precursor to indole-acetic acid (IAA), which causes plant cell elongation and aids in the production of biomass. Additionally, it is necessary for a variety of photosynthetic processes as well as for the preservation of cell membrane structure. When soil moisture and organic matter are decreased, roots are less able to absorb zinc (Rengel 2015). Nowadays, it is preferred to use nanoscale particles to increase the uptake of nutrients by plants, thereby improving their agronomic effectiveness. Through slow-release mechanisms, nanomaterials have greater potential today for enhancing nutrient use efficiency and minimising adverse environmental effects (Kopittke et al. 2019). The development of fertilisers at the nanoscale for the best plant nutrition is the result of the application of nanotechnology (Liu and Lal 2015). When applied in smaller quantities compared to conventional fertilisers (Davarpanah et al. 2016), nanomaterials, such as nano-fertilizers (NFs), also corrected the micronutrient deficiency by supplementing associated nutrients in nano-scale particles. According to Subramanian et al. (2015) NFs are the nutrient carriers at nano-dimension (10^{-9} m) that have a large surface area and can hold a lot of nutrient ions. According to Zahedi et al. (2019) plants that received NFs successfully manage abiotic stress to maintain fruit quality. They have distinctive qualities that aid in ultra-high absorption to enhance crop performance, such as high surface area, reactivity, dispensability and better catalytic activity. Foliar application of nano fertilizers has been shown to prevent toxicity symptoms in plants and to address micronutrient deficiencies (Kannan 2010). Furthermore, according to concentration and crop specificity the effectiveness of NFs was assimilated 15-20 times more than that of conventional analogues (Rajput et al. 2018). The application of nano fertilizers s also prevents the rapid burning of leaves that is typically related to fertiliser formulations that are soluble (Kopittke et al. 2019). The ability of nanoparticles to mobilise native nutrients in the rhizosphere depends on their special characteristics (Zahra et al. 2017). Given their controlled, gradual release and the potential for absorption by both plant roots and leaves, NFs are preferred to traditional fertilisers (Solanki et al. 2015, Khan and Rizvi 2017 and Zahedi et al. 2019). Nano-forms are roughly 20–30% more effective than traditional forms, according to a critical comparison (Kah et al. 2018). In comparison to conventional fertilisers, which are available for 4–10 days, NFs are available for 40–50 days, which has a positive impact on their efficiency. Reduced particle size produces more particles per unit weight of applied Zn, increasing the surface area of a fertiliser and boosting its effectiveness (Singh et al. 2017). Up to a certain concentration, ZnO-NPs can promote growth (Faizan et al. 2018), where they offer Zn^{2+} as a micronutrient (Liu and Lal 2015). ZnO-NPs play important roles in plant by minimising the negative effects of ROS on cell organelles (Faizan et al. 2020). On the other hand, NP efficacy varies with concentration and also from crop to crop.

The arbuscular mycorrhizal fungi (AMF) are a group of endotrophic fungi that are prevalent in nearly all terrestrial ecosystems. They are known to form symbiotic relationships with flowering plants, ferns and bryophytes (Wu et al. 2016 and Begum et al. 2019). AMFs are necessarily biotrophic organisms that symbiotically associate with plant roots. These organisms establish a mutualistic symbiosis by colonising the tissues of the radicular cortex (Sadhana 2014). This symbiosis may stimulate the production of secondary metabolites, which may enhance the plant's tolerance to biotic and abiotic stress (Pandey et al. 2018). In addition to enhancing the accumulation of antioxidant compounds in plant tissues, these characteristics may be advantageous to human health (Baslam et al. 2011). The inoculation of sterile soil with AMFs and growth-promoting bacteria may enhance strawberry physiological quality parameters such as sugar and anthocyanin concentrations, as well as pH and malic acid concentration (Todeschini et al. 2018).

According to Subramanian et al. (2011), foliar Zn application has the potential to aid in the absorption of Zn associated with hyphal transport, biochemical alterations in the rhizosphere and plant physiological changes, thereby enhancing the efficiency of the symbiosis between AMF and host plants. They have also highlighted the potential of AMF in solubilizing residual Zn into exchangeable or organically bound Zn (soluble Zn) in order to increase its availability. However, colonisation of roots by AMF can result in reduced accumulation of Zn (and other metals) in plant tissues under high soil Zn concentrations (Zhu et al. 2001, Christie et al. 2004 and Hildebrandt et al. 2006) suggesting that AMF may have a role to play in improving the nutritive value of crops grown in areas with low soil Zn concentrations.

Selenium's (Se) physiological effects on both people and animals have been extensively studied. The recommended daily intake of Se is between 55 and 70 µg and can reach up to 200 µg in a Se supplement (Schiavon et al. 2013) in order to strengthen resistance to HIV infections and reduce the incidence of prostate cancer. Degenerative cardiac illnesses like Keshan disease, which was discovered in Keshan, China, can be brought on by selenium insufficiency and inadequate daily dietary intake of selenium (Renwick et al. 2008 and Wu et al. 2015). The effectiveness of selenium as a cancer chemopreventive depends on its dosage and formulation. Selenium is also an inducer of apoptosis and an inhibitor of cell proliferation, which may account for its cancer-preventive properties (Sinha et al. 2005). Selenium can lower oxidation and raise the *in vivo* activity levels of antioxidant enzymes. The physiological roles of Se in plant growth and development as well as stress resistance have been documented in studies on a variety of crops. The early emergence and quick development of young seedlings, as well as an increase in net photosynthetic rate and chlorophyll content, can all be facilitated by the application of an appropriate Se concentration (Kieliszek and Błażejak 2016). It also plays a significant protective role in the reduction of oxidative stress (Mora et al. 2008). Selenium is an indispensable component of glutathione peroxidase and other selenoproteins. Selenium concentrations in fruits and vegetables range from 0.001 to 0.022 µg/g. Their high water content and low protein content are responsible for this (Kieliszek and Błażejak 2016). In order to alleviate Se deficiency-induced human disorders, it is crucial to increase Se uptake by plants and ultimately, its concentration in the human diet. Se biofortification is the most efficient method for boosting Se concentrations in agricultural products.

Biofortification of food crops increases their nutrient content in soils with insufficient amounts of essential elements. In many countries, plants are the most abundant source of selenium, followed by meat and seafood. It can be accomplished via agronomic techniques, conventional plant breeding, or modern biotechnology. Selecting plant species that can absorb the micronutrient in their edible parts and thereby improve the diet of animals will enable Se bio-fortification to be successfully carried out in Se-deficient soils. Numerous microbes help plants absorb nutrients from soil, withstand abiotic stress, growth and yield better. It is also possible to use these advantageous microbes for biofortification. For Se bio-fortification, numerous mycorrhizal and root endophytic fungi, plant growth-promoting rhizobacteria (PGPR), etc. are used (Hossain et al. 2021). In several nations, including Australia, Finland and New Zealand, agronomic biofortification has been used to increase the Se content in plants through the use of Se fertilisers. Recently, selenium biofortification with plant growth-promoting bacteria (PGPB) has been used. Selenobacteria are bacteria that can metabolise and transform inorganic selenium into elemental Se nanospheres (NanoSe) and other important organic selenium forms based on effective inoculation of rhizospheric bacteria with AMF (Acuna et al. 2013, Duran et al. 2013, Duran et al. 2014 and Duran et al. 2015). Of lately, such selenobacteria are known to be plant beneficial bacteria and tend to support plant growth (Duran et al. 2014).

With the afore mentioned information in mind, the current study was conducted to assess the impact of nanozinc, the viability of co-inoculating AMF and selenobacteria to increase Se content, as well as their potential interaction with one another on strawberries grown under protected conditions.

Objectives:

i) To study the stimulative effects of nano zinc, AM fungi and selenobacteria on growth, yield and quality attributes.

ii) To study the interactive effects of nano zinc, AM fungi and selenobacteria on rhizosphere characteristics.

iii) To study the effect of nano zinc along with rhizoinoculation of AM fungi and selenobacteria for selenium biofortification.

Chapter-2

REVIEW OF LITERATURE

The biggest obstacle to worldwide food and nutrition safety is feeding the world's expanding population. Therefore, it is crucial to boost production of good quality food with the necessary amount of nutrients and protein. The primary goals of sustainable agriculture are to decrease the use of synthetic fertilisers, lessen the amount of nutrients lost during the fertilisation process and maximise crop yields by careful management of available nutrients to feed the ever increasing population and without causing any harm to the environment. A brief review of literature pertaining to the effect of Zn nano formulation, AMF and selenobacteria on growth, flowering, yield related traits, soil properties, leaf and fruit nutrient content have been mentioned below under different heads and sub-heads:

2.1 Effects of zinc and selenium on growth, yield and quality

2.1.1 Zinc

Zinc (Zn) is one of the significant micronutrients required for various metabolic activities of fruit crops. It is an indispensable micronutrient generally absorbed as divalent cations (Zn^{++}) which is limiting crop growth and yield. The immobile nature of Zn and poor soil conditions limit its availability to crop plants (Sharma et al. 2013). Zn changes the effects of auxin by controlling the synthesis of tryptophan, which is a precursor of indole-3-acetic acid. This causes cells to grow longer and helps plants make more biomass (Alloway 2004 and Brennan 2005) through protein biosynthesis (Cakmak 2000) and carbohydrate metabolism (Sadeghzadeh and Rengel 2011). As stated by Hasani et al. (2012), Zn is also necessary for maintaining the composition of cell membranes as well as many photosynthetic processes. Changes in the anatomical structure of conducting tissue and adverse soil conditions, such as low organic matter, high pH, clay content, and calcium carbonate content, influence Zn transport in plants as a function of the root-shoot barrier (Sharma et al. 2013). The extensive application of zinc (Zn) fertilizers, due to its classification as a heavy metal, has a significant influence on the overall health and productivity of soil (Khanm et al. 2018).

2.1.1.1 Growth

Abdollahi et al. (2010) observed an increase in vegetative growth when 100-200 mg/L zinc sulphate was administered to strawberry cv. Selva. Kassem et al. (2010) noted a significant increase in vegetative growth characteristics of persimmon cv. Costata when Zn (0.30 g/L) was applied during the pea and marble stages. Yadav et al. (2010) observed that Zn EDTA (40 g/plant) enhanced banana cv. Grand Naine plant height, leaf number, and leaf area.

In a study conducted by Hasani et al. (2012), it was observed that the application of foliar sprays containing $ZnSO_4$ at a concentration of 0.3% resulted in a significant augmentation of the leaf area in pomegranate plants. After being treated with $ZnSO_4$ (0.5%), Khan et al. (2012) found that early leaf area and tree height improved in mandarin cv. Feutrell. Similar to this, strawberry cv. Camarosa had a larger leaf area after being treated with $ZnSO_4$ (100 mg/L) (Lolaei et al. 2012).

In grapevine, Ashoori et al. (2013) found that applying zinc sulphate at a concentration of 1.5 mg/L stimulated an increase in the vegetative growth rate. Maximum plant height was recorded by Razzaq et al. (2013) when zinc sulphate (0.6%) was applied to the Mandarin cv. Kinnow. However, foliar spraying of zinc sulphate at a concentration of 0.75 percent resulted in a considerable increase in leaf area in guava cv. Dharidar (Waskela et al. 2013).

Hada et al. (2014) found that the treatment of $ZnSO_4$ (0.8%) in guava cv. Lucknow-49 resulted in the highest number of leaves and the largest leaf area. In strawberry cv. Pajaro, Kazemi (2014) found that foliar spraying of $ZnSO_4$ at concentrations of 50, 100 and 150 mg/L resulted a rise in leaf area. According to Manjunatha et al. (2014), the treatment of zinc sulphate (0.25%) led to the greatest number of leaves being produced by papaya plants. In a study conducted by Qadir et al. (2014), it was observed that the utilisation of Zn at a concentration of 1.3 g/L resulted in a significant enhancement in the vertical growth of lemon plants.

Baiea et al. (2015) observed an increase in the leaf area and limb length of mango cv. Keitt following the application of zinc sulphate at a concentration of 200 ppm. In their study on strawberry, Mehraj et al. (2015) came to the conclusion that a concentration of $ZnSO_4$ of

100 ppm produced the highest plant height and the greatest number of leaves. According to Singh et al. (2015), after receiving foliar sprays of $ZnSO_4$ (0.3%) three times at monthly intervals, strawberry cv. Chandler reported gains in plant height, number of leaves and leaf area.

Pushkar et al. (2016) obsreved that application of Zn EDTA (0.1%) exhibited significant increase in plant height of mandarin cv. Kinnow. According to the research conducted by Rahman et al. (2016), the application of $ZnSO_4$ at 225 mg/L resulted in an increase in the plant height, leaf area, and number of runners in strawberry. Similarly, treatment of $ZnSO_4$ (0.5%) on sweet orange cv. Mosambi resulted in a significant increase in leaf area (Singh et al. 2018).

When Zn EDTA (75 mg/L) was administered to Olive cvs. Khodeiri, Dremalali and Sorani at 30 day intervals beginning in April, an increased leaf area was seen as a result of the treatment (Al-Aareji et al. 2020). Nandita et al. (2020) observed an increase in plant height in sweet orange cv. Mosambi after applying Zn EDTA at a concentration of 0.5 percent.

2.1.1.2 Fruit set

Hassan et al. (2010) found that plum cv. Hollywood had higher fruit set when treated with Zn EDTA at a concentration of 0.05 per cent. In Guava cv. Seedy Montakhab the application of Zn EDTA at a concentration of 3000 ppm resulted in a significant increase in the amount of fruits produced by each tree (El-Sisy 2011).

Abdollahi et al. (2012) reported that the application of $ZnSO_4$ (100 mg/L) to strawberry cv. Selva resulted in a considerable increase in the number of fruits produced. According to Lolaei et al. (2012), the application of $ZnSO_4$ at a concentration of 150 mg/L resulted in a better fruit set in strawberry cv. Camarosa. In papaya, Modi et al. (2012) found that applying $ZnSO_4$ at a concentration of 0.5% led to the highest number of fruit production. During the months of May and June, foliar spraying with 3% zinc sulphate caused improved fruit set in pomegranate cv. Salemy, as observed by Obaid and Al-Hadethi (2013).

Hada et al. (2014) concluded that the application of $ZnSO_4$ (0.8% of the total solution) in guava cv. Lucknow-49 led to the highest number of fruits and fruit set per cent. Jat and Kacha (2014) revealed that applying $ZnSO_4$ (0.6%) before flowering and three weeks after the initial spray resulted in the maximum fruit retention and the greatest number of fruits produced per plant in their investigation on the guava cv. Bhavnagar. Application of $ZnSO_4$ (1 and 2 g/L) in avocado cv. Fuerte resulted in a considerable increase in fruit set, according to the findings of Abdel-Karim et al. (2015).

In their study, Rahman et al. (2016) found that strawberry plants that were treated with an application of $ZnSO_4$ (225 mg/L) produced 26.3 percent more fruits than those that did not get the treatment. According to Saadati et al. (2016), foliar spraying of $ZnSO_4$ (2.5 kg/m3) considerably boosted the amount of fruit that was set on olive trees. Application of $ZnSO_4$ at a concentration of 0.75 % increased fruit set on guava plants during the course of the winter (Baranwal et al. 2017).

Using a foliar application of Zn EDTA at 49 ppm, Mohammed et al. (2018) concluded that lemon fruit set was enhanced. Fruit set in sweet orange cv. Mosambi was shown to improve after being treated with $ZnSO_4$ (0.5%), as reported by Singh et al. (2018). Zn EDTA application at 0.5% throughout the month of April increased fruit set in sweet orange cv. Mosambi (Nandita et al. 2020).

2.1.1.3 Yield

Abd El-Moneim (2007) found that the application of Zn EDTA (0.4%) significantly enhanced the fruit yield of a sweet orange cv. Washington Navel. Hassan et al. (2010) found that the administration of Zn EDTA (0.5% concentration) increased plum cv. Hollywood. fruit yield. According to the findings of Abdollahi et al. (2010), treatment with $ZnSO_4$ (100-200 mg/L) led to an increase in fruit output in strawberry cv. Selva. Kassem et al. (2010) found that treating persimmon cv. Costata with Zn EDTA at 0.3 g/L at the pea stage and the marble stage enhanced the fruit output. The application of zinc EDTA at a concentration of 3000 ppm, as discovered by El-Sisy (2011), considerably improved the fruit yield in guava cv. Seedy Montakhab.

Bhatt et al. (2012) found that when $ZnSO_4$ (0.5%) was put on mango cv. Dashehari at the marble stage, it gave the maximum number of fruits. According to Modi et al. (2012), applying 0.5% $ZnSO_4$ to papaya cv. Madhu Bindu plants increased their fruit production. Cakici and Arslan (2012) reported an improved fruit yield in strawberry cv. Camarosa after the plant was treated with foliar applications of $ZnSO_4$ at a concentration of 400 ppm three times. The treatment of $ZnSO_4$ (0.6%) on Aonla cv. Banarasi resulted in the highest possible fruit yield, according to Singh et al. (2012).

According to Aboutalebi and Hassanzadeh (2013), the highest possible fruit yield was achieved in citrus cv. Sweet Lime by applying $ZnSO_4$ at a concentration of 0.5 percent. In their study on pomegranate cv. Salemy, Obaid and Al-Hadethi (2013) found that foliar spraying with 3% zinc sulphate throughout the months of May and June led to an improved fruit output. In their study on mandarin cv. Kinnow, Prasad et al. (2013) found that applying $ZnSO_4$ at a concentration of 0.5% increased the fruit output. In their study on acid lime cv. Kagzi Lime, Jagtap et al. (2013) found that foliar treatment of zinc sulphate at a concentration of 0.5% improved fruit yield.

Jat and Kacha (2014) found that spraying guava cv. Bhavnagar with 0.6% ZnSO4 at flowering and three weeks after the first spray gave the highest fruit yield. Kazemi (2014) reported that when 150 mg/L of $ZnSO_4$ was put on strawberry cv. Pajaro, the fruit output went up. Qadir et al. (2014) observed that 1.3 g/L of Zn EDTA made a big difference in the amount of fruit a lemon tree produced.

According to Mehraj et al. (2015), strawberry plants that received $ZnSO_4$ (100 ppm) foliar applications three times at 30, 45, and 60 days after transplanting produced the highest number of fruit per plant. Masroor et al. (2015) found that applying $ZnSO_4$ to mango trees at a concentration of 1% increased fruit yield.

Pushkar et al. (2016) observed an improvement in fruit yield in mandarin cv. Kinnow after applying Zn EDTA at 0.1 percent. Pre-harvest $ZnSO_4$ spraying at 225 mg/L resulted in the highest strawberry fruit production ever recorded (Rahman et al. 2016). Walworth et al. (2017) found that the application of Zn EDTA led to an improved fruit output in pecan nut cvs. Western and Wichita, which was reported at 4.4 kg/ha.

According to Singh et al. (2018), the application of $ZnSO_4$ at a concentration of 0.5% had a substantial impact on the amount of fruit produced by sweet orange cv. Mosambi. Jangid et al. 2019 found that the treatment of $ZnSO_4$ at a concentration of 0.6% in Aonla cv. Chakiya resulted in a greater fruit yield. Nandita et al. (2020) came to the conclusion that applying Zn EDTA at a concentration of 0.5% to sweet orange cv. Mosambi improved the amount of fruit produced.

2.1.1.4 Quality

Hassan et al. (2010) reported that the use of Zn EDTA (0.05%) increased the number of fruits, fruit weight and also yielded firmest fruits in plum cv. Hollywood. Kassem et al. (2010) found that the application of Zn EDTA at 0.3 g/L at the pea stage and marble stage enhanced the fruit weight of persimmon cv. Costata. Through the application of $ZnSO_4$ (0.4%), TSS, total sugars, and titratable acidity were increased in guava cv. Lucknow-49 (Rawat et al. 2010).

Bhowmick and Banik (2011) measured the highest TSS, total sugars, and non-reducing sugars in mango cv. Himsagar by applying $ZnSO_4$ (1.5%) at the marble stage. The application of Zn at a concentration of 3000 ppm increased the average fruit weight and length. It also enhanced Guava cv. Seedy Montakhab TSS, reducing sugars, non-reducing sugars, and total sugars content (El-Sisy 2011). Yadav et al. (2011) revealed that application of Zn EDTA at a rate of 40 g/plant resulted in the highest TSS content in banana cv. Grand Naine.

In strawberry, Abdollahi et al. (2012) found that $ZnSO_4$ at a concentration of 100 mg/L caused a size increase in the fruit. Ahmad et al. (2012) observed a notable increase in fruit dimension after applying $ZnSO_4$ (0.5%) at the stage of fruit setting in the mandarin cv. Early Feutrell. According to the findings of Bhatt et al. (2012), application of $ZnSO_4$ (0.5%) during the marble stage led to the greatest increase in fruit weight in mango cv. Dashehari. The highest levels of total soluble solids, total sugars, non-reducing sugars, and ascorbic acid were found in the fruit of the mango cv. Amrapali variety after the application of $ZnSO_4$ (1%) during the pea and marble stage (Bhowmick et al. 2012).

Cakici and Arslan (2012) discovered that the TSS content of strawberry increased after receiving foliar applications of $ZnSO_4$ at a concentration of 400 ppm three times. Goswami et al. (2012) observed that foliar application of $ZnSO_4$ (0.4%) resulted in the greatest fruit length and fruit width in guava cv. Sardar. Hasani et al. (2012) reported an increase in TSS and TSS:acid ratio in pomegranate due to the application of $ZnSO_4$ (0.3% foliar spray) twice.

Khan et al. (2012) reported an increase in fruit weight after applying $ZnSO_4$ (0.5%) at the stage when the fruit is setting in the mandarin cv. Fuetrell's Early. After applying $ZnSO_4$

at a concentration of 150 mg/L before to blooming in strawberry cv. Camarosa, Lolaei et al. (2012) found that there was an increase in TSS. The concentration of ascorbic acid and the titratable acidity also increased significantly. Modi et al. (2012) found that the application of $ZnSO_4$ (0.5%) increased the fruit weight of papaya.

According to Sajid et al. (2012), foliar treatment of $ZnSO_4$ (1% concentration) significantly increased the amount of TSS, ascorbic acid and non-reducing sugars in sweet orange. Singh et al. (2012) evaluated the effect of $ZnSO_4$ (0.2%, 0.4% and 0.6%) on aonla cv. Banarasi and recorded the highest level of ascorbic acid.

In a study conducted by Aboutalebi and Hassanzadeh (2013), it was observed that the application of $ZnSO_4$ (0.5%) resulted in increased levels of total soluble solids (TSS), acidity, and ascorbic acid content in citrus fruits. By applying foliar $ZnSO_4$ (0.5%) to acid lime cv. Kagzi lime, Jagtap et al. (2013) found an increase in fruit weight and diameter. Through the treatment of $ZnSO_4$ (0.6%) on mandarin cv. Kinnow, Razzaq et al. (2013) noted the maximum fruit diameter and fruit weight.

According to Bakshi et al. (2013), the application of $ZnSO_4$ (0.6%) in strawberry cv. Chandler resulted in the highest levels of total soluble solids, ascorbic acid and TSS:acid ratio. It was shown that foliar spraying pomegranate cv. Salemy with $ZnSO_4$ at a concentration of 3% during the months of May and June led to increased fruit weight (Obaid and Al-Hadethi 2013).

Etehadnejad and Aboutalebi (2014) observed an increase in the diameter of the fruit following foliar spraying of zinc sulphate solution at a concentration of 6 g/L in apple cv. Golab Kohanz. Kazemi (2014) reported that treating strawberry cv. Pajaro with $ZnSO_4$ at 150 mg/L raised the amount of total soluble solids, the titratable acidity and the amount of ascorbic acid. According to Qadir et al. 2014, the use of Zn EDTA at a concentration of 1.3 g/L resulted in an increase in the total quantity of fruits produced by the lemon plant. Parmar et al. (2014) showed that the treatment of $ZnSO_4$ at a concentration of 0.6% considerably enhanced both the fruit weight and the fruit diameter in guava cv. Bhavnagar Red. Tomar et al. (2014) observed that the application of $ZnSO_4$ (0.5%) in mango cv. Langra resulted in the highest levels of total sugars, total TSS, reducing sugars, and non-reducing sugars, as well as the lowest levels of titratable acidity.

After applying $ZnSO_4$ at a concentration of 1%, Gurjar et al. (2015) found that the mango variety Amrapali produced fruits with a greater weight. Masroor et al. (2015) concluded that applying $ZnSO_4$ at a concentration of 1 percent led to increased fruit weight as well as an increase in fruit size.

In a study conducted by Abdel-Salam (2016), it was observed that the application of Zn EDTA at concentrations of 50 and 100 mg/L resulted in enhanced fruit weight, as well as an increase in total soluble solids (TSS) and titratable acidity in the grape cv. Bez El Naka. Pushkar et al. (2016) observed an increase in TSS, acidity, TSS:acid ratio, reducing sugars, total sugars and ascorbic acid content of mandarin cv. Kinnow with the application of Zn EDTA at 0.1 per cent. Rahman et al. (2016) noted maximum fruit weight and TSS with the application of $ZnSO_4$ (225 mg/L) in strawberry. According to Baranwal et al. (2017), the winter season guava exhibited a significant increase in TSS (total soluble solids), total sugars, and ascorbic acid content when treated with $ZnSO_4$ (1%).

According to Ekka et al. (2018), the utilisation of $ZnSO_4$ (0.4%) led to a significant enhancement in the dimensions of strawberry cv. Chandler, including fruit length, fruit diameter, and fruit weight. In the study conducted by Mohammed et al. (2018), it was observed that the application of Zn EDTA foliar spray at a concentration of 49 ppm resulted in an increase in fruit dimension, average fruit weight and firmness in lemon. The utilisation of a 0.5% of $ZnSO_4$ in the cultivation of sweet orange cv. Mosambi resulted in a notable enhancement in fruit length, fruit breadth, and fruit weight, as revealed by Singh et al. in 2018.

The application of $ZnSO_4$ (0.6%) in aonla cv. Chakiya resulted in an increase in the fruit's length, fruit breadth, and fruit weight, as reported by Jangid et al. (2019). Nandita et al. (2020) showed an increase in the TSS:acid ratio in sweet orange cv. Mosambi after applying Zn EDTA at a concentration of 0.5%.

2.1.2 Selenium

Selenium (Se) is essential to selenoamino acids and selenoproteins. Therefore, agricultural products enriched with Se can mitigate the health complications caused by Se deficiency.

2.1.2.1 Growth and Yield

Esringu et al. (2015) investigated how selenium (Se) fertilisation affected lettuce growth, yield, and selenium accumulation. The findings indicate that the application of Selenium (Se) had a notable impact on the growth parameters and yield of iceberg, romaine, and leaf lettuce, as compared to the control group. The application of 50-100 mg kg^{-1} of selenium on iceberg lettuce, romaine lettuce, and leaf lettuce resulted in an increase in yield ratio, average head weight, head diameter, head length, stem diameter, head and root dry weight by 71-116%, 65-105%, 26-30%, 17-31%, 18-22%, 1-6%, and 14-26%, respectively.

Jing et al. (2017) found that the yield of Winter jujube was significantly higher at 50 mg/L of Se compared to that of the control plants, and that the average weight of a fruit on trees that were sprayed with either 50 mg/L or 100 mg/L of Se had a significantly stronger effect on the overall output.

Mimmo et al. (2017) concluded that the application of 100 mM Se to strawberry plants resulted in a 17% increase in leaf area, as compared to plants treated with 10 mM Se or no Se at all (control). The shoot tissues of the plants were found to contain Se concentrations ranging from 10.48-1.20 mg/g when supplied with 10 mM Se, and 125.08-13.89 mg/g dry weight when supplied with 100 mM Se. Apart from selenium (Se), the shoot concentration of sulphur (S) in strawberry plants treated with 100 mM Se was the only parameter that exhibited a significant increase compared to the control and 10 mM Se-treated plants.

Shalaby et al. (2017) investigated into the use of selenium (Se) to improve lettuce growth and yield. The application of a substance at a concentration of 100 ppm resulted in a significant increase in the weight of the plant's head, the area of its leaves, the dry weight of leaves and the amount of chlorophyll present. Specifically, these increases were 46.4%, 66.4%, 61.8%, and 31.5%, respectively, when compared to plants that did not receive the selenium.

Bakr et al. (2018) came to the conclusion that spraying Orange cv. Washington Navel with selenium at 80 ppm led to the highest numbers of leaves per shoot (11.3 and 14.2), that spraying trees with 160 ppm selenium gave a slightly higher initial fruit set percentage (79.5) in the first season, but that spraying trees with 20 ppm selenium gave a slightly higher initial fruit set percentage (82.2) in the second season. During the first and second seasons, the best (312.9 and 292.9) number of fruits per tree had a concentration of 160 ppm.

Sabatino et al. (2019) evaluated the impact of Se application rate and type (fertigation or foliar spray) on yield of Endive. The application of fertigation technique using a concentration of 4.0 mol Se L^{-1} resulted in a significant increase in the weight of endive heads and subsequently, the yield by 42.6% as compared to the control group without Se. Additionally, the fertigation technique with Se showed a significant increase in stem diameter values by 14.7% and an increase in the number of leaves by 39.8%.

Moteshare et al. (2020a) investigated the effect of sodium selenate on the dry weight, concentration of phosphorus, potassium, zinc, iron, and selenium in *Medicago* shoots and roots. The calcareous soil and foliar Se or soil and foliar application resulted in the greatest dry matter and nutrient content in shoots.

Hu et al. (2022) observed that foliar application of Si (1 mM) and Se (0.025 mM), either alone or together, could successfully promote cucumber growth, yield and quality, with the combined effects of Si and Se being superior to their individual effects.

Kalil and Al-Aareji (2022) investigated the impact of foliar spraying with selenium on strawberry cv. Albion growth, flowering and yield. Foliar spraying with selenium at a concentration of 6 mg se L^{-1} considerably increased the number of fruits (32.55) produced by each plant, as well as the fresh fruit weight, fruit yield per plant and fruit yield per hectare as compared to the control plant, which produced 16.39 g, 481.77 g per plant and 364573 kg/ ha respectively.

Eisa et al. (2023) found that selenium, when given to bananas at doses of either 50 or 100 ppm either single or in combination, significantly improved finger weight, finger length and finger diameter as compared to the control treatment. Pourebrahimi et al. (2023) investigated the effects of combined application of selenium and hydrogen sulphide under salinity stress on strawberry yield. The application of H_2S+Se, H_2S and Se treatments resulted in a reduction of yield by 82%, 66% and 63%, respectively.

2.1.2.2 Quality

Pezzarossa et al. (2012) found that the leaf Se content increased from 50 g kg^{-1} in untreated plants to 100 g kg^{-1} in plants dosed with 0.1 mg Se L^{-1} and 225 g kg^{-1} in plants sprayed with 1 mg Se L^{-1}. The Se content of the produce increased from 0.1 g kg^{-1} in untreated plants to 35 and 55 g kg^{-1} when Se was sprayed at concentrations of 0.1 and 1 mg

L^{-1}, respectively. Foliar selenium application enhanced flesh firmness and solid soluble content.

Foliar application of selenium fertiliser appeared effective in increasing fruit selenium content and in improving fruit quality in pear-jujube with the application of less than 300 g ha^{-1} of selenium fertiliser. In terms of fruit firmness, vitamin C, soluble protein, total soluble sugar and organic acid content, the higher Se concentration in fruit led to an improvement in fruit quality (Zhao et al. 2013).

Castillo-Godina et al. (2016) studied the effect of selenium on the elemental concentration and antioxidant enzyme activity of tomato plants. The introduction of 5 mg L^{-1} of selenium led to noteworthy enhancements in the selenium concentration on a dry basis. The concentration reached 20.4 micrograms per gram (µg g^{-1}) in leaves, 52.3 µg g^{-1} in stems, and 35.8 µg g^{-1} in fruits. The augmentation of enzyme activity in the fruits was amplified by the administration of 5 mg L^{-1} of selenium. The catalase activity was boosted by up to 352.7%, glutathione peroxidase activity by 312.2%, and superoxide dismutase activity by 200.8% in comparison to the control.

Winter jujube trees were sprayed three times between July and August with selenium (as sodium selenite) at five different doses (0, 25, 50, 100, or 200 mg/L of Se). Total Se content in leaves grew dramatically and quickly with concentrations ranging from 50 mg/L to 200 mg/L. At 50 mg/L, it was 0.69 times greater than that of the control trees, 7.68 times greater at 100 mg/L, and 17.80 times greater at 200 mg/L. At 50 mg/L, vitamin C concentrations were 20.94% higher, soluble sugars were 29.48% higher, and the sugars to acid ratio was 41.81% higher than in the control (Jing et al. 2017).

Mimmo et al. (2017) observed that total soluble solids (TSS) were significantly affected by the treatment; specifically, a 30% increase in TSS was observed in strawberry plants treated with 100 mM Se compared to the control and 10 mM Se-treated strawberry plants. Both fructose and sucrose concentrations were significantly higher in plants supplied with 10 and 100 mMSe than in control plants. The application of foliar Se fertiliser resulted in an increase in soluble sugar, vitamin C, soluble protein, and the quality of soluble solid nutrition, while also lowering the grapes' organic acid content. Application of foliar se fertiliser enhanced K and Ca nutritional content in grape berries while reducing deposition of Pb, Cr, Cd, As and Ni heavy metals (Zhu et al. 2017).

Alfredo et al. (2018) evaluated the application of selenium (Se) as sodium selenite (Na_2SeO_3) to strawberry at concentrations of 0, 2 and 4 mg L^{-1}. On the first days of harvest, the antioxidant status of fruits treated with 2 mg L^{-1} exhibited a positive effect. Se concentration exhibited a differential distribution, with the highest levels in the roots, followed by the leaves and crowns, and the lowest levels in the fruits, which averaged 31.2 mg kg^{-1} dried weight.

Andrejiova et al. (2019) monitored the impact of selenium foliar biofortification in the form of an aqueous sodium selenate solution. The selenium dose of 150 g ha^{-1} significantly increased the selenium content and marginally increased the total polyphenols content of the fruits. In this manner, selenium and polyphenols, which are antioxidants, can be added to tomatoes to increase their health benefits.

Babalar et al. (2019) examined the effects of foliar applications of 0, 0.5, 1 and 1.5 mg Se L^{-1} on apple quality traits, Se accumulation, and fruit ripening. The application of selenium to the leaves resulted in a significant increase in the concentration of selenium in both the leaves and fruit. The augmentation of selenium (Se) levels resulted in an improvement of the flesh turgidity, titratable acidity and soluble solid content of the fruit. The application of Se treatments resulted in a significant increase in the levels of antioxidant enzymes, namely superoxide dismutase (SOD), catalase (CAT) and ascorbate peroxidase (APX), in comparison to the control group.

Zahedi et al. (2019) investigated the effects of foliar Se and N-Se sprays on the yield, quality, and chemical characteristics of pomegranate fruit and juice. The application of Se and N-Se treatments resulted in a significant increase in the total phenolic content, antioxidant activity, and antioxidant content. With increasing concentrations of Se source in the range of 20–100 mg L^{-1}, both the leaf and branch Se concentrations increased swiftly. Significant increases in leaf and branch Se concentrations were observed at > 100 mg L^{-1}. Under Se treatment, the concentration of soluble particulates was 1.0–1.2 times higher than under control conditions (Deng et al. 2019).

Groth et al. (2020) utilised various selenium forms and treatment levels to the two apple cvs. Golden Delicious and Jonagold, in their investigation. When 0.15 kg of selenium per hectare was applied, the maximum content 5.6 g Se/100 g fresh weight was obtained in both kinds.

Wen et al. 2021 examined the effects of sodium selenite aqueous solutions at concentrations of 0 mg/L (CK, water treatment), 50 mg/L, 100 mg/L, 150 mg/L, and 200 mg/L on the growth, nutrition, and fruit quality of *citrus unshiu*. 150 mg/L of exogenous Se increased the citrus fruit's longitudinal and transverse diameters by 9.15% and 9.99%, respectively. Compared to the results of the control treatment, 50 and 100 mg/L Se fertiliser concentrations could considerably increase the Ca content of the leaves by 3.34 and 16.38 percent, respectively. The application of exogenous Se fertiliser at 50, 100, 150, and 200 mg/L increases the TSS, total sugar, reducing sugar, and VC concentrations in the sarcocarp significantly. The percentage content of TSS increased by 10.68%, 13.88%, 18.16% and 23.3% relative to the CK results.

Lu et al. (2022) investigated how sodium selenite (Na_2SeO_3) controlled the amount of vitamin C in strawberry fruit. All concentrations of sodium selenite (Na_2SeO_3) exhibited a significant increase in the levels of vitamin C and selenium (Se). The enzymatic activity responsible for vitamin C metabolism in strawberry fruit was found to be significantly improved by the addition of 30 mg/L of sodium selenite (Na_2SeO_3) when compared to other concentrations. This resulted in an increase in the vitamin C content of the fruit.

According to the findings of Sun et al. (2023), the addition of Na_2SeO_4 and Na_2SeO_3 significantly raised the weight of the fruit and kernel of walnut when compared to the water control by 14.1% and 9.1%, and 18.2% and 20.5%, respectively. The Na_2SeO_4 and Na_2SeO_3 treatments resulted in a significant rise in the selenium content levels of the leaves by 100 and 95 times, respectively, the pericarp grew by 24 and 23 times and the kernel increased by 64 and 60 times.

2.2 Effects of Nano fertilizers on growth, yield and quality

Nanotechnology has received a lot of attention as of late due to the fact that nanoparticles (NPs) are very minute. The likelihood of NPs being released into the environment has increased dramatically as the use of NPs has risen with a wide variety of applications. Zinc oxide nanoparticles (ZnO-NPs) are considered a ‘biosafe material’ for organisms. ZnO-NPs' antimicrobial action has been shown to have promising applications in promoting seed germination and plant growth, as well as in suppressing disease and protecting plants (Faizan et al. 2020). Nano fertilizers are a significant application of nanotechnology that have the potential to enhance productivity in the horticultural industry

(Chhipa and Joshi 2016). According to Sharma et al. (2022) the utilisation of nanofertilizers has been observed to enhance the blossoming, development, and productivity of fruit plants. However, there is limited data available regarding their impact on the flowering of fruit crops. It is also known to minimise the effects of abiotic stressors and to boost the crop's ability to use nutrients (Abou El-nour et al. 2010). In addition, the nanoparticles have the potential to be a useful tool as an alternate source of nutrients and packaging that improves the fruits' development, production, quality, and shelf life (Chowdhury et al. 2017 and Kaphale et al. 2018).

2.2.1 Growth, flowering, fruit set and yield

Adhikari et al. (2012) conducted an experiment to investigate the impact of 100 nm zinc oxide nanoparticles on the growth of maize plants. The experiment was carried out using a solution culture system. Zinc (Zn) was administered in different concentrations using nano-zinc oxide (ZnO) particles (100 nm) in suspension form and in ionic form through zinc sulphate ($ZnSO_4$) salt in Hoagland solution culture. The experimental findings indicate that the utilisation of nanozinc oxide particles can effectively improve and sustain the growth of maize plants, comparable to the conventional Zn fertiliser ($ZnSO_4$). The application of zinc oxide nanoparticles resulted in an improvement in plant parameters such as plant height, root length, root volume, and dry matter weight.

Raliya et al. (2013) found that 250 mg/kg of ZnO nano particles increased tomato plant height to its optimum. The greatest number of flowers were observed when 250 ppm ZnO nano particles were applied via foliar sprinkling, indicating that foliar spraying is a viable method for delivering nutrients to plants. At 66 days after tomato fertilisation, these nanoparticles produced 81.9% more tomato fruit (by weight) than the control.

Davarpanah et al. (2016) reported that single foliar spray with relatively modest amounts of B or Zn nano-fertilizers (636 mg Zn per tree) increased pomegranate fruit yield, primarily due to an increase in the number of fruits per tree.

According to Kumar et al. (2017), the treatment of ZnO nano particles at a concentration of 150 ppm in strawberry cv. Chandler, produced the highest quantity of fruits per plant. They also observed that the application of ZnO NPs (150 ppm) resulted in an increase in various plant characteristics of strawberry cv. Chandler. These characteristics included plant height (17.24 cm), number of leaves (46.67 cm), and petiole length (9.22 cm).

The researchers also documented highest count of 50% flowering (59.40), days to 1st harvesting (97.93), number of fruits per plant (32.27), fruit weight (15.71 g), fruit diameter (26.21 mm), and fruit yield per plant (478 g).

El-Sayed et al. (2017) concluded that the application of ZnO nanoparticles at a concentration of 10 ppm to the date plam cv. Zaghloul resulted in improved fruit set. Mahdieh et al. (2018) examined the impact of zinc oxide (ZnO) nanoparticles and two types of zinc (Zn) fertilisers, namely Zn sulphate and Zn chelate, on the vegetative and yield characteristics of two pinto bean cultivars, namely "KS21191" and "KS21193". There were 24 treatments in total, consisting of three different fertiliser applications and eight levels of Zn fertiliser. The results showed that foliar application twice or once improved the growth and yield characteristics of both pinto bean cultivars, compared to seed application.

El-Desouky et al. (2021) conducted a study aimed to assess the impact of nano-iron (Fe) fertilization on the growth, physiological processes, and yield of tomatoes cultivated in a greenhouse environment. The application of Nano-Fe at a concentration of 100 mg/kg resulted in a significant increase in various plant growth parameters including height, leaf count and size, as well as fresh and dry weights of both shoots and roots. They also observed highest fruit diameter, fruit numbers per plant, total fruit weight per plant, mean fruit weight per plant, total fruit numbers per hectare and total fruit weight per hectare. Nano-Fe at a concentration of 50 mg/kg also showed favourable results compared to other sources and rates of Fe.

Rahman et al. (2021) aimed to examine the impact of hybrid nanocomposite (HNC) and nanozeolite (NZ) on the growth and production of strawberry plants. They also evaluated the effects of combined nano fertiliser (HCN + NZ) on the same parameters. The utilisation of NZ_S from soil resulted in a significant increase in the maximum plant length (12.17 cm), average number of leaves (29.21), average number of fruits (25.52), and average fruit weight (12.95 g).

2.2.2 Fruit Quality

Davarpanah et al. (2016) came to the conclusion that Zn nano-fertilizer (636 mg Zn tree^{-1}) increased pomegranate fruit yield, primarily due to an increase in the number of fruits per tree. Fertilisation with zinc nano fertilizer (120 mg Zn L^{-1}) also resulted in considerable improvements in fruit quality at harvest, including 4.4–7.6% increases in TSS, 9.5–29.1%

decreases in TA, 20.6–46.0% increases in maturity index, and 0.28–0.60 pH unit increases in juice pH. The application of ZnO nanoparticles in cauliflower led to an increase in total sugars and TSS, according to Singh et al. (2013).

Zahedi et al. (2020) explored the effects of foliar spray on strawberries using nanoparticles (NPs) that contained silicon (Si) and selenium (Se) - specifically, SiO_2 nano particles, Se nano particles, and Se/SiO_2^- nano particles on the fruit's yield and quality during drought stress. The application of Se^-, SiO_2^-, and Se/SiO_2 nano particles resulted in a significant increase in the levels of anthocyanin, total phenolic compounds and ascorbic acid content.

According to Rahman et al. (2021) the incorporation of HNCF (hybrid nanocomposite) applied through foliar application with NZ_S (nano zeolite) as soil treatment significantly increased the vitamin A and mineral contents in strawberry. Similarly, the [HNCF + NZ_S] treatment also improved the antioxidant qualities. However, soil and leaves of strawberry treated with HCN (HNC_{SF}) significantly (P 0.05) influenced the proximate composition in terms of ash, protein and fat, while [HNCF + NZ_S] improved carbohydrate and energy.

Montano-Herrea et al. (2022) assessed the bioactive compound content and antioxidant activity of apple fruits as affected by foliar applications of selenium and zinc nanoparticles as well as edaphic fertilisation applications of N, P and K. The investigation demonstrated that the foliar administration of Se nanoparticles at a concentration of 50 ppm and Zn nanoparticles at a concentration of 250 ppm resulted in a significant elevation in the levels of total phenols and flavonoids. These bioactive compounds were found to have a significant impact on the antioxidant activity of the fruits.

Kumar et al. (2022) in their analysis of quality parameters in rice, found that treatment combination of ZnO NPs @ 150 ppm + FeO NPs @ 150 ppm performed best in terms of TSS (16.97 0 B), acidity (0.51), pH (3.36), ascorbic acid (57.43), chlorophyll a (2.70), chlorophyll b (3.87) and total chlorophyll content (4.77).

2.2.5 Nutrient Use Efficiency

Prasad et al. (2012) recorded significant increase in kernel zinc content through application of ZnO nanoparticles (1000 ppm) as compared to chelated $ZnSO_4$ in *Arachis* *hypogaea*. Johnson and Day (2013) observed the increase in leaf Zn content with the application of ZnO nanoparticles (225 g/plant) in California plum.

Zagzog and Gad (2017) reported that application of ZnO nanoparticles (0.5, 1 g/L) significantly increased the leaf mineral (N, P, K and Zn) content in mango cvs. Ewasy and Zebda. El-Sayed et al. (2017) recorded improved leaf Zn content through ZnO nanoparticles (10 ppm) application in date plam cv. Zaghloul.

El-Said et al. (2019) reported maximum leaf Zn content through ZnO nanoparticles at 0.4 ppm in grapes cv. Flame Seedless. Khanm et al. (2018) reported maximum Zn accumulation in fruits through foliar spray of ZnO NPs (400 ppm) in tomato.

2.3 Effect of biofortification with micro nutrients on growth, yield and quality

Utilising nutrient-enriched fertilisers, agronomic biofortification is a simple and rapid way to increase the nutritional value of a crop, and consumption of such crops improves human nutrition (Cakmak and Kutman 2017). In general, agronomic biofortification relies on fertiliser application techniques, mineral element solubilization, and mobilisation from source to sink (consumable plant parts). As macro minerals, nitrogen (N), phosphorus (P) and potassium (K) contribute to yield goals (Bhardwaj et al. 2022). The application of zinc through foliar treatment has been found to be an effective agronomic approach for enhancing the zinc concentration and accessibility in rice grains, as reported by Wei et al. (2012), Boonchuay et al. (2013), Mabesa et al. (2013) and Ram et al. (2016). The application of Zn as a foliar spray along with soil application in soils with low Zn levels resulted in an increase in the Zn concentration in rice grain, as reported by Guo et al. (2016). According to Lata-tenesaca et al. (2023), the application of iron to the leaves of quinoa plants, can be an effective agronomic method for producing quinoa grains that are biofortified with iron. It was discovered that application of Se to the nutrient solution at a dose of 12 mg dm^3 at the first and second cuts significantly increased the total phenol content in basil leaves (Puccinelli et al. 2020). The concentration of zinc in beans was increased through the application of foliar fertiliser containing zinc, as reported by (Ibrahim and Ramadan 2015) and (Ram et al. 2016). Valentinuzzi et al. (2017) found that the Si concentration of strawberry fruit increased as Si availability in the nutrient solution increased. The addition of KIO_3 increased the iodine content of apples and pears to approximately 50-60 g without affecting their growth or marketability (Budke et al. 2021). Liu et al. (2022) found that spraying 2.32 g hm^{-2} sodium selenite on the leaves of buckwheat during the early flowering stage was the most effective selenium biofortification programme.

2.4 Effect of AM fungi and Seleno bacteria on soil and plant characteristics

2.4.1 Effect of AM fungi on soil and plant characteristics

Arbuscular mycorrhizal fungi (AMF) establish a symbiotic relationship with plant roots. Through the extensive hyphal network, mineral nutrients, primarily phosphorus, nitrogen, zinc and water are extracted from the soil and transferred to the plant. In exchange, organic carbon compounds are transferred to the AMF. They are also known to enhance plant nutrient assimilation, protect plants from pathogens (Borowicz 2001, Ismail and Hijri 2012 and Ren et al. 2013) and act as a buffer against adverse environmental conditions, particularly drought (Smith et al. 2010 and Robinson-Boyer et al. 2015). Arbuscular mycorrhizal fungi (AMF) settle in roots of angiosperms while ectomycorrhizal fungi are found in gymnosperms. AMF play an important role in plant nutrition by providing access to soil derived nutrients from sources not necessarily otherwise accessible to roots (Smith and Read 1997).

2.4.1.1 Effect of AM fungi on soil characteristics

AMF has an effect on plant growth and production, but it has also been reported that they improve certain soil characteristics, including soil aggregation, soil nutrients availability, water retention, microbial activities, nitrogen, carbon and phosphorus cycling and soil acidity correction (Sadhana 2014, Jamiokowska et al. 2018 and Parihar et al. 2020). The Arbuscular Mycorrhizae Fungi exhibit a positive impact on the structure of soil. According to de Novais et al. (2019), the AMF mycelia can be found in significant amounts within soil. The mycelia or hyphae possess the ability to form enduring soil aggregates. The extramatrical mycelia of mycorrhizal fungi produce a glycoprotein known as glomalin, which serves as a soil binding agent over an extended period (Singh et al. 2020).

Glomalin is a type of substance that exhibits hydrophobic properties and is capable of withstanding high temperatures, making it thermo-tolerant or heat-resistant in the soil. The water-resistant properties of soil aggregates are attributed to the hydrophobic nature of glomalin. The production of this substance is at its highest during the senescence of mycelia. The glycoprotein can be biodegraded by bacteria and fungi present in the soil, albeit at a slow rate. Glomalin serves as a stabiliser for soil aggregations, according to research conducted by

Hu et al. (2019) and Mubekaphi (2019). It acts as a binding agent that adheres to soil micro-aggregations with a diameter of less than 250µm, resulting in the formation of stable macro-aggregations, as noted by Lehmann et al. (2020).

Soil macro-aggregations play a crucial role in enhancing soil quality and crop productivity. They facilitate improved water infiltration, reduced surface runoff, controlled soil erosion, minimised nutrient and organic matter losses, and increased gas exchange. Additionally, they aid in better retention of water and minerals, particularly potassium, which ultimately leads to improved crop productivity. These findings have been supported by Demenois et al. (2018) and Parihar et al. (2020). Furthermore, it is noteworthy that the mycelial network undergoes continuous self-renewal, and the expired mycelia serve to maintain the integrity of the soil structure until they undergo decomposition, as indicated by Gianinazzi et al. (2010). The deceased mycelia play a role in the accumulation of organic material and act as a physical binding agent in the process of soil aggregation, as noted by Hamel and Plenchette (2017).The implementation of these mechanisms serves to mitigate the likelihood of soil compaction and enhance soil fertility, as posited by Norton et al. (2020).

AMFs are known to enhance soil structure via their chemical and biophysical mechanisms, including enmeshment and alignment. Nonetheless, there exists a dearth of data regarding the duration of glomalin's existence within the soil and the impact of anthropogenic practises, such as controlled burning of vegetation, on soil glomalin (Fall et al. 2022).

Arbuscular Mycorrhizae fungi symbionts are recognised as significant microbial contributors to the formation of the three major biogeochemical cycles of soils (P, N and C). Consequently, the proliferation of mycorrhizal plants is enhanced (Fall et al. 2022). AMF performs a crucial role in enhancing soil P availability. In fact, it is a P activator that can speed up the transformation of P into bio-available forms through a variety of chemical reactions and biological interactions (Zhu et al. 2018).

According to Zhang et al. (2016), recent studies indicate that AMF do not possess the ability to release phosphatases into the soil. However, these fungi are capable of enlisting the help of Phosphate Solubilizing Bacteria (PSB) that are known to produce phosphatase. This enzyme is responsible for the mineralization of organic P and performs a function that is not present in AMF. Zhang et al. (2018) and Etesami and Jeong (2021) also support this finding.

AMF has the ability to convert inorganic phosphate into soluble forms through various processes such as acidification, chelation, exchange reactions, and production of organic acids, H+, and metabolites. This has been documented in studies conducted by Relwani et al. (2008) and Behera et al. (2014). According to Liu et al. (2013), the alkaline phosphatases produced by AMF's metabolic activities are responsible for breaking down soil substrates and rendering phosphate available. Furthermore, AMFs facilitate the liberation of phosphorus (P) from rock phosphate (RP) fertiliser. The effectiveness of RP is low. The reason for this occurrence is that when utilised as fertiliser, only a single component is available for plant uptake, while the remaining portion is transformed into insoluble fixed forms, as noted by Billah et al. (2019). According to Andrino et al. (2021), AMF has the ability to dissolve insoluble phosphate from RP, thereby rendering it accessible in the soil. Insoluble phosphorus is converted into soluble forms by AMF through the production of acids during their metabolic activities, as stated by Kalayu (2019).

Arbuscular mycorrhizal fungi facilitate the mobilisation of NH^{+4}, which is the inorganic form of nitrogen, from the soil. This has been demonstrated by Casieri et al. in 2013. The AMF mycelium has the capability to assimilate nitrogen through various sources such as ammonium ions (NH^{+4}), nitrates (NO^{-3}), and amino acids, as reported by Chen et al. (2018), Drechsler et al. (2018) and Jansa et al. (2019).

The Arbuscular Mycorrhizae Fungi have a crucial function in the worldwide carbon cycle. The hyphae of AMF play a crucial role in the translocation of carbon into the soil, serving as a vital connection in the carbon cycle of terrestrial ecosystems (Finlay 2008). Studies have shown that mycorrhizal roots have the ability to create a carbon sink demand. According to Drigo et al. (2010), an increase in atmospheric CO_2 leads to a corresponding increase in the allocation of carbon from plants to AMF, resulting in the stimulation of AMF growth. The host plant supplies the required C through the C fixed via photosynthesis, as stated by Parihar et al. (2020). AMF extramatrical hyphae account for 20-80% of the soil microbial biomass, which is composed of 15% of soil organic carbon, according to Kabir et al. (1997) and Leake et al. (2004).

AMF have a significant role in the creation and preservation of soil aggregates by generating Glomalin. Glomalin is a substance that safeguards organic matter from microbial breakdown. It also enhances the hydrophobicity and stability of macro-aggregations, which regulate soil carbon loss and boost soil carbon storage. AMF have been found to enhance the absorption of low mobility trace elements in soils, including potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), zinc (Zn), iron (Fe), manganese (Mn), and cobalt (Co) (Garcia et al. 2016 and Hashem et al. 2018).

The fertility of soil is enhanced by the microbial activities that occur through a combination of microorganisms working together in synergy, competing with each other, and engaging in parasitism, as described by Topalovic and Vestergård (2021)**.** AMFs engage in interactions with various microorganisms present in the soil to enhance soil fertility. Veresoglou and Rillig (2012) have shown that the secretions of AMF have an impact on the microbial communities in the rhizosphere, both in terms of their composition and activity. The influence of AMF communities on the physicochemical environment of the rhizosphere and their control over various soil microbial interactions have been documented by Alimi et al. (2021). The process of mycorrhization has a direct impact on both the quantity and quality of root exudates. The exudates have an impact on the microflora composition of the rhizosphere, as stated by Baltrus in 2017.

2.4.1.2 Effect of AM fungi on plant characteristics

Arbuscular mycorrhizal fungi are extensively spread in a variety of ecosystems, including stressed situations, and they form symbiotic connections with the roots of vascular plants (Sadhana 2014). This symbiosis improves soil nutrients like phosphorus (P), nitrogen (N), sulphur (S), potassium (K), calcium (Ca), copper (Cu), and zinc (Zn) (Nadeem et al. 2014 and Turrini et al. 2018). It has been demonstrated that up to 60% of a plant Cu, 25% N, 25% Zn and 10% K can be delivered by the external hyphae of AMF (Marschner and Dell 1994).

Fan et al. (2008) found that when compared to the control, the blossom date was shortened by 3 days and the fruit ripening date was shortened by 4 days with AMF inoculated plants in strawberry cv. Zozi. Inoculation of strawberry seedlings with AMF significantly increased berry yield, being 7.1% more over control (Singh et al. 2010).

Cekik (2012) also showed that inoculated plants with *Glomus mosseae*, *Glomu sintraradices*, *Glomus etunicatum* and the mixture of these fungi exhibited an increase in shoot, root dry weight, P and Zn content compared to control plants. Also the mycorrhizal inoculated pepper seedlings flowered earlier than non-inoculated plants.

There was a greater accumulation of proteins, proline and soluble sugars on the onion leaves of plants that had been inoculated with AMF, as reported by Bettoni et al. (2014). This resulted in the onion seedlings being able to tolerate environmental challenges better, which led to improved growth.

Bona et al. (2015) investigated the effect of inoculation with a mixture of arbuscular mycorrhizal fungi (AMF) and/or two strains of plant growth-promoting bacteria (PGPB) on strawberry fruit quality and yield. They observed an increased percentage of dry mass, higher sucrose content and ascorbic acid in fruits inoculated with AMF.

Hart et al. (2015) carried out an experiment to study whether inoculation by AM fungi (*Rhizophagus irregularis*, *Funneliformis mosseae*, or both) can affect food quality of tomato fruits, particularly common minerals, antioxidants, carotenoids, a set of vitamins, and flavor compounds (sugars, titratable acids and volatile compounds). It was found that inoculation of AM fungi increased the nutrient quality of tomato fruits for most nutrients except for vitamins. Inoculated plants had fruit with higher antioxidant capacity, more carotenoids and increased fruit mineral concentration.

Robinson et al. (2016) reported that strawberry inoculated with Liquid spore suspension (L_AMF) and granular commercial inoculum (G_AMF) of *R.irregularis*. AMF-treated strawberries (particularly G_AMF) had increased fruit production in the mid to late harvest period. On average the G_AMF and L_AMF treatments led to a greater ($P < 0.05$) number of fruit than the control.

Chandel et al. (2017) carried out an investigation to study the effect of various mycorrhizal products on growth, yield and quality of tomato (*Solanum lycopersicum* L.) cv. Arka Vikas. Results from the analysis revealed that soil application with Myc100 @ 250 g/ha had the best performance with respect to most of the characters namely number of nodes per plant (23.57), number of fruits per plant (31.00), fruit length (5.69 cm), average fruit weight (91.95 g), fruit yield per plant (2696.27 g), fruit yield per plot (67.41 kg) and fruit yield (748.96 q/ha) while Foliar application with Ratchet @ 300 mL/ha 2 applications at 30 and 60 DAT obtained highest value (132.17) pertaining to the plant height (cm) and for the parameters like Internodal length (6.76 cm), days to 50% flowering (33.33) and flower drop (33.31%) the maximum value was observed in untreated Control.

Todeschini et al. (2018) studied effect of three different AMF (*Funneliformis mosseae, Septoglomus viscosum,* and *Rhizophagus irregularis*) in combination with three different strains of *Pseudomonas* sp. (19Fv1t, 5Vm1K and Pf4) to inoculate plantlets of *Fragaria×ananassa* var. Eliana F1. AMF mostly affected the parameters associated with the vegetative portion of the plant. Castellanos et al. (2012) found that the leaf area of AMF (*Glomus intraradices)* inoculated strawberry plants was significantly higher than non-inoculated plants with 3.0 mmol L^{-1} N at 49 days.

Chiomento et al. (2019) reported that strawberry plants inoculated with the AMF produced fruits containing and develop a more profuse root system, on average, 65% more anthocyanins compared to fruits of non-mycorrhized plants. The impact of the AMF inoculation on the physicochemical qualities of strawberry fruit in the field was assessed by Cordeiro et al. (2019). The inoculation of strawberry plants in the field with AMF enhanced the physicochemical characteristics of the fruit, including the pH, soluble solids content, soluble solids/titratable acidity ratio, and phenolic compounds content.

Cao et al. (2021) conducted research to investigate how AM fungus influence the quality of citrus fruit. Under the conditions of AMF inoculation, the single fruit weight, equatorial diameter, polar diameter, fruit peel weight, sarcocarp weight, total soluble solids content, and coloration value were significantly increased by 38.8, 18.0, 14.0, 70.0, 43.1, 14.6 and 4.7% respectively, in comparison to the non-AMF treatment.

Masrahi et al. (2023) evaluated the useful influences of the combinations between phosphorus fertilizer rates and arbuscular mycorrhizal fungi (AMF) in Barley. They observed significant changes in plant height, spike length, and spikes weight of barley were obtained among treatments in 2018-19 and 2019-20. The tallest plants were obtained with AMF + 100% RDP (Recommended dose of phosphorus) and AMF + 66% RDP and the increase was by 19.76 % and 17.76 % in the first year, while the increase was by 19.86 % and 17.84 % in the second year, respectively. AMF + 100% RDP achieved the heaviest weight of spikes. The increase in the weight of the spike was by the percentage of 40.08 and 40.47 during both seasons.

2.4.2 Effect of Seleno bacteria on soil and plant characteristics

Numerous studies have been conducted in recent years to explore different techniques for enhancing the Se content in crops. This is due to the scarcity of Se in most soils and the fact that plants are the primary source of this element in the diet of humans and animals (Schiavon et al. 2013). According to Amato et al. (2020), the conversion of inorganic Se to organic forms with higher bioavailability in plants makes agronomic Se biofortification a more advantageous method compared to direct Se supplementation. Plant endophytes have the ability to extract and convert trace amounts of selenium from soil, subsequently transferring it to the plant in a bioavailable form through reduction. Selenobacteria are a unique group of bacteria that can accumulate and transform selenium, an essential trace element, in the environment. These bacteria play an important role in selenium biogeochemistry and can influence a variety of soil properties.

Selenobacteria have been discovered to be bacteria that benefit plants and promote their growth (Duran et al. 2014 and Trivedi et al. 2020). Thus the application of selenobacteria to crops is a viable method for achieving this objective.

2.4.2.1 Effect of Seleno bacteria on soil characteristics

Selenobacteria are known to play an important role in the selenium cycle in soils. They can transform various species of selenium and contribute to the transformation of inorganic selenium into organic forms. This process has been investigated in a range of environments, including agricultural soils and selenium-rich habitats.

Selenobacteria interact with other soil microorganisms, such as bacteria, fungi, and archaea. These interactions can affect the composition and diversity of the soil microbial community, which in turn can have an effect on a variety of soil properties and processes. *Stenotrophomonas maltophilia, C. testosteroni*, and other rhizobacteria transform toxic Se(IV) and Se(VI) into nontoxic Se species. The transformation of stable Se species in soil by various soil microorganisms increases the bioavailability of Se and plant uptake of Se (Lindblom et al. 2014).

2.4.2.2 Effect of Seleno bacteria on plant characteristics

Duran et al. (2013) studied that plants inoculated with Enterobacter sp. B16 strain had the highest Se concentration in wheat grain. The relative Se content in grain from plants inoculated with selenite-enriched selenobacteria was 25-34% (113-236 mg/kg) in relation to total Se in plant tissues for mycorrhizal and non-mycorrhizal plants, respectively.

Duran et al. (2016) reported a positive effect of endophytic selenobacteria on foliar macronutrient and micronutrient concentrations in lettuce shoots. Plants inoculated with endophytic selenobacteria showed significant macronutrient (P, K, Ca, Mg) and micronutrient (Mn, Fe, Cu, Zn) acquisition compared to the non-inoculated plants.

Trivedi et al. (2020) in their study, investigated the impact of three selenobacteria strains, specifically *Paraburkholderia megapolitana, Alcaligenes faecalis* and *Stenotrophomonas maltophilia,* on the growth of *Glycine max* plants under drought conditions. The researchers determined that *Paraburkholderia megapolitan* exhibited the highest efficacy in enhancing plant growth and demonstrated exceptional selenium fortification, which was 7.4 times greater than the control. The application of *P. megapolitana* on plants resulted in a significant rise in selenium concentration across different plant tissues. Notably, the highest increase was observed in leaves, which exhibited a 7.4-fold increase compared to the control. Similarly, fruits, roots, and shoots showed a 6.6-fold, 6.4-fold, and 5.8-fold increase, respectively, compared to the control.

Moteshare et al. (2020b) found that spinach plants grown in calcareous soil and treated with Se by selenobacter inoculant and foliar application had the highest shoot length (up to 126% compared to control) and dry weight

2.5 Interactive effects of AM fungi, micronutrient applications and bacterial inoculants on soil and plant characteristics

Many microbes assist plants to take up nutrients from soils, resist abiotic stress, and improve their growth and yield. These beneficial microbes may also be exploited for bio-fortification. Dark septate fungi, mycorrhizal and root endophytic fungi, plant growth-promoting rhizobacteria (PGPR), etc. are used for Se bio-fortification.

Lingua et al. (2013) in an experiment recorded that AMF and PGPB increased the concentration of anthocyanin in strawberry cv. Selva compared to control. Strawberry plants inoculated with AMF and/or PGPB showed an increased productivity compared to uninoculated ones, both in conventional and in reduced fertilization. Inoculation also induced earlier flowering and fruiting (2 and 3 weeks in advance, respectively) compared to CFD and CRD plants. AMF and PGPB positively affected fruit size, measured as mean fresh weight, length, and diameter (Bona et al. 2015).

Golubkina et al. (2019) evaluated the interactions between AMF inoculation and the supply of organic or inorganic Se forms to shallot plants. The application of AMF led to a significant increase in production. However, the impact of selenium treatment varied depending on the form of the compound used. Sodium selenate had a positive effect on bulb yield only when applied to plants that had been inoculated with AMF. The inoculation of AMF resulted in an increase in bulb quality indicators, macro- and microelements, ascorbic acid, and antioxidant activity. The two forms of selenium exhibited a positive effect on most of the quality attributes and macroelements, as well as selenium and ascorbic acid. The application of AMF resulted in a significant increase of 530% in the selenium content of the bulb. Furthermore, the biofortification of selenium using selenocystine and sodium selenate increased the bulb selenium content by 36% and 21%, respectively. Higher values of anthocyanin observed with, the AMF-inoculated fruits of the Camarosa, Aromas and Monterrey cultivars of strawberry in relation to non-inoculated plants (Cordeiro 2019).

Golubkina et al. (2020) studied the effects of AMF inoculation, sodium selenate foliar application, and the combination AMF + selenium (Se), compared to an untreated control, were assessed regarding the bulb yield, biochemical characteristics, and mineral composition. The application of AMF and selenium (Se) resulted in the highest yield, monosaccharides, and Se content in both *Allium sativum* and *Allium cepa* bulbs. Additionally, there was an increase in ascorbic acid and flavonoids in onion, and flavonoids in garlic. The bulbs exhibited a significant rise in microelement levels (Boron, Copper, Iron, Manganese, Silicon, Zinc) when subjected to AMF and Selenium (Se) treatment.

Antoniou et al. (2021) investigated the impact of Selenium and/or inoculation on the growth and development of strawberry plants. With or without inoculating the root system with AMF, four Se concentrations (0, 1, 5, and 10 mg L^{-1}) in the nutrient solution were assessed. The inoculation of AMF primarily triggered the activation of antioxidative pathways in the fruits and enhanced nutrient uptake in plants cultivated under high selenium (Se) levels. Strawberries appear to be a good candidate for Se biofortification, and mycorrhizal inoculation can improve the nutritional value of strawberry fruits. This will increase the amount of Se that consumers consume.

Jiang et al. (2023) examined the effects of microorganisms on the Se availability of Se-enriched lateritic red soil and the Se absorption by pak choi. Following incubation with selenobacteria (*Stenotrophomonas maltophilia*) and AMF agent, the available Se content of soils increased by 90.50–234.40%, from 35 to 66.69–117.04 g/kg. After adding the AM fungi agent and selenobacteria, the Se bioconcentration and translocation factors in pak choi rose. The soil acid phosphatase activity increased, as did the pak choi root length, surface area, and diameter.

Lachinani et al. (2023) conducted an evaluation of the impact of AMF, *Trichoderma* and selenium (Se) on the yield of strawberry crops and the activity of antioxidant enzymes. Treatments with trichomonia and mycorrhizal fungi raised yield by 39.6% and 27.1%, respectively. The application of *Trichoderma*, mycorrhizae, and Se was employed to optimise catalase activity to a level of 4 mg^{-1} kg soil. The facilitation of enhanced element absorption by mycorrhizal fungi and *Trichoderma* seems to result in an increase in enzyme yield and activity.

Chapter-3

MATERIALS AND METHODS

The present study entitled **"Interactive effects of nano zinc, AM fungi and selenobacteria for selenium biofortification in strawberry (*Fragaria* × *ananassa* Duch.)"** was carried out during two consecutive years 2020-21 and 2021-22 under protected conditions. The detail of the materials and methodologies used during the course of study has been described under the following heads:

3.1 General

3.1.1 Geographical conditions

The experiment was carried out in the Experimental block of Department of Fruit Science, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh. The study area is typically sub-temperate and lies in the geographical coordinates between 30°52' North (latitude) and 77°11' East (longitude) at an elevation of 1275 m above mean sea level.

3.1.2 Climate

Maximum mean air temperature was 33.8°C, while, minimum mean air temperature was 14.3°C during the growth period. The highest and lowest average soil temperatures recorded were 21.9°C and 17.2°C, respectively. However, since trial was conducted under protected conditions the above parameters were not recorded in the polyhouse since the conditions were controlled.

3.1.3 Soil Properties

Physico-chemical properties of soil were determined before the start of experiment and detailed information is presented in Table 3.1.

Table 3.1: The physico-chemical characteristics of the experimental soil before the start of experiment

Sr No.	Soil Properties	Content (0-30 com soil depth)
1	pH	6.60
2	EC (dSm^{-1})	0.20
3	OC (%)	0.40
4	N ($kg\ ha^{-1}$)	352.11
5	P ($kg\ ha^{-1}$)	37.74
6	K ($kg\ ha^{-1}$)	320.21

3.2 Experimental Detail

3.2.1 Planting material

The experiment was carried out on day neutral strawberry cv. Sweet Charlie during second fortnight of October for two successive cropping seasons (2020-21 and 2021-22). Healthy runners that were free of any diseases, insects, or pest incidence were chosen. In the second year of the experiment, runners from the first year were used as planting material. All runners were given uniform cultural practices during the entire course of study.

3.2.2 Zn nutrient source

The efficacy of Zn nutrient source on cropping behavior and soil properties of strawberry plantlets was studied. In the experiment, nano zinc oxide served as the Zn source. Nano ZnO contained 7.91-8.15 % zinc and had an average particle size of less than 100 nm and a specific surface area of 15-25 (m^2/g), sourced from Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu.

3.2.3 Selenobacteria source

Bacterial strains (*Stenotrophomonas maltophilia* and *Alcaligenes faecalis*) used in the study were procured from National Bureau of Agriculturally Important Microorganisms (NBAIM), Kushmaur, Mau Nath Bhanjan (UP).

3.2.4 AMF source

Mychorrizal biofertilizer in the name of VAM Shakti was procured from International Panacea limited, Gurugram, Haryana.

3.2.5 Field trial

The experimental unit comprised of 2 × 1 m plot with each bed 0.5 m apart. The runners were transplanted on raised beds at 30 × 60 cm spacing and accommodated approximately 55,000 number of runners per hectare using double-row planting method given by Guleryuz et al. 1997. The experiment was laid in Randomized Block Design and replicated thrice. Prior to transplanting, the runners were dipped in bavistin for 10 minutes to prevent any disease infestation during cropping period. The runners also received routine horticultural care in accordance with the scientific commercial strawberry production practices including application of farm yard manure, recommended dose of NPK (80:40:40 kg/ha), weed control, the optimal operations for irrigation and other plant protection measures.

3.2.6 Foliar spray and application

10 g of Vesicular Arbuscular Mycorrhiza (VAM) having an average of 100 propagules g^{-1} were inoculated into each plant in the mycorrhizal treatments at the time of

Plate 1. Overview of experimental field

transplanting, 30 and 45 days after transplanting. Two strains of selenobacteria were grown in 200 mL of nutrient broth (Oxoid, Ltd., UK) supplemented with 5 mM of sodium selenite [Se(IV), Na_2SeO_3] and sodium selenate [Se(VI), Na_2SeO_4] (Merk, Inc.). After growth at 30ºC for 24 h with continuous shaking (150 rpm), the bacterial cells were collected by centrifugation (1500 × g) for 10 min, rinsed twofold with sterile saline solution (SSS) (0.85% NaCl) and resuspended in 30 mL of SSS ($1\text{-}2 \times 10^9$ cfu mL^{-1}) (Duran et al. 2013). 5ml of solution per plant were inoculated thrice, at the time of transplanting, 30 and 45 days after transplanting. Nano ZnO solution was prepared with distilled water. The required amount of Nano ZnO was weighed and final volume was made to one litre. Before use, from the stock solution, further dilutions of desired concentrations were prepared. The final dilutions were put in sprayer and sprayed uniformly on the plants. Foliar application was carried out twice at 30 and 60 days after transplanting.

3.2.7 Treatment combination:

T1	AM_0	SeB_0	ZnO_0
T2	AM_0	SeB_0	ZnO_1
T3	AM_0	SeB_0	ZnO_2
T4	AM_0	SeB_1	ZnO_0
T5	AM_0	SeB_1	ZnO_1
T6	AM_0	SeB_1	ZnO_2
T7	AM_0	SeB_2	ZnO_0
T8	AM_0	SeB_2	ZnO_1
T9	AM_0	SeB_2	ZnO_2
T10	AM_1	SeB_0	ZnO_0
T11	AM_1	SeB_0	ZnO_1
T12	AM_1	SeB_0	ZnO_2
T13	AM_1	SeB_1	ZnO_0
T14	AM_1	SeB_1	ZnO_1
T15	AM_1	SeB_1	ZnO_2
T16	AM_1	SeB_2	ZnO_0
T17	AM_1	SeB_2	ZnO_1
T18	AM_1	SeB_2	ZnO_2

AM_0:without AMF
AM_1: with AMF

SeB_0 :without Selenobacteria
SeB_1:*Stenotrophomonas maltophilia*
SeB_2 :*Alcaligenes faecalis*

ZnO_0: 0
ZnO_1: 100 ppm
ZnO_2 : 200 ppm

3.3 OBSERVATIONS RECORDED

3.3.1 Growth indexes

3.3.1.1 Plant height

Plant height of randomly selected and tagged strawberry plants was measured at the interval of 60, 90 and 120 days after transplanting with a measuring scale from the crown level to apex of the primary leaf. The average was taken and the values were expressed in centimetre (cm).

3.3.1.2 Number of leaves

Fully expanded leaves were counted from randomly selected and tagged plants during the season and the results were expressed as average number of leaves per plant.

3.3.1.3 Leaf area

Ten fully expanded leaves were collected randomly during the grand growth period in the month of March. Leaf area (LA) was recorded with Li-COR 3100 leaf area meter. The average values of leaf area were expressed in square centimetre (cm^2).

3.3.1.4 Number of crowns

Number of crowns was counted at the end of fruiting season from randomly selected and tagged plants. The average values were expressed as total number of crowns per plant.

3.3.1.5 Number of runners

Average number of runners emerged throughout the cropping cycle were counted at the end of fruiting season from each plot. It was recorded by counting their number from randomly selected and tagged plants in each replication for each treatment. Their average was expressed in terms of number of runners per plant.

3.3.2 Flowering traits

3.3.2.1 Flower initiation after transplanting

The days between date of planting and opening of first flower was recorded as time of initiation of flowering in randomly selected and tagged plants.

3.3.2.2 Duration of flowering

The date of opening of first flower and opening of last flower during the cropping season was recorded to calculate the duration of flowering.

3.3.2.3 Number of flowers per plant

Total numbers of flowers were counted from randomly selected and tagged plants and the average was expressed as number of flowers per plant.

3.3.3 Yield related attributes

3.3.3.1 Fruit set per cent

To record observation on fruit set, counting the number of fruits at twenty days interval was done according to Westwood (1978) using the formula:

$$\text{Fruit set (\%)} = \frac{\text{Total number of fruit set}}{\text{Total number of flower}} \times 100$$

3.3.3.2 Number of fruits

The primary, secondary and tertiary fruits were counted throughout the season and the total number of fruits was expressed as cumulative fruit number.

3.3.3.3 Fruit yield

The fruit were handpicked twice a week with a total eight to ten times of harvesting throughout the cropping period. The observations were recorded on total marketable yield of berries, and expressed in grams per plant (g/plant).

3.3.3.4 Yield efficiency

Yield efficiency (YE) was calculated as per the formula suggested by Westwood (1978) on leaf area basis as gram per square centimetres of leaf area (g/cm^2 of LA).

$$\text{Yield efficiency} = \frac{\text{Fruit yield per plant}}{\text{Leaf area}}$$

3.3.4 Fruit quality parameters

The strawberry fruits produced during the cropping cycle were sampled and then rapidly transferred to the laboratory for physical and biochemical analyses using standard procedures (A.O.A.C. 1980).

3.3.4.1 Physical Parameters

3.3.4.1.1 Fruit dimension

Fruit dimension (length and breadth) of ten randomly selected fruits (berries) was measured with the help of digital vernier scale (±0.05 mm accuracy). Average of fruit length and breadth was calculated and the values were expressed in millimetres (mm).

3.3.4.1.2 Fruit weight

Fruit weight of randomly selected ten fruits was measured on a top pan electronic balance. The average was taken and the values were expressed in grams (g).

3.3.4.1.3 Fruit firmness

Fruit firmness was determined using Effegi Penetrometer model FT-011 (used for berries) and the values were expressed in pound per square inch (lbs/inch^2).

3.3.4.1.4 Shape index

The ratio of length to width of fruits was used to calculate shape index of the samples.

3.3.4.2 Biochemical Attributes

3.3.4.2.1 Total soluble solids

Total soluble solids (TSS) content in fruit samples were determined with Erma Hand Refractometer (0-32) by putting a drop of fruit juice squeezed (at full ripe stage) on its prism. The refractometer was calibrated with distilled water before use. After each test, the prism plate was cleaned with distilled water and wiped with a soft tissue. Ten readings from each sample were averaged and the results obtained were expressed as °Brix.

3.3.4.2.2 Titratable acidity

Ten grams of fruit pulp was crushed in a Warring blender, adding distilled water and the final volume was made up to 100 ml. The contents were filtered through Whatman No. I filter paper. Ten ml of extract was titrated against 0.1 N NaOH solution using phenolphthalene as an indicator. The appearance of pink colour indicated the end point. The total titratable acidity was calculated on the basis of 1 ml of 0.1 N NaOH equivalents to 0.0067 gram of anhydrous malic acid. The results were expressed as percentage of total titratable acidity on fresh fruit weight basis.

$$\text{Titratable acidity (\%)} = \frac{T \times N \times V1 \times E}{V2 \times W \times 1000} \times 100$$

Where,

T = Titre value
N = Normality of NaOH
V1 = Volume made
E = Equivalent weight of acid
V2 = Aliquot taken
W = weight of sample (g)

3.3.4.2.3 TSS: acid

TSS: acid ratio was worked out by dividing the total soluble solids (TSS) to the titratable acidity (TA) of the fruit samples.

3.3.4.2.4 Total sugars

Twenty five grams of fruit pulp was taken in a 250 ml volumetric flask and thoroughly homogenized in distilled water. To this 10 ml of 45 per cent saturated lead acetate was added and the contents were shaken and filtered and kept for ten minutes. Thereafter, ten ml of 22 per cent potassium oxalate was added to precipitate the excess of lead and make the final volume 250 ml with distilled water. Then the contents were again filtered and 100 ml of the filtrate was taken in another 250 ml volumetric flask and 5 ml of concentrated hydrochloric acid was added to it. The hydrolysis was carried out by keeping it overnight. The excess of acid was then neutralized by adding saturated sodium hydroxide and the final volume was made to 250 ml with distilled water. The hydrolyzed aliquot was then taken in a burette and titrated against a boiling mixture of 5 ml solution each of Fehling A and Fehling B using methylene blue as an indicator (A.O.A.C. 1980). The end point was indicated by the appearance of brick red colour. Total sugars were expressed in per cent on fresh fruit weight basis.

$$\text{Total sugars (\%)} = \frac{0.05 \times \text{Dilution}}{\text{Titre value} \times \text{weight of sample taken} \times \text{volume of aliquot taken}} \times 100$$

3.3.4.2.5 Reducing sugars

The remaining unhydrolyzed solution obtained after the estimation of total sugars was titrated against boiling solution of 5 ml each of Fehling A and Fehling B using methylene blue as an indicator (A.O.A.C. 1980). The end point was marked by the appearance of brick red colour. The reducing sugars content was expressed as the per cent of fresh weight of fruit pulp.

$$\text{Reducing sugars (\%)} = \frac{0.05 \times \text{Dilution}}{\text{Titre value} \times \text{weight of sample taken}} \times 10$$

3.3.4.2.6 Non-reducing sugars

The amount of non-reducing sugars was worked out by subtracting the reducing sugars from total sugars and multiplying the difference with a standard factor i.e. 0.95. The results were expressed as per cent of non-reducing sugars using formula as

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

3.3.4.2.7 Ascorbic acid

Extraction solution

Fifteen grams of metaphosphoric acid pellets were dissolved in 40 ml of glacial acetic acid and 200 ml of distilled water. The volume was made to 500 ml by using distilled water. The solution was filtered rapidly through Whatman No. 1 filter paper and stored in coloured bottle in refrigerator.

Preparation of solution

100 g of analytical grade ascorbic acid (reference standard) was weighed accurately on electronic balance and dissolved in 10 ml of metaphosphoric acid extraction solution. The content was then transferred to a 100 ml volumetric flask and the final volume was made to 100 ml with metaphosphoric acid solution. The solution was then diluted to 1 litre before use with metaphosphoric acid solution, so that it consumes less dye.

Indophenol Standard Solution

50 mg of 2, 6-dichlorophenol indophenol sodium salt was dissolved in 150 ml distilled water in a beaker. 42 mg of sodium bicarbonate was added to it. The contents were

shaken vigorously and when 2, 6-dichlorophenol indophenol was dissolved, it was diluted with distilled water to 200 ml. It was then filtered and stored in dark coloured bottle in refrigerator.

$$\text{Dye factor} = 0.5/\text{ titre value}$$

Estimation

25 g of fruit pulp was homogenized in metaphosphoric acid (extraction solution) and the volume was made to 100 ml in a volumetric flask. The 10 ml of this solution was then titrated against 2, 6-dichlorophenol indophenol dye as indicated by appearance of light pink colour (the end point). The amount of ascorbic acid present in the fruit juice was calculated by using formula:

$$\text{Ascorbic acid (mg/100g)} = \frac{\text{Dye factor} \times \text{Titre value} \times \text{Volume made up}}{\text{Weight of fruit taken} \times \text{Volume used for estimation}} \times 100$$

3.3.4.2.8 Anthocyanin content (mg/100g)

Total anthocyanin present in the samples were determined by the method given by Rangana (2007). The procedure involved extraction of the anthocyanins with methanolic-HCl and measurement of colour at the wavelength of 535 nm against blank of methanolic-HCl using a UV -VIS spectrophotometer (Model Shimadzu, Japan). The anthocyanins were calculated and expressed as mg per 100 ml using the formula given below:

$$\text{OD/100ml} = \frac{\text{Optical density (OD)} \times \text{Volume made up of the extract used for the color} \times \text{Total volume}}{\text{Volume of the extract used} \times \text{Volume of the sample taken}} \times 100$$

$$\text{Total anthocyanin content (mg/100 ml)} = \frac{\text{X}}{\text{E}}$$

Where, X = Total OD per 100 ml

E = Extinction coefficient (98.2)

3.3.5 Plant analysis

3.3.5.1 Collection and preparation of samples

A composite sample of twenty fully expanded trifoliate leaves (petiole along with leaflets) was prepared for each treatment (Chapman 1964). The leaf samples were brought to laboratory thoroughly washed under tap water followed by 0.1 N HCl to remove the dust particles. Distilled water was used for final washing. The samples were firstly air dried and then kept in oven at 65 ± 5 °C for final drying. The dried samples were finely ground and homogenized. The ground samples were then stored in butter paper bags and kept in a cool, dry and shady place for nutrient elements estimation. Sampling and the preparation for leaf chemical analysis was carried out using standard procedure. The ripe berries (fruits) produced during the cropping cycle were also sampled, and then rapidly transferred to the laboratory for nutrient analysis using standard procedures.

3.3.6.2 Digestion of leaf and fruit samples

For the estimation of nitrogen, one gram of leaf and fruit sample were separately digested in 20 ml concentrated H_2SO_4 along with digestion mixture comprising potassium sulphate (K_2SO_4, 400 parts), copper sulphate ($CuSO_4$, 20 parts), mercuric oxide (HgO, 3 parts) and selenium powder (Se, 1 part). The completely digested sample was indicated by the appearance of light blue colour. To estimate P, K and Zn content, 0.5 g of the leaf sample was digested in diacid mixture of HNO_3 and $HClO_4$ in the ratio of 4:1 (Piper 1966). The end point of digestion was 2-3 ml of colourless sample. After the completion of digestion, the final volume of the extract obtained was made to 100 ml with distilled water for all the samples.

3.3.6.3 Estimation of nutrients

Leaf N was estimated by Macro-Kjeldahl's method and leaf and fruit P content was determined using vanado molybdate phosphoric yellow colour method (Jackson 1973).

The phosphorous was estimated by Vanado-molybdo-phosphoric acid method (Jackson 1973). Five ml of extract (di-acid digested sample) was taken in 25 ml of volumetric flask. To this flask 20 ml of working solution was added and final volume was made to 25 ml with distilled water. The contents were mixed and used for estimation of phosphorous on Spectronic-20 D at 470 ηm wavelength using red filter. The colour intensity (yellow) was recorded and the phosphorous content was measured with the help of standard curve.

The potassium in plant tissue was estimated on flame photometer (Jackson 1973). The digested samples were diluted to 100 ml with distilled water. 5 ml of this prepared sample was diluted to 50 ml with distilled water. The samples vis-à-vis to standards are fed one by one to the Flame photometer and readings were recorded in ppm.

The quantification of Zn, Fe, Cu, Mn and Se was carried out on Perkin Elmer atomic absorption spectrophotometer.

3.3.6 Soil properties

Collection and preparation of soil samples

Soil sample from 0-15 cm depth were collected and a composite sample (weighed up to 1kg) was prepared for each treatment. The samples were air-dried in shade, grounded and sieved through 2 mm mesh sieve. The processed samples were kept in cloth bags with suitable labels for estimation of chemical properties.

3.3.6.1 Chemical properties

3.3.6.1.1 Soil pH

The soil pH was determined in soil: water suspension of 1:2:5 using a pH meter, as described by Jackson (1973). The same extract kept for subsequent determination of electrical conductivity.

3.3.6.1.2 Electrical conductivity

The electrical conductivity in 1:2:5 soil suspension kept overnight was measured by Systronic's conductivity meter and expressed as dS m^{-1} (Jackson 1973).

3.3.6.1.3 Organic carbon

Organic carbon was determined by Chromic acid titration method of Walkley and Black (1934).

3.3.6.1.4 Available Nitrogen

Twenty gram of soil was weighed and moistened with distilled water. Then, it is added to Kjeldahl distillation flask and 100 ml of 0.32 per cent $KMnO_4$ and 100 ml of 2.5 per cent NaOH were added to the assembly and cork was fitted immediately (Subbiah and Asija 1956). 25 ml of 0.02 N H_2SO_4 was taken in conical flask and 2-3 drops of methyl red indicator were added. Heater was switched on to distill ammonia gas and 30-50 ml of distillate was collected in 0.02N H_2SO_4 containing conical flask. The excess of H_2SO_4 in conical flask was titrated against 0.02 N NaOH and change in colour from pink to yellow was noted as end point. Simultaneously, a blank was also used taking all the chemicals except the soil.

$$\text{Available Nitrogen (\%)} = \frac{(\text{B}-\text{A})\times 0.00028}{\text{Weight of soil}} \times 100$$

Where, A = Volume of 0.02 N NaOH used in sample
B = Volume of 0.02 N NaOH used in blank

3.3.6.1.5 Available Phosphorus

One gram of soil was taken in a 100 ml conical flask followed by the addition of pinch of Darco-G 60 and 20 ml of 0.5 N sodium bicarbonate of pH 8.5 (Olsens et al. 1954). The contents were shaken for thirty minutes and filtered to obtain clear filtrate. To 5 ml of the filtrate, 5 ml of ammonium molybdate was added. The mixture was thoroughly shaken to remove the CO_2 evolved and the contents of the flask were diluted to about 20 ml. Thereafter, one ml of working solution of stannous chloride was added and final volume of 25 ml was made. The content was mixed thoroughly and the blue colour intensity was measured after five minutes at 660 nm keeping blank for setting zero.

$$\text{ppm of available phosphorus in soil} = \text{A} \times \text{total dilution}$$

where,

A = Concentration of P read from the standard curve
Available Phosphorus kg/ha = ppm × 2.24

3.3.6.1.6 Available Potassium

Five gram of soil was transferred to a 150 ml of conical flask. Twenty five ml of neutral ammonium acetate solution was added and the contents were shaken on electric shaker for five minutes. The contents of the conical flask were filtered and the filtrate was fed to the atomizer of the flame photometer. The reading was noted and expressed in ppm (Mervin and Peech 1951).

$$\text{ppm of available potassium in soil} = \text{Y} \times \text{Total dilution}$$

where,

Y = ppm as read from the standard curve
Available potassium kg/ ha = ppm × 2.24

3.3.6.1.7 Ca [cmol (p+) kg^{-1}] and Mg [cmol (p+) kg^{-1}]

Extraction with 1 N ammonium acetate solution (pH 7.0) and Ca was estimated using flame photometer while Mg was estimated on atomic absorption spectrophotometer.

3.3.6.1.8 DTPA Extractable Micronutrients (Zn, Fe, Cu and Mn)

The analysis of soil micronutrients was carried out as per method suggested by Lindsey and Novell (1978). The method consists shaking of 10 g soil with a buffered solution of DTPA (diethylene triamine penta-acetic acid). This chemical acts as a mild chelating agent, which extracts the easily soluble Zn, Fe, Cu and Mn. The extracting solution was buffered at 7.3 pH by TEA (tri-ethanolamine) and in addition included calcium chloride to prevent the dissolution of calcium carbonate. These conditions permit the light amount of Zn, Fe, Cu and Mn to be dissolved and $CaCl_2$ stabilizes the pH of the extractant. The samples with extracting solution were shaken for two hours and filtered through Whatman No. 42 filter paper. The dissolved elements in extracts were then estimated on the Atomic Absorption Spectophotometer (AAS).

3.3.6.1.9 Available Selenium

A soil sample weighing between 1 g was collected for analysis. In a teflon beaker, 0.5 g of soil was mixed with 5 ml concentrated HNO_3 and 10 ml HF. HNO_3 was added again and evaporated to dryness. After cooling the beaker, the residue was dissolved in 6 M HCl, transferred to a glass vessel of 25 ml and made up to 25 ml with 6 M HCl. To convert Se (VI) to Se (IV), the solution was transferred to a closed plastic bottle (50 ml) and heated to 80ºC for 30 minutes. A standard stock solution with a concentration of 100 mg/L was made. One g of selenium metal was dissolved in the smallest amount of strong nitric acid and dried to dryness twice. The residue was dissolved in 6 M hydrochloric acid and diluted to one liter with the same solution. Subsequent dilutions were made as needed. After first digestion the residues were dark black and in such cases, 5-10 ml H_2O_2 (30%) and 1–2 ml concentrated HNO_3 were added and heated on a steam bath to decompose the organic matter. The selenium levels in the collected samples were determined with Inductive Coupled Plasma- Mass Spectrophotometer (ICP-MS) (de León et al. 2003).

3.3.6.2 Microbiological Properties

3.3.6.2.1 Serial dilution

Soil sample for each treatment after collection from field was sieved through 2 mm sieve. Serial dilution technique was employed for the isolation of microbes. 1 g of soil was taken and transferred to 9 ml sterilized blank prepared from distilled water and was agitated on shaker for 5-10 minutes. This resulted in 10^{-1} dilution and subsequently 10^{-2} to 10^{-9} dilutions were prepared.

3.3.6.2.2 Total bacterial count

Standard plate count technique was used for the total microbial count (Wollum 1982). Nutrient agar media was prepared and autoclaved. The cooled media was poured into sterile petri plates under sterile conditions. Aliquot of 0.1 ml from dilution blank was spread over solidified media (Rangaswamy 1966). After inoculation, the plates were incubated for 48 hours at 28 ± 2 °C in inverted position in the incubator. After complete incubation the microbial count was expressed as colony forming units per gram (cfu/g) of soil. The composition of nutrient agar media is described as below:

Content	Quantity (g)
Beef extract	3.0
Peptone	5.0
NaCl	5.0
Agar-agar	15.0
Distilled water	1000 ml

3.3.6.2.3 Selenobacterial count

The soil sample was serially diluted and used to isolate endophytes on Nutrient agar plates. Obtained endophytes were further screened on the nutrient agar medium supplemented with 2 mM sodium selenite (Na_2SeO_3) as selenium enriched medium and incubated at 37 °C for 24-48 hours (Ghosh et al. 2008). Filter sterile 0.2 mM sodium salts of selenite was added to the medium as selenite which is sensitive to high temperature. The bacterial colonies acquiring Selenium from the medium turned red on growth, isolates showing red colonies and were considered as selenobacteria.

3.3.6.2.4 Phosphorus solubilizing bacteria

Twenty four hour old culture from different test bacteria formed on nutrient agar was spotted on pre-poured solid violet coloured PVK agar plate and incubated for 48-72 hours at 37°C in inverted position. Formation of colonies with yellow zone and yellowish fluorescence on dark violet/ pinkish medium indicated the production of phosphorus solubilizing bacteria (Pikovskaya, 1948). The compositions of Pikovskaya's Agar media is described as below:

Content	**Quantity (g)**
Yeast extract	0.50
Glucose	10.00
$CaPO_4$	5.00
$(NH_4)_2SO_4$	0.50
KCl	0.20
$MgSO_4$	0.10
$MnSO_4$	0.0001
$FeSO_4$	0.0001
Agar-agar	15.0
Distilled water	1000 ml

The phosphorus solubilizing bacteria were counted and percentage was calculated as:

$$\text{Phosphorus solubilizing bacteria (\%)} = \frac{\text{Number of Phosphorus solubilizing bacteria}}{\text{Total bacterial count}} \times 100$$

3.3.6.2.5 AM spore count

The spore population of AMF in soil was determined after extraction from soil by wet sieving and decanting technique of Gerdemann and Nicolson (1963). 50 g soil was suspended in 200 ml water in a flask, stirred vigorously and the heavier particles were allowed to settle down for few seconds. The suspension was then decanted through a series of sieves (300, 250, 106 and 45 µ) arranged one over another in a descending order. The residue left in each sieve was thoroughly washed under tap water and whatever residue left in the sieve was collected in a beaker and the final volume was made to 20 ml. 2 ml of the suspension was transferred to the counting plate and examined under stereoscopic binocular microscope and the number of spores per 50 g soil basis were thus calculated.

3.3.6.3 Soil enzymes

Acid and alkaline phosphatases were assessed by spectrophotometer (420 nm). One gram of fresh soil was incubated at 37 °C for 1 h, with 0.2 ml of toluene, 4 ml buffer (pH-6 for acid phosphatase and pH-11 for alkaline phosphatase) and 1 ml of p-nitrophenyl phosphate (0.05 mol l^{-1}). After incubation, the filtered extract was treated with 1 ml of $CaCl_2$

(0.5 mol l^{-1}) and 5 ml of NaOH (0.5 mol l^{-1}) and used for determining enzymatic activities, based on the hydrolysis of p-nitrophenyl and the determination of the p-nitrophenol generated (Tabatabai and Bremner 1969).

3.4 Statistical analysis

Statistical analysis of the data was carried out using general linear model of the standard errors of the mean. The data obtained in Randomized Block Design (factorial) for each parameter were tested by ANOVA using MS-Excel and OPSTAT. The difference between the treatments was compared by critical difference (CD) at 5 per cent level of probability (confidence), wherever the results were significant (Gomez and Gomez 1984).

Analysis of Variance (ANOVA):

Sources of variation	**Degrees of freedom**	**Sum of squares**	**Mean sum of squares**	**F cal**
Treatment	(t-1)	S_t	$S_t/(t-1) = M_t$	M_t/M_e
A	(a-1)	S_a	$S_a/(a-1) = M_a$	M_a/M_e
B	(b-1)	S_b	$S_b/(a-1) = M_b$	M_b/M_e
AB	(a-1)(b-1)	S_{ab}	$S_{ab}/(a-1) = M_{ab}$	M_{ab}/M_e
C	(c-1)	S_c	$S_c/(a-1) = M_c$	M_c/M_e
AC	(a-1)(c-1)	S_{ac}	$S_{ac}/(a-1)(c-1) = M_{ac}$	M_{ac}/M_e
BC	(b-1)(c-1)	S_{bc}	$S_{bc}/(b-1)(c-1) = M_{bc}$	M_{bc}/M_e
ABC	(a-1)(b-1)(c-1)	S_{abc}	$S_{abc}/(a-1)(b-1)(c-1) = M_{abc}$	M_{abc}/M_e
Error	abc(r-1)	S_e	$S_e/abc(r-1)= M_e$	
Total	a*b*c*r-1	S_T		

Where,

r = Number of replications

t = Number of treatments

S_t = Sum of squares due to treatments

S_a = Sum of squares due to factor A

S_b = Sum of squares due to factor B

S_{ab} = Sum of squares due to factor AB

S_c = Sum of squares due to factor C

S_{ac} = Sum of squares due to factor AC

S_{bc} = Sum of squares due to factor BC

S_{abc} = Sum of squares due to factor ABC

M_t = Mean sum of squares due to treatments

M_a = Mean sum of squares due to factor A

M_b = Mean sum of squares due to factor B

M_{ab} = Mean sum of squares due to factor AB

M_c = Mean sum of squares due to factor C

M_{ac} = Mean sum of squares due to factor AC

M_{bc} = Mean sum of squares due to factor BC

M_{abc} = Mean sum of squares due to factor ABC

M_e = Mean sum of squares due to error

S_T = Total sum of squares

Where,

A = AMF

B = Selenobacteria

C = Nano zinc

AB = AMF × Selenobacteria

AC = AMF × Nano zinc

BC = Selenobacteria × Nano zinc

ABC = AMF × Selenobacteria × Nano zinc

The treatment mean sum of square will be tested against mean sum of square due to error by 'F-test' for (t-1), (a-1), (b-1), (a-1)(b-1), (c-1), (a-1)(c-1), (b-1)(c-1), (a-1)(b-1)(c-1), abc(r-1) degree of freedom at 0.05 level of significance. The calculated F-value will be compared with tabulated F-value at 5% level of significance. If 'F'calculated is greater than 'F' table value than, the treatment effect will be considered significant i.e. one of the treatment pair differ significantly and critical difference will be calculated to find out the superiority of one treatment over the others.

The standard error of mean SE (m), SE (d) and critical difference (CD) for comparing the means of any two treatments will be calculated as per details given below:

SE (m) = $\pm\sqrt{Me/r}$

SE (d) = $\pm\sqrt{2\,Me/r}$

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

Where,

SE (m) = Standard error of mean

SE (d) = Standard error of difference

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

Chapter-4

RESULTS AND DISCUSSION

The present study entitled "**Interactive effects of nano zinc, AM fungi and selenobacteria for selenium biofortification in strawberry (*Fragaria* × *ananassa* Duch.)**" was carried out in the experimental farm of Department of Fruit Science, Dr. Y S Parmar University of Horticulture and Forestry during two consecutive years between 2020 and 2021 under protected conditions. The experimental results obtained during the study are presented and discussed in this chapter under the following heads:

4.1 Effects of nano zinc, AM fungi and selenobacteria on cropping behaviour

- 4.1.1 Vegetative growth
- 4.1.2 Flowering traits

4.2 Effects of nano zinc, AM fungi and selenobacteria on yield related traits

- 4.2.1 Number of fruits
- 4.2.2 Fruit set percentage
- 4.2.3 Fruit yield
- 4.2.4 Yield efficiency

4.3 Effects of nano zinc, AM fungi and selenobacteria on fruit quality characteristics

- 4.3.1 Physical characteristics
- 4.3.2 Biochemical characteristics

4.4 Effects of nano zinc, AM fungi and selenobacteria on leaf and fruit nutrient content

- 4.4.1 Leaf nutrient content
- 4.4.2 Fruit nutrient content

4.5 Effects of nano zinc, AM fungi and selenobacteria on soil properties

- 4.5.1 Chemical properties
- 4.5.2 Microbiological properties
- 4.5.3 Soil enzymes

4.1 EFFECTS OF NANO ZINC, AM FUNGI AND SELENOBACTERIA ON CROPPING BEHAVIOUR

4.1.1 Vegetative growth parameters

The data recorded during 2020 and 2021 to elucidate effects of nano zinc, AM fungi and selenobacteria on the vegetative growth attributes of strawberry namely, plant height, number of leaves, leaf area, number of crowns and number of runners have been presented in Tables 4.1(a) to 4.5(b).

4.1.1.1 Plant height (cm)

The perusal of pooled data of two years given in Table- 4.1(a and b) indicated that nano zinc, AM fungi and selenobacteria levels not only had significant effect individually but their interactions also had significant results (Appendix- LVII).

Table-4.1a: Effect of nano zinc, AM fungi and selenobacteria on plant height (cm) in strawberry plant

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	17.41	20.41	**18.91**	17.19	20.19	19.34
ZnO_1	20.29	22.06	**21.18**	20.49	22.31	20.73
ZnO_2	20.85	23.44	**22.15**	21.99	23.21	21.24
Mean	**19.52**	**21.97**		**19.89**	**21.90**	**20.44**
$CD_{0.05}$						
AM 0.19 SeB 0.24 ZnO 0.24			AM × ZnO 0.33 SeB× ZnO 0.41			

Table-4.1b: Interactive effects of nano zinc, AM fungi and selenobacteria on plant height (cm) in strawberry plant

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	15.80	17.67	18.75	18.58	22.72	19.93
ZnO_1	19.66	20.74	20.45	21.31	23.88	21.00
ZnO_2	20.64	21.10	20.82	23.34	25.31	21.66
Mean	**18.70**	**19.84**	**20.01**	**21.08**	**23.97**	**20.86**
$CD_{0.05}$						
AM × SeB	0.33		AM × SeB× ZnO	0.58		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

Based on the collected data regarding the impact of arbuscular mycorrhizal fungi (AMF) on plant height, the findings indicate a statistically significant increase in plant height. The mean value of plant height was recorded as 21.97 cm following the application of AM fungi (AM_1).

The impact of selenobacteria on plant growth was investigated, specifically focusing on the plant height increase observed with SeB_1 (*Stenotrophomonas maltophilia*), which showed a significantly higher plant height with a mean value of 21.90 cm.

Similarly, the effect of foliar application of nano zinc oxide, showed that the highest plant height with a value of 22.15 cm, which was recorded with the foliar application of nano zinc oxide (ZnO_2) applied @ 200 ppm.

As regards the interaction of AM fungi (AM) and nano zinc oxide (ZnO) the plants with maximum height (23.44 cm) were recorded in the interaction, AM_1 x ZnO_2. They were found significantly taller over all other interactions of AM fungi and nano zinc oxide sprays.

The interaction of selenobacteria (SeB) and nano zinc oxide (ZnO) reveals that the maximum plant height (23.21 cm) was observed in the interaction, $SeB_1 \times ZnO_2$ .They were found to be significantly superior in comparison to all other interactions of selenobacteria and nano zinc oxide sprays.

The interaction between AM fungi (AM_0 and AM_1) and selenobacteria (SeB_0, SeB_1 and SeB_2) exhibited that the plants with maximum height (23.97 cm) were observed in the interaction, $AM_1 \times SeB_1$.

The interaction effect of AM fungi (AM) × selenobacteria (SeB) × nano zinc oxide (ZnO) reveals that the maximum height of plants (25.31 cm) was observed in the interaction, $AM_1 \times SeB_1 \times ZnO_2$. This was found to be significantly higher in comparison to all other interactions.

4.1.1.2 Number of leaves

The pooled data pertaining to the number of leaves have been depicted in the Table - 4.2 (a and b). A perusal of data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced number of leaves of strawberry plants significantly (Appendix- LVII).

Table-4.2a: Effect of nano zinc, AM fungi and selenobacteria on number of leaves per plant in strawberry plant

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	18.72	22.66	**20.69**	21.04	21.32	19.71
ZnO$_1$	22.26	25.34	**23.80**	23.85	24.80	22.75
ZnO$_2$	22.91	24.48	**23.70**	23.30	24.22	23.57
Mean	**21.30**	**24.16**		**22.73**	**23.44**	**22.01**
CD$_{0.05}$						
AM	0.22		AM × ZnO	0.38		
SeB	0.27		SeB× ZnO	0.47		
ZnO	0.27					

Table-4.2b: Interactive effects of nano zinc, AM fungi and selenobacteria on number of leaves per plant in strawberry plant

Nano Zinc Oxide	AM$_0$			AM$_1$		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	19.06	18.93	18.16	23.03	23.70	21.27
ZnO$_1$	21.64	22.85	22.29	26.06	26.76	23.21
ZnO$_2$	21.07	23.53	24.13	25.53	24.90	23.02
Mean	**20.59**	**21.77**	**21.53**	**24.87**	**25.12**	**22.50**
CD$_{0.05}$						
AM × SeB	0.41		AM × SeB× ZnO	0.72		

AM$_0$:without AMF	SeB$_0$:without Selenobacteria	ZnO$_0$: 0
AM$_1$:with AMF	SeB$_1$:*Stenotrophomonas maltophilia*	ZnO$_1$: 100 ppm
	SeB$_2$:*Alcaligenes faecalis*	ZnO$_2$: 200 ppm

In regards to AM fungi, plants that received rhizoinoculation with the AM fungi produced significantly maximum number of leaves with a mean value of 24.16 leaves per plant.

The application of selenobacterial strain *Stenotrophomonas maltophilia* had significantly affected the number of leaves in strawberry plants. Thus, the maximum number of leaves (23.44) were produced with its application of selenobacteria.

Considering the effect of foliar application of nano zinc oxide applied with different concentrations, the maximum number of leaves (23.80) were observed with nano zinc oxide applied @100ppm. However, the effect of nano zinc oxide applied @ 200 ppm, showed similar trend for the number of leaves (23.70) which was statistically at par with the effect of nano zinc oxide @ 100 ppm.

The interaction of AM fungi and nano zinc oxide exhibited maximum number of leaves (25.34) in the interaction, in which the plants were treated with AM fungi and the foliar application of nano zinc oxide @ 100 ppm.

As regards the interaction of selenobacteria and nano zinc oxide, the results showed that the number of leaves (24.80), were significantly increased in the interaction of selenobacterial strain *Stenotrophomonas maltophilia* and nano zinc oxide @ 100 ppm and found to be significantly higher over all the other interactions of selenobacteria and nano zinc oxide.

The interaction of AM fungi and selenobacteria revealed that the maximum number of leaves (25.12) were found in the interaction, where the plants were treated with AM fungi and selenobacterial strain *Stenotrophomonas maltophilia*. However, the interaction, where the plants were treated with only AM fungi, the number of leaves (24.87) produced was statistically at par with the maximum value.

The interaction of AM fungi, selenobacteria and nano zinc oxide revealed that the maximum number of leaves (26.76) were observed in the interaction, where the plants were treated with the AM fungi, selenobacteria (*Stenotrophomonas maltophilia*) and nano zinc oxide @100 ppm. However, the interaction effect of AM fungi, nano zinc oxide applied @ 100 ppm and no selenobacteria application on plants also showed similar trend with number of leaves (26.06) which were statistically at par with $AM_1 \times SeB_1 \times ZnO_1$.

4.1.1.3 Leaf area (cm^2)

The perusal of pooled data of two years given in Table- 4.3 (a and b) indicated that nano zinc, AM fungi and selenobacteria levels significantly influenced the leaf area of the strawberry plants individually along with their interactions (Appendix- LVII).

Considering the data pertaining to the effect of AMF on the leaf area the results showed a leaf area (76.70 cm^2) with significant higher value in plants treated with AM fungi.

As per the effect of the selenobacteria, the significantly larger leaf area (75.20 cm^2) was observed with SeB_1.

Table-4.3a: Effect of nano zinc, AM fungi and selenobacteria on leaf area (cm^2) in strawberry plant

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	64.05	74.24	**69.14**	67.54	68.70	71.19
ZnO_1	74.22	79.71	**76.96**	76.94	78.69	75.26
ZnO_2	75.60	76.16	**75.88**	75.65	78.19	73.80
Mean	**71.29**	**76.70**		**73.38**	**75.20**	**73.42**
CD$_{0.05}$						
AM 0.50 SeB 0.62 ZnO 0.62			AM × ZnO 0.87 SeB× ZnO 1.07			

Table-4.3b: Interactive effects of nano zinc, AM fungi and selenobacteria on leaf area (cm^2) in strawberry plant

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	60.65	63.14	68.36	74.43	74.26	74.03
ZnO_1	73.69	74.03	74.93	80.19	83.36	75.59
ZnO_2	75.46	75.69	75.63	75.83	80.69	71.97
Mean	**69.93**	**70.95**	**72.97**	**76.82**	**79.44**	**73.86**
CD$_{0.05}$						
AM × SeB 0.87			AM × SeB× ZnO 1.51			

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As regards the interaction of AM × ZnO, the plants with leaves of maximum leaf area (79.71 cm^2) were produced in the interaction, $AM_1 \times ZnO_1$

The interaction effect of SeB × ZnO revealed that the plants with maximum leaf area (78.69 cm^2) were produced in the interaction, $SeB_1 \times ZnO_1$. However, the interaction effect of $SeB_1 \times ZnO_2$ on leaf area (78.19 cm^2) was found to be statistically at par with $SeB_1 \times ZnO_1$.

The interaction between AM × SeB exhibited maximum leaf area (79.44 cm^2) with the interaction, $AM_1 \times SeB_1$ and it was found significantly higher over all the other interactions of AM fungi and selenobacteria.

The interaction among AM × SeB × ZnO reveals that plants with maximum leaf area (83.36 cm^2) were produced in the interaction, AM_1 × SeB_1 × ZnO_1 and it was found to be significantly maximum in comparison to all the other interactions.

4.1.1.4 Number of crowns per plant

A cursory glance of pooled data presented in the Table- 4.4 (a and b) indicated that nano zinc, AM fungi and selenobacterial applications have influenced number of crowns per plant significantly. However, the interaction effects among nano zinc, AM fungi and selenobacterial applications were found to be non-significant (Appendix- LVII).

Table-4.4a: Effect of nano zinc, AM fungi and selenobacteria on number of crowns per plant in strawberry plant

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.33	6.22	**5.28**	5.23	5.52	5.08
ZnO_1	5.47	6.82	**6.15**	6.08	6.36	5.99
ZnO_2	5.56	6.53	**6.04**	6.30	6.43	5.40
Mean	**5.12**	**6.52**		**5.87**	**6.10**	**5.49**
$CD_{0.05}$						
AM SeB ZnO	0.35 0.42 0.42		AM × ZnO SeB× ZnO	NS NS		

Table-4.4b: Interactive effects of nano zinc, AM fungi and selenobacteria on number of crowns per plant in strawberry plant

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.13	4.67	4.20	6.33	6.37	5.97
ZnO_1	5.60	5.59	5.23	6.57	7.13	6.75
ZnO_2	5.67	5.90	5.10	6.93	6.97	5.70
Mean	**5.13**	**5.38**	**4.85**	**6.61**	**6.82**	**6.14**
$CD_{0.05}$						
AM × SeB	NS		AM × SeB× ZnO		NS	

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As per the effects of AM fungi, maximum number of crowns per plant (6.52) were recorded in the plants that were treated with AM fungi and found to be significantly higher.

As regards the use of selenobacteria (*Stenotrophomonas maltophilia*), it was observed to produce maximum number of crowns per plant (6.10). However the number of crowns (5.87) produced by the plants that were not treated with selenobacteria were at par with the effect of selenobacteria (*Stenotrophomonas maltophilia*).

The foliar application of nano zinc oxide @ 100 ppm recorded maximum number of crowns per plant (6.15) and they were found to be significantly higher. However, effect of nano zinc oxide @ 200 ppm on the production of number of crowns (6.04) was significantly at par with nano zinc oxide @ 100 ppm.

4.1.1.5 Number of runners per plant

The pooled data on production of runners per plant have been contained in Table - 4.5 (a and b) and closely presents that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced production of number of runners per plant significantly (Appendix- LVII).

Table-4.5a: Effect of nano zinc, AM fungi and selenobacteria on number of runners per plant in strawberry plant

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	AM_1		SeB_0	SeB_1	SeB_2
ZnO_0	18.59	30.61	**24.60**	22.84	25.13	25.83
ZnO_1	24.36	32.84	**28.60**	26.23	30.37	29.20
ZnO_2	23.88	33.50	**28.69**	26.82	30.68	28.59
Mean	**22.28**	**32.32**		**25.29**	**28.72**	**27.87**
$CD_{0.05}$						
AM SeB ZnO	0.58 0.71 0.71		AM × ZnO SeB× ZnO	1.01 1.23		

Table-4.5b: Interactive effects of nano zinc, AM fungi and selenobacteria on number of runners per plant in strawberry plant

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2
ZnO_0	17.49	19.47	18.80	28.18	30.78	32.85
ZnO_1	23.90	24.89	24.28	28.55	35.84	34.12
ZnO_2	24.08	24.60	22.97	29.56	36.75	34.21
Mean	**21.82**	**22.99**	**22.02**	**28.76**	**34.46**	**33.73**
$CD_{0.05}$						
AM × SeB	1.01		AM × SeB× ZnO	1.74		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As per the effect of AM fungi, the result showed that maximum number of runners per plant (32.32) were recorded, when the plants were treated with AM fungi (AM_1) as compared to the control.

The use of selenobacteria significantly influenced the production of number of runners per plant and the maximum value 28.72 was found to be in the plants applied with the strain *Stenotrophomonas maltophilia*, compared to the control.

The foliar application of nano zinc oxide @ 200 ppm recorded maximum number of runners per plant (28.69) and they were found to be significantly highest. However, the number of runners per plant (28.60) recorded with the plants treated with nano zinc oxide @ 100 ppm were statistically at par with the effect of nano zinc oxide @ 200 ppm.

The interaction effects of AM fungi and nano zinc oxide indicated that the highest number of runners per plant (33.50) were recorded in the interaction, $AM_1 \times ZnO_2$. However, the interaction effect of $AM_1 \times ZnO_1$ produced the runners (32.84) which were statistically at par with the above interaction ($AM_1 \times ZnO_2$).

As regards the interaction effects of selenobacteria and nano zinc oxide, maximum number of runners per plant (30.68) were produced in the interaction, $SeB_1 \times ZnO_2$. However the interaction, $SeB_1 \times ZnO_1$ produced the number of runners (30.37) which were statistically at par with the interaction, $SeB_1 \times ZnO_2$.

The interaction effects of AM fungi and selenobacteria revealed maximum number of runners per plant (34.46) in the interaction, $AM_1 \times SeB_1$.

The interaction of AM fungi, nano zinc oxide and selenobacteria, exhibited maximum number of runners per plant (36.75) in the interaction, $AM_1 \times SeB_1 \times ZnO_2$. However, the runners (35.84) produced in the interaction of $AM_1 \times SeB_1 \times ZnO_1$ was statistically at par with the effect of the interaction of $AM_1 \times SeB_1 \times ZnO_2$.

The results of the present investigation revealed that vegetative growth traits (plant height, number of leaves, leaf area, number of crowns and number of runners) were significantly influenced by the AM fungi, selenobacteria and nano zinc oxide levels as well as with their interaction effects, with minimum values being exhibited by control (i.e. no application of AM fungi, selenobacteria and nano zinc oxide). The study showed that AM fungi had a positive effect on all the vegetative growth parameters of the plant. The observed enhancement in vegetative growth resulting from the presence of arbuscular mycorrhizal (AM) fungi may be attributed to its mutualistic association with plant roots, facilitating improved nutrient and moisture uptake by the plants through the presence of fungal hyphae. The beneficial impact of arbuscular mycorrhizal fungi (AMF) on vegetative characteristics can also be attributed to the release of organic acids and the process of mineralization/solubilization of organic phosphorus. Additionally, its capacity for biosynthesis or release of certain phytohormones may have contributed to the augmentation of vegetative characteristics (Jabborova et al. 2021 and Masrahi et al. 2023). Chauhan et al. (2010) observed a nearly seven-fold increase in plant height in strawberry plants that were inoculated with AMF, compared to the control. Rhizoinoculation of AMF has also been reported to promote the growth of horticultural crops such as tomato (Bona et al. 2017), strawberry (Todeschini et al. 2018), lettuce (Kohler et al. 2010), and spinach (Khalid et al. 2017).The results are also in conformity with the studies of various researchers where they have reported that the application of AMF have increased the plant growth traits (Sharma et al. 2009, Gogoi and Singh 2011, Singh et al. 2011 and Sharma and Kayang 2017).

The enhanced vegetative growth of the strawberry plants was also significantly impacted by the application of selenobacteria (*Strenotophomonas maltophilia*). This positive influence on vegetative traits can be ascribed to its various plant growth-enhancing attributes including higher auxin production, more differentiated roots, greater number of leaves, greater dry weight and increased shoot length (Yasin et al. 2015). Moreover, the addition of strain *Strenotophomonas maltophilia* has been reported to improve the fresh weight as this strain produce secretions such as auxin, gibberellin, and cytokinin, which are known to stimulate the growth of plant (Jiang et al. 2023).

The enhanced vegetative growth characteristics observed in strawberry plants treated with nano ZnO can be attributed to the stimulation of carbohydrate metabolism resulting from an elevated photosynthetic rate (Elizabath et al. 2017). The photosynthetic activity is influenced by the presence of zinc in proteins and enzymes involved in photosynthesis, affecting both their structure and catalytic function (Rout and Sahoo 2015 and Mohammadi et al. 2018). This zinc interference also impacts the activity of meristematic tissues and the growth of cell walls, leading to increased vegetative growth. In a study, Singh et al. (2017) found that nano fertilisers increase the production and translocation of photosynthates to various plant parts, the rate of photosynthesis and the chlorophyll content, resulting in an increase in plant height, leaf number and leaf area. In addition, ZnO nanoparticles are absorbed more efficiently than conventional fertilisers due to their larger surface area (Taheri et al. 2015) and result in a continuous increase in leaf area (Patel et al. 2019). In addition, nano ZnO increased the plant's height via., increased cell elongation and cell division (Kumar et al. 2017), which was caused by the activation of the amino acid tryptophan, which increased the synthesis of IAA in the plant system (Khan et al. 2007, Suriyaprabha et al. 2012 and Van et al. 2013). Activation of enzymes associated with plant metabolism, synthesis of IAA (Nagula and Usha 2016), absorption of water and transport of nutrients (Ahmed et al. 2019) were also reflected in increased vegetative growth traits (El-Sayed et al. 2017). Due to the increased activity of phosphorous-mobilizing enzymes, nanoscale ZnO application has been found to increase the number of leaves on plants (Raliya and Tarafdar 2013). The increased number of strawberry crowns observed by Rahman et al. (2016) can be attributed to Zn's role in promoting effective cell division and enhanced photosynthesis in plants. These results are also in accordance with those of strawberry (Kumar et al. 2017), mulberry (Nithya et al. 2018) and flame seedless grapes (El-Said et al. 2019).

The better vegetative growth of strawberry plants can be ascribed to the cumulative effect of the effect of AM fungi, selenobacteria (*Strenotophomonas maltophilia*) and nano zinc oxide applied at different levels as well as their interactive effects.

4.1.2 Flowering traits

4.1.2.1 Days taken to first flowering (days)

The pooled data on days taken to first flowering have been presented in Table - 4.6 (a and b) and clearly reveal that nano zinc, AM fungi and selenobacteria applications as well as the interactions among them have influenced number of days taken to first flowering significantly (Appendix- LVII).

As regards the effects of AM fungi (AM), minimum days (52.45 days) taken by the plants to produce its first flower were recorded in the plant that were treated with AM fungi.

The use of selenobacteria (*Stenotrophomonas maltophilia*) was found to have resulted in earlier production of flowers where the minimum number of days (53 days) were reported to produce its first flowering.

Table-4.6a: Effect of nano zinc, AM fungi and selenobacteria on days taken to first flowering in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	58.36	55.57	**56.96**	58.42	55.50	56.98
ZnO_1	52.61	49.30	**50.95**	50.19	50.29	52.37
ZnO_2	55.08	52.47	**53.78**	52.45	53.20	55.69
Mean	**55.35**	**52.45**		**53.69**	**53.00**	**55.01**
$CD_{0.05}$						
AM 0.51 SeB 0.63 ZnO 0.63			AM × ZnO 0.89 SeB× ZnO 1.08			

Table-4.6b: Interactive effects of nano zinc, AM fungi and selenobacteria on days taken to first flowering in strawberry

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	58.98	56.17	59.94	57.85	54.82	54.02
ZnO_1	51.84	53.53	52.45	48.54	47.06	52.29
ZnO_2	54.49	55.34	55.42	50.41	51.06	55.95
Mean	**55.10**	**55.01**	**55.94**	**52.27**	**50.98**	**54.09**
$CD_{0.05}$						
AM × SeB 0.89			AM × SeB× ZnO 1.5			

AM_0:without AMF SeB_0 :without Selenobacteria ZnO_0: 0
AM_1: with AMF SeB_1:*Stenotrophomonas maltophilia* ZnO_1: 100 ppm
SeB_2 :*Alcaligenes faecalis* ZnO_2 : 200 ppm

The application effects of nano zinc oxide @ 100 ppm resulted in the minimum days (50.95 days) to produce its first flowering and found to be significantly lowest over all other applications of nano zinc oxide.

Considering the interaction of AM × ZnO, the results exhibited that minimum days to first flowering (49.30 days) was observed in the interaction, AM_1 × ZnO_1

With the interaction effect of SeB × ZnO, the minimum days to first flowering (50.19 days) were observed in the interaction, SeB_0 × ZnO_1.

The interaction of AM × SeB reveals, that minimum days to first flowering (50.98 days) was recorded in the interaction, AM_1 × SeB_1. It was significantly early in comparison to all the other interactions of AM and SeB.

The interaction of AM × ZnO × SeB recorded the minimum days to first flowering (47.06 days) in the interaction, AM$_1$ × SeB$_1$ × ZnO$_1$. This was found to be significantly earliest in comparison to all the other interactions.

4.1.2.2 Duration of flowering (days)

The pooled data pertaining to the duration of flowering (days) have been depicted in the Table - 4.7 (a and b). A perusal of data clearly reveals that nano zinc, AM fungi and selenobacteria applications individually as well as the interactions were significant. However, the interaction of SeB × ZnO and AM × ZnO × SeB were non significant (Appendix- LVII).

Table-4.7a: Effect of nano zinc, AM fungi and selenobacteria on duration of flowering (days) in strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	131.76	142.22	**136.99**	134.90	139.23	136.84
ZnO$_1$	142.38	146.48	**144.43**	143.21	146.62	143.46
ZnO$_2$	141.93	145.21	**143.57**	142.40	145.00	143.32
Mean	**138.69**	**144.64**		**140.17**	**143.62**	**141.21**
CD$_{0.05}$						
AM	1.20		AM × ZnO	2.08		
SeB	1.47		SeB× ZnO	NS		
ZnO	1.47					

Table-4.7b: Interactive effects of nano zinc, AM fungi and selenobacteria on duration of flowering (days) in strawberry

Nano Zinc Oxide	AM$_0$			AM$_1$		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	130.53	132.51	132.23	139.27	145.95	141.44
ZnO$_1$	140.79	143.78	142.57	145.63	149.46	144.35
ZnO$_2$	139.36	142.52	143.92	145.43	147.48	142.73
Mean	**136.89**	**139.60**	**139.57**	**143.44**	**147.63**	**142.84**
CD$_{0.05}$						
AM × SeB	2.08		AM × SeB× ZnO		NS	

AM$_0$:without AMF	SeB$_0$:without Selenobacteria	ZnO$_0$: 0
AM$_1$: with AMF	SeB$_1$:*Stenotrophomonas maltophilia*	ZnO$_1$: 100 ppm
	SeB$_2$:*Alcaligenes faecalis*	ZnO$_2$: 200 ppm

As regards to AM fungi, maximum duration of flowering (144.64 days) was recorded in the plants that were treated with AM fungi.

The application of selenobacteria significantly affected the duration of flowering in strawberry plants. Maximum duration of flowering (143.62 days) was observed with the application of *Stenotrophomonas maltophilia* (SeB_1).

Considering the effect of foliar application of nano zinc oxide applied with different concentrations, the maximum duration of flowering (144.43 days) was observed in the plants that were treated with nano zinc oxide applied @100ppm (ZnO_1). However, the effect of nano zinc oxide applied @ 200 ppm, recording the duration of flowering (143.57 days) which was statistically at par with ZnO_1.

The interaction of $AM_1 \times ZnO_1$, exhibited maximum duration of flowering (146.48 days). However, the interaction effect of $AM_1 \times ZnO_2$ on duration of flowering (145.21 days) was found to be statistically at par with the interaction effect of $AM_1 \times ZnO_1$.

The interaction of $AM_1 \times SeB_1$, observed the maximum duration of flowering (147.63 days) and was found to be significantly higher in comparison to all other interactions of AM fungi and selenobacterial applications.

4.1.2.3 Number of flowers per plant

The pooled data on number of flowers per plant have been contained in Table- 4.8 (a and b) and closely depicts that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced the production of number of flowers per plant significantly (Appendix- LVII).

As regards the effect of AM_1, it was observed that the significantly higher number of flowers per plant (34.14) were produced by the plants that were treated with AM fungi.

The use of SeB_1 (*Stenotrophomonas maltophilia*) resulted in the production of maximum number of flowers per plant (32.25) and found to be significantly higher over the plants applied with the other strain (*Alcaligenes faecalis*).

The effect of ZnO_1 influenced the production of flowers and it was recorded that significantly higher number of flowers per plant (32.05) were produced.

The interaction effect of $AM_1 \times ZnO_1$, indicated that the maximum number of flowers per plant (35.91) were produced in the interaction and they were found to be significantly higher over all other interactions of AM fungi and nano zinc oxide.

Table-4.8a: Effect of nano zinc, AM fungi and selenobacteria on number of flowers per plant in strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	21.92	33.11	**27.51**	25.49	29.47	27.58
ZnO_1	28.20	35.91	**32.05**	31.20	34.98	29.98
ZnO_2	27.05	33.40	**30.22**	29.95	32.30	28.42
Mean	**25.72**	**34.14**		**28.88**	**32.25**	**28.66**
$CD_{0.05}$						
AM SeB ZnO	0.54 0.67 0.67		AM × ZnO SeB× ZnO	0.94 1.15		

Table-4.8b: Interactive effects of nano zinc, AM fungi and selenobacteria on number of flowers per plant in strawberry

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	20.33	23.30	22.12	30.64	35.64	33.05
ZnO_1	29.27	28.78	26.55	33.12	41.18	33.42
ZnO_2	28.46	27.14	25.55	31.45	37.47	31.29
Mean	**26.02**	**26.41**	**24.74**	**31.73**	**38.10**	**32.59**
$CD_{0.05}$						
AM × SeB		0.94		AM × SeB× ZnO	1.63	

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As regards the interaction effect of $SeB_1 \times ZnO_1$, the maximum number of flowers per plant (34.98) were produced in the interaction and it was observed to be significantly higher as compared to all other interactions of selenobacteria and nano zinc oxide doses.

The interaction of $AM_1 \times SeB_1$, revealed that the maximum number of flowers per plant (38.10) were produced in the interaction and was found to be significantly higher in comparison to all other interactions of AM fungi and selenobacterial applications.

The interaction of all the three inputs, $AM_1 \times SeB_1 \times ZnO_1$ exhibited maximum number of flowers per plant (41.18) in the above interaction. This was found to be significantly superior in comparison to all other interactions.

In the present investigation, the flowering parameters (days to first flowering, number of flowers per plant and duration of flowering) were also significantly improved with the application of AM fungi. It has been reported that AMF alters the physiology of plant reproduction, causing earlier flowering, a longer flowering period, and an increase in the number of flower buds and inflorescences. Our results are inconfirmation with those of Harrier and Watson (2004), Scagel (2004), Aimo et al. (2010) and Nzanza et al. (2012). AMF is a well-recognized regulator of plant auxins and gibberellins content, both of which are essential for floral development, this supports the finding of an increase in flower count (Zhang et al. 2014). Inoculation of AMF impacted flowering time leading to early flowering and maturity in tomato (Ortas et al. 2013) and cucmber (Copetta et al. 2020). The results are in accordance with the findings of Bona et al. (2015), where they have reported earlier flowering in plants of *Fragaria × ananassa* var. Selva which were inoculated with a "consortium" of AMF (*R. intraradices, G. aggregatum, G. viscosum, Claroideoglomus etunicatum,* and *C. claroideum*). Similarly, Todeschini et al. (2018) reported that mycorrizal inoculation in plants led to a significant increase in the induction of flowering by approximately 35%.

The findings of the present study for the flowering parameters are in consonance with the work of Zagzog and Gad (2017) in mango and Kumar et al. (2017) in strawberry who also recorded reduced number of days for flowering. The early onset of flowering has been documented as a result of the enhanced permeability of ZnO nanoparticles (Prasad et al. 2012) and their ability to traverse the expanded leaf surface area, as well as the release of ions across the cuticle (Da Silva et al. 2006). The positive effect on flowering is subsequently observed through the penetration of the leaf cuticle (Laware and Raskar 2014). Previous studies have demonstrated the beneficial effects of Zn on chlorophyll synthesis, photosynthetic efficiency, carbohydrate accumulation, enzymatic energy production, growth regulation, and flowering in plants (Alloway 2004). Zinc (Zn) has been shown to have positive effects on the formation of pollen tubes (Taiz and Zeiger 2002, Mohammed et al. 2018 and Ibraheen and Abed 2017). This, in turn, leads to an increase in the number of flowers as it enhances vegetative growth characteristics (Laware and Raskar 2014 and Kode et al. 2015). The utilisation of nitrogen in plants plays a crucial role in maintaining the stability of the cell membrane (Tufail et al. 2017) and facilitating protein synthesis through the accumulation of soluble nitrogen compounds like amino acids (Cakmak 2000) and regulating various metabolic responses within the plant system (Shankar and Prasad 1998). The application of ZnO nanoparticles has been found to enhance the number of flowers through their involvement in cell division and photosynthesis (Abdollahi et al. 2012). Additionally, the potential cause for the occurrence of early flowering, coupled with an extended duration of flowering, has facilitated the process of flower setting and the optimal development of flowers (Devil et al. 2017). The study conducted by Kumar and Sen (2005) demonstrated that the application of zinc had an impact on the biosynthesis of auxin (IAA) and nucleic acid levels in plants. Additionally, it activated enzymes involved in protein synthesis, which ultimately influenced vegetative growth and flowering characteristics (Eid et al. 2010 and Shah et al. 2015). The application of zinc as a nano-fertilizer has been found to enhance the solubility of nutrients while reducing immobilisation. This, in turn, leads to a significant improvement in flowering parameters (De Rosa et al. 2010 and Naderi and Danesh-Shahraki 2013).

4.2 EFFECTS OF NANO ZINC, AM FUNGI AND SELENOBACTERIA ON YIELD RELATED TRAITS

4.2.1 Cumulative fruit number per plant

A perusal of pooled data in Table- 4.9 (a and b) and Fig. 4.1 to 4.7 indicated that nano zinc, AM fungi and selenobacteria doses had exhibited significant effects on cumulative fruit number per plant. The interactions among them were also found to be significant (Appendix- LVII).

Table-4.9a: Effect of nano zinc, AM fungi and selenobacteria on cumulative fruit number per plant in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	15.05	26.65	**20.85**	18.84	22.90	20.71
ZnO_1	21.55	30.22	**25.89**	25.28	29.08	23.21
ZnO_2	19.81	26.81	**23.31**	22.55	25.64	21.62
Mean	**18.80**	**27.91**		**22.22**	**25.87**	**21.85**
$CD_{0.05}$						
AM	0.48		AM × ZnO	0.82		
SeB	0.58		SeB× ZnO	1.00		
ZnO	0.58					

Table-4.9b: Interactive effects of nano zinc, AM fungi and selenobacteria on cumulative fruit number per plant in strawberry

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	12.77	16.95	15.32	24.92	28.84	26.11
ZnO_1	22.95	22.14	19.54	27.61	36.02	26.87
ZnO_2	20.70	20.20	18.39	24.39	31.08	24.86
Mean	**18.81**	**19.76**	**17.75**	**25.64**	**31.98**	**25.95**
$CD_{0.05}$						
AM × SeB	0.82		AM × SeB× ZnO		1.41	

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As regards the effect of AM fungi, AM_1 was observed to have significantly maximum cumulative fruit number (27.91 per plant) as compared to AM_0.

The use of selenobacteria, SeB_1, resulted in production of maximum cumulative fruit number per plant (25.87 per plant) and found to be significantly highest over the plants.

As regards the effect of nano zinc oxide, ZnO_1, it was observed that it significantly influenced the production of fruits and thus the maximum cumulative fruit number (25.89 per plant) was recorded with the foliar application of nano zinc oxide @ 100 ppm.

Among the interaction effects of AM fungi and nano zinc oxide, the highest cumulative fruit number (30.22 per plant) was recorded in the interaction, AM_1 × ZnO_1 and it was found to be significantly higher over all other interactions of AM fungi and nano zinc oxide.

The interaction of selenobacteria and nano zinc oxide revealed that the maximum cumulative fruit number (29.08 per plant) was recorded in the interaction, SeB_1 × ZnO_1. It was observed to be significantly superior in comparison to the other interactions of selenobacteria and nano zinc oxide sprays.

As regards the interaction effects of AM fungi and selenobacteria, it was observed that the maximum cumulative fruit number (31.98 per plant) was recorded in the interaction AM_1 × SeB_1 and was significantly highest in comparison to all other interactions of AM fungi and selenobacterial applications.

The interaction of AM fungi × nano zinc oxide × selenobacteria exhibited maximum cumulative number of fruits per plant (36.02) in the interaction, AM$_1$ × SeB$_1$ × ZnO$_{1.}$ It was found to be significantly superior in comparison to all other interactions.

4.2.2 Fruit set percentage

The perusal of pooled data presented in Table 4.10 (a and b) indicated that nano zinc, AM fungi and selenobacteria applications alone have influenced fruit set percentage of strawberry fruits significantly, while, the interactions were found to be non-significant (Appendix- LVII).

As regards the effects of AM fungi, maximum fruit set percentage per plant (81.44 %) was recorded with AM$_1$ and it was found to be significantly higher.

Table-4.10a: Effect of nano zinc, AM fungi and selenobacteria on fruit set (%) in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	68.47	80.50	**74.49**	72.17	76.92	74.37
ZnO$_1$	76.43	83.80	**80.12**	81.02	82.24	77.08
ZnO$_2$	73.17	80.00	**76.59**	75.28	78.70	75.78
Mean	**72.69**	**81.44**		**76.16**	**79.29**	**75.75**
CD$_{0.05}$						
AM	2.36		AM × ZnO	NS		
SeB	2.90		SeB× ZnO	NS		
ZnO	2.90					

Table-4.10b: Interactive effects of nano zinc, AM fungi and selenobacteria on fruit set (%) in strawberry

Nano Zinc Oxide	**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	62.89	72.87	69.65	81.44	80.97	79.09
ZnO$_1$	78.59	77.01	73.69	83.46	87.48	80.47
ZnO$_2$	73.13	74.41	71.98	77.44	82.99	79.58
Mean	**71.54**	**74.76**	**71.78**	**80.78**	**83.81**	**79.72**
CD$_{0.05}$						
AM × SeB	NS		AM × SeB× ZnO	NS		

AM$_0$:without AMF SeB$_0$:without Selenobacteria ZnO$_0$: 0
AM$_1$: with AMF SeB$_1$:*Stenotrophomonas maltophilia* ZnO$_1$: 100 ppm
SeB$_2$:*Alcaligenes faecalis* ZnO$_2$: 200 ppm

Similarly, the foliar application of nano zinc oxide, ZnO$_{1,}$ was observed to record maximum fruit set percentage per plant (80.12 %) as compared to ZnO$_0$ and ZnO$_2$.

With the use of selenobacteria, SeB$_1$ resulted in the production of maximum fruit set percentage per plant (79.29 %) in comparison to the effect of SeB$_0$ and SeB$_2$.

4.2.3 Fruit yield per plant (g)

The pooled data on production of fruit yield (g) per plant have been contained in Table- 4.11 (a and b) and Fig. 4.1 to 4.7 and closely depicts that nano zinc, AM fungi and selenobacteria applications as well as their interactions have positively impacted of fruit yield per plant (g) significantly (Appendix- LVII).

As regards the effects of AM fungi, the results showed that signifcantly maximum fruit yield per plant (415.77 g) was recorded, when the plants were treated with AM fungi.

The effect of selenobacterial strain *Stenotrophomonas maltophilia*, was observed to have resulted in the production of significantly higher fruit yield per plant (389.75 g).

Table-4.11a: Effect of nano zinc, AM fungi and selenobacteria on fruit yield per plant (g/plant) of strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	172.14	369.22	**270.68**	229.72	309.83	272.48
ZnO$_1$	300.20	478.57	**389.38**	380.76	466.96	320.43
ZnO$_2$	259.23	399.51	**329.37**	313.65	392.45	282.01
Mean	**243.86**	**415.77**		**308.04**	**389.75**	**291.64**
CD$_{0.05}$						
AM	7.88		AM × ZnO	13.65		
SeB	9.65		SeB× ZnO	16.72		
ZnO	9.65					

Table-4.11b: Interactive effects of nano zinc, AM fungi and selenobacteria on fruit yield per plant (g/plant) of strawberry

Nano Zinc Oxide	AM$_0$			AM$_1$		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	128.81	200.77	186.83	330.63	418.89	358.14
ZnO$_1$	316.47	322.75	261.37	445.04	611.18	379.50
ZnO$_2$	260.34	282.25	235.11	367.96	502.65	328.91
Mean	**235.21**	**268.59**	**227.77**	**380.88**	**510.91**	**355.51**
CD$_{0.05}$						
AM × SeB	13.65		AM × SeB× ZnO	11.63		

AM$_0$:without AMF
AM$_1$: with AMF

SeB$_0$:without Selenobacteria
SeB$_1$:*Stenotrophomonas maltophilia*
SeB$_2$:*Alcaligenes faecalis*

ZnO$_0$: 0
ZnO$_1$: 100 ppm
ZnO$_2$: 200 ppm

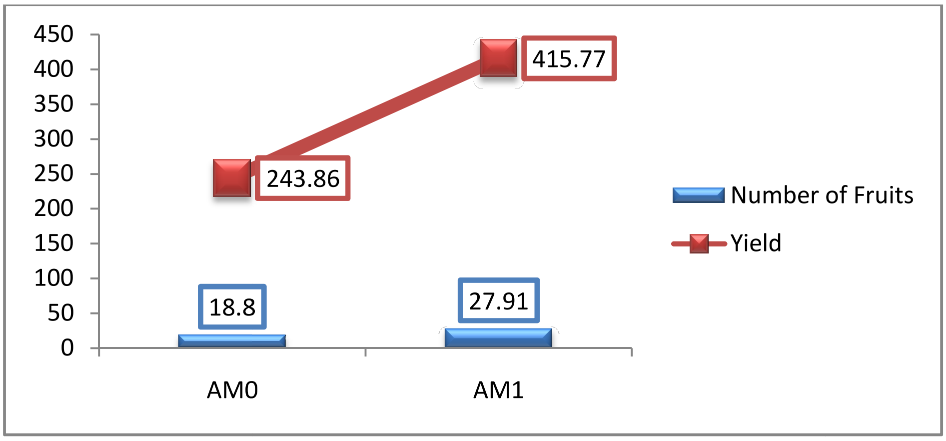


Fig. 4.1: Effect of AM fungi on cumulative fruit number and yield per plant

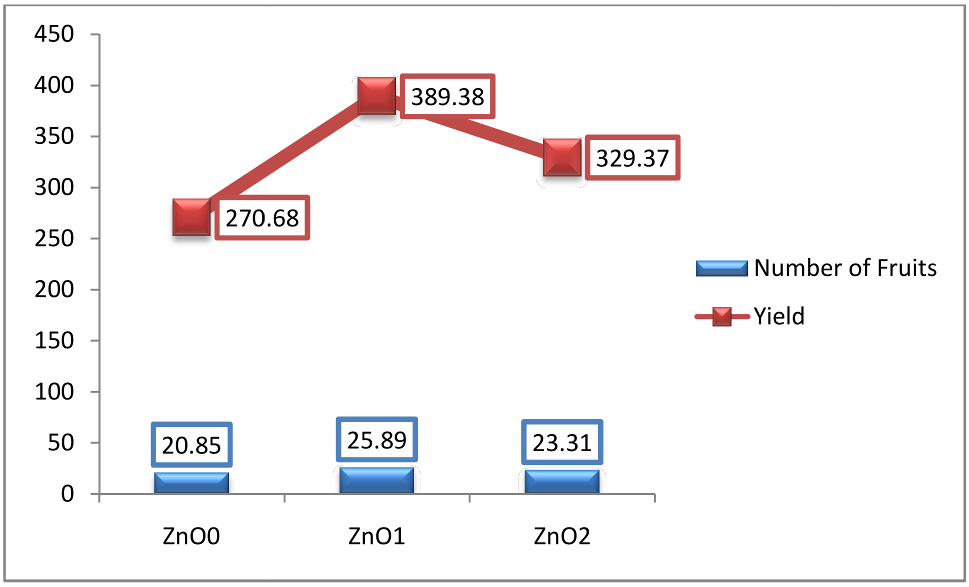


Fig. 4.2: Effect of nano zinc oxide on cumulative fruit number and yield per plant

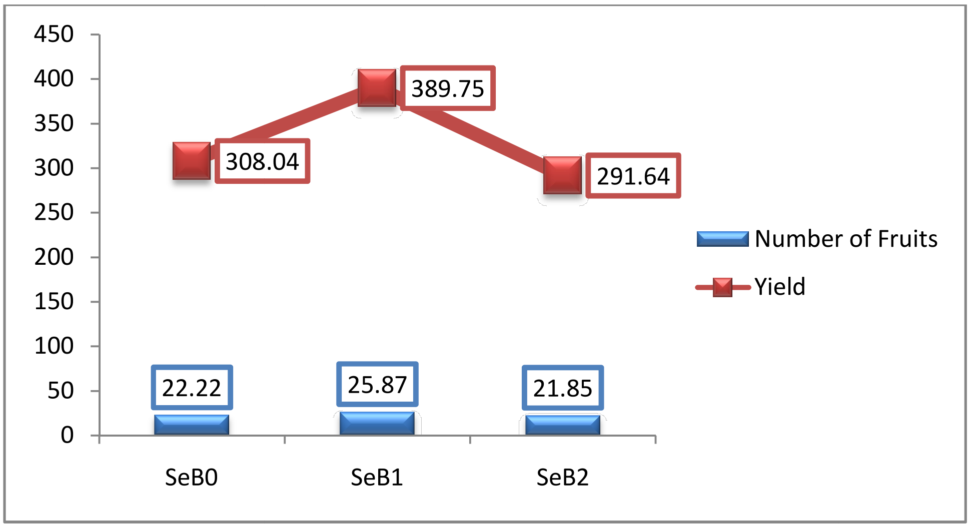


Fig. 4.3: Effect of selenobacteria on cumulative fruit number and yield per plant

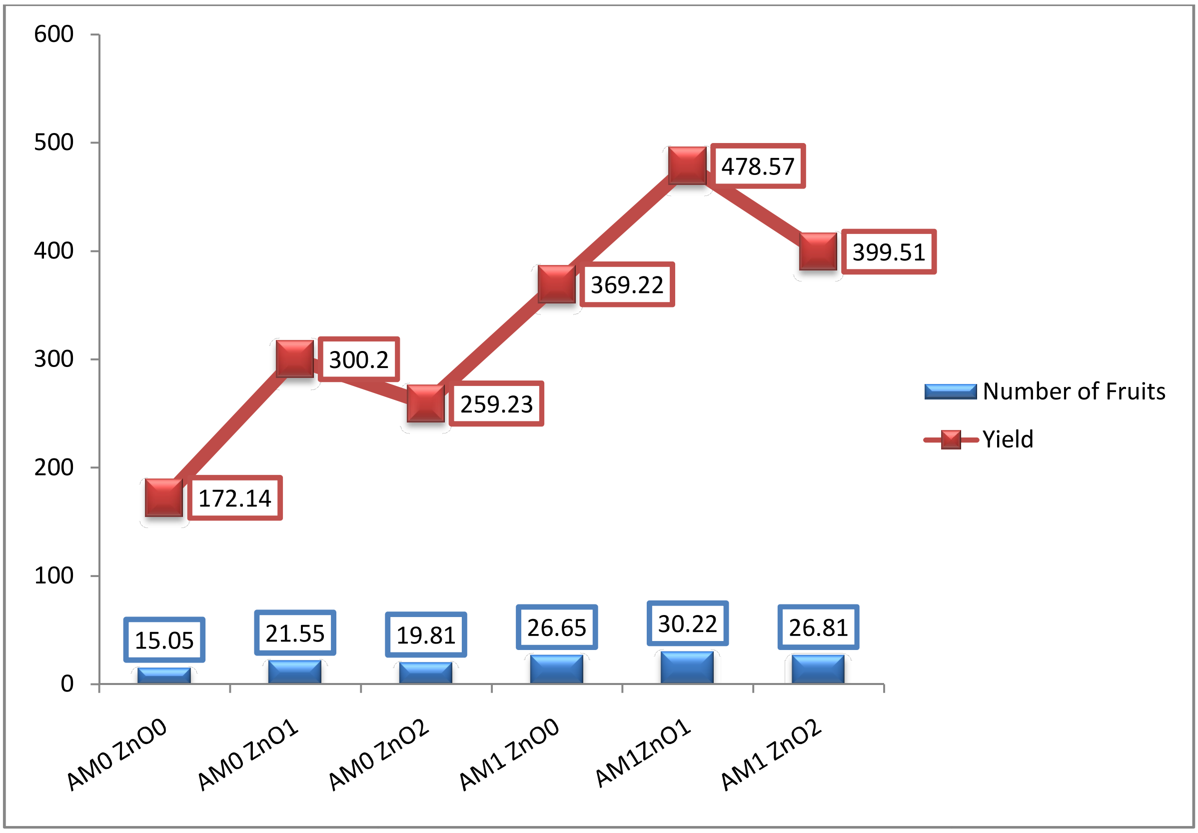


Fig. 4.4: Effect of AM fungi and nano zinc oxide on cumulative fruit number and yield per plant

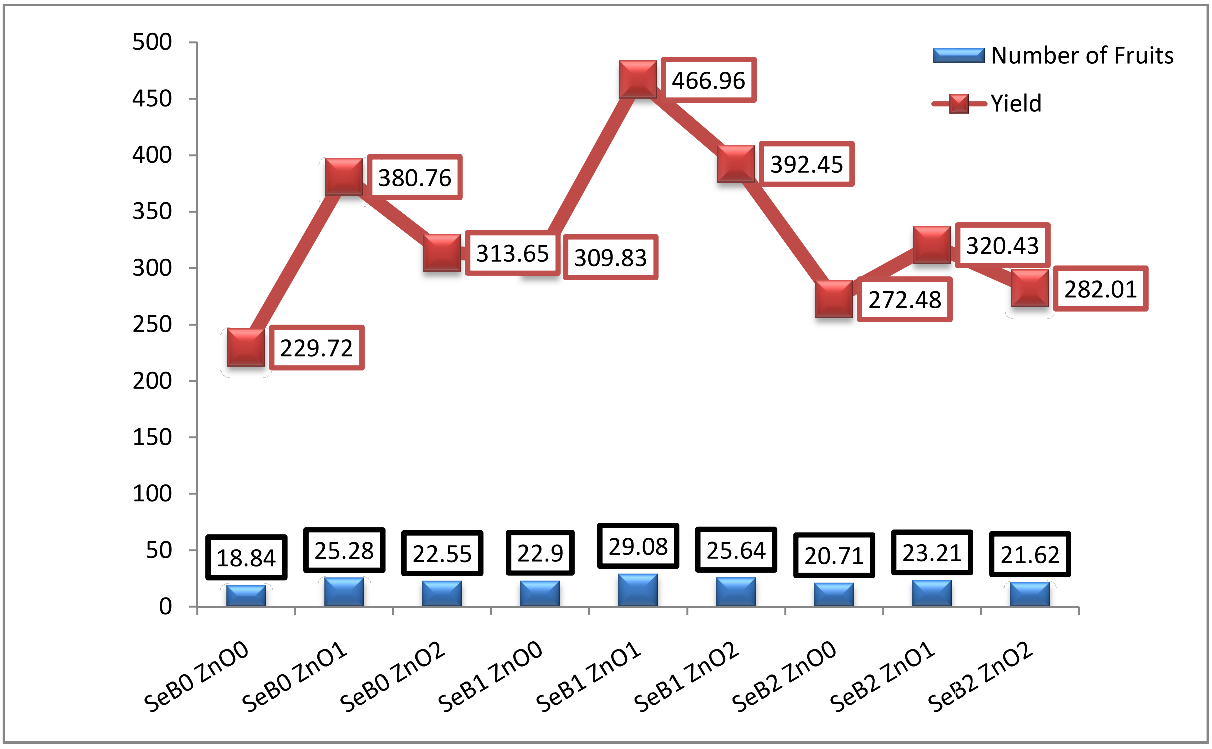


Fig. 4.5: Effect of nano zinc oxide and selenobacteria on cumulative fruit number and yield per plant

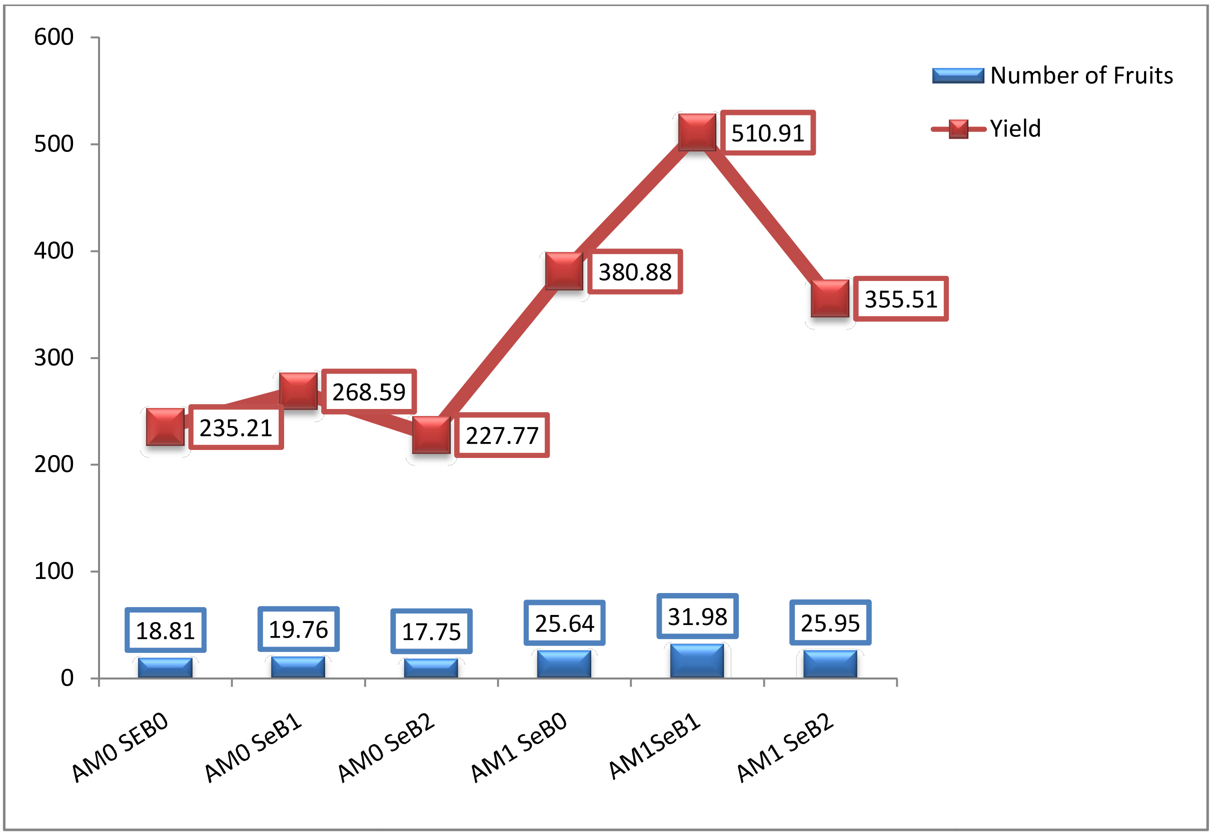


Fig. 4.6: Effect of AM fungi and selenobacteria on cumulative fruit number and yield per plant

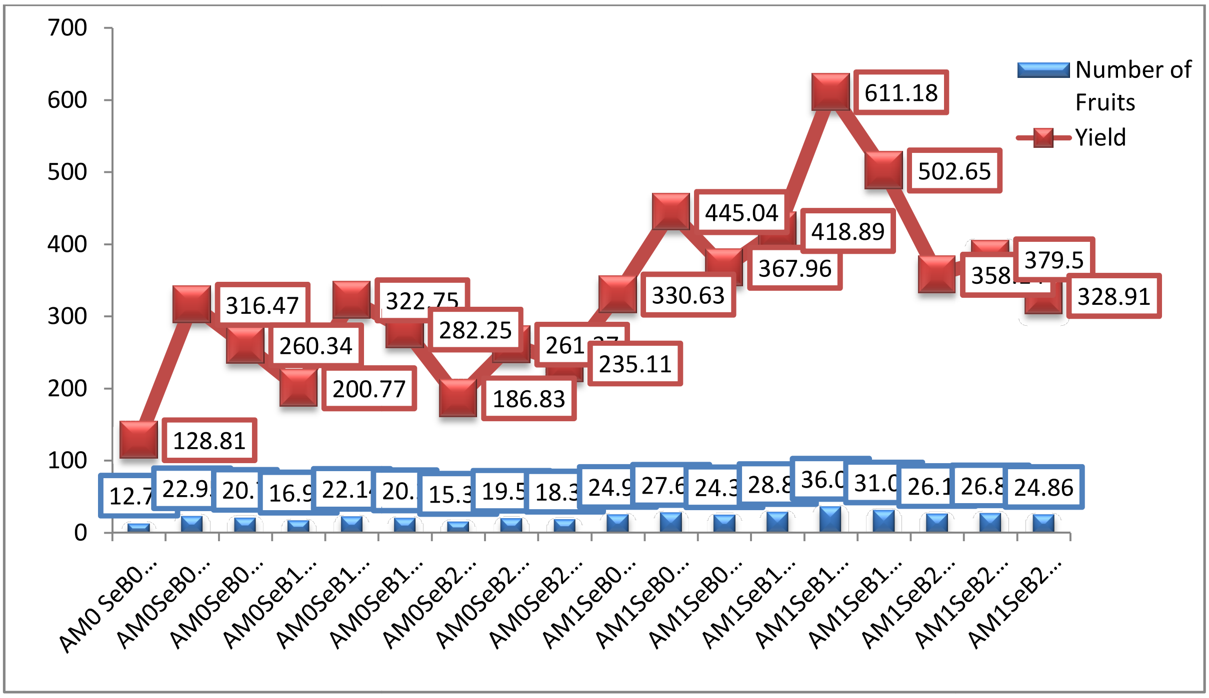


Fig. 4.7: Effect of AM fungi, nano zinc oxide and selenobacteria on cumulative fruit number and yield per plant

The foliar application of nano zinc oxide @ 100 ppm also positively influenced the fruit yield and thus, recorded maximum fruit yield per plant (389.38 g). It was found to be significantly higher over the other dose of nano zinc oxide.

The interaction effects of AM fungi and nano zinc oxide indicated that the significantly higher fruit yield per plant (478.57 g) was recorded in the interaction, where plants were treated with AM fungi and foliar application of nano zinc oxide @ 100 ppm. This result was followed by the interaction $AM_1 \times ZnO_2$ where the fruit yield of 399.51 g per plant was recorded.

As regards the interaction effects of selenobacteria and nano zinc oxide, significantly higher fruit yield per plant (466.96 g) was produced in the interaction, where the plants were treated with the selenobacteria (*Stenotrophomonas maltophilia*) and foliar spray of nano zinc oxide @ 100 ppm. However, this result was followed by the interaction, $SeB_1 \times ZnO_2$, where the fruit yield per plant (392 g) was recorded.

The interaction effects of AM fungi and selenobacteria revealed that the significantly higher fruit yield per plant (510.91 g) was recorded in the interaction, $AM_1 \times SeB_1$ and it was maximum in comparison to all other interactions.

The interaction of AM fungi × nano zinc oxide × selenobacteria exhibited a significantly higher fruit yield per plant (611.18 g) in the interaction, $AM_1 \times SeB_1 \times ZnO_1$ This was found to be significantly superior in comparison to all other interactions.

4.2.4 Yield efficiency (g/cm^2 LA)

The perusal of pooled data of two years given in Table- 4.12 (a and b) indicated that nano zinc, AM fungi and selenobacteria levels not only had significant effect individually but their interactions also had significant results on the yield efficiency (g/cm^2 LA) (Appendix-LVII).

The effect of AMF on yield efficiency was evident and it was observed to show a significant increase in yield efficiency (5.39 g/cm^2 LA) in plants treated with AMF.

The rhizoinoculation of selenobacterial strain *Stenotrophomonas maltophilia*, significantly impacted yield efficiency (5.08 g/cm^2 LA) in strawberry plants.

As regards the interaction of AM fungi and nano zinc oxide, the interaction, AM$_1$ × ZnO$_1$ was observed to show the maximum yield efficiency (5.97 g/cm^2 LA) and it was significantly higher over other interactions of AM fungi and nano zinc oxide.

Similarly, with the foliar application of nano zinc oxide, the highest increase in yield efficiency (5.01 g/cm^2 LA) was recorded with the nano zinc oxide @ 100 ppm and it was significantly maximum.

Table-4.12a: Effect of nano zinc, AM fungi and selenobacteria on yield efficiency (g/cm^2 LA) in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	2.68	4.97	**3.83**	3.29	4.41	3.79
ZnO$_1$	4.05	5.97	**5.01**	4.92	5.85	4.26
ZnO$_2$	3.43	5.21	**4.32**	4.14	4.98	3.84
Mean	**3.39**	**5.39**		**4.12**	**5.08**	**3.96**
CD$_{0.05}$						
AM	0.11		AM × ZnO	0.18		
SeB	0.13		SeB× ZnO	0.22		
ZnO	0.13					

Table-4.12b: Interactive effects of nano zinc, AM fungi and selenobacteria on yield efficiency (g/cm^2 LA) in strawberry

Nano Zinc Oxide	**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	2.13	3.18	2.73	4.44	5.64	4.84
ZnO$_1$	4.30	4.36	3.49	5.55	7.34	5.02
ZnO$_2$	3.45	3.73	3.11	4.84	6.23	4.57
Mean	**3.29**	**3.76**	**3.11**	**4.94**	**6.40**	**4.81**
CD$_{0.05}$						
AM × SeB	0.18		AM × SeB× ZnO	0.32		

AM$_0$:without AMF SeB$_0$:without Selenobacteria ZnO$_0$: 0
AM$_1$: with AMF SeB$_1$:*Stenotrophomonas maltophilia* ZnO$_1$: 100 ppm
SeB$_2$:*Alcaligenes faecalis* ZnO$_2$: 200 ppm

With regards the interaction effect of both selenobacteria and nano zinc oxide on yield efficiency, it was observed that the interaction, SeB$_1$ × ZnO$_1$ showed the maximum yield efficiency (5.85 g/cm^2 LA). It was significantly higher over other interactions of selenobacteria and nano zinc oxide.

Similarly, the effect of interaction between AM fungi and selenobacteria, the interaction, AM_1 × SeB_1 exhibited maximum yield efficiency (6.40 g/cm^2 LA) and it was significantly higher over other interactions of AM fungi and selenobacteria.

The interaction of AM fungi, selenobacteria and nano zinc oxide application reveals that the significantly higher yield efficiency (7.34 g/cm^2 LA) was observed in the interaction, AM_1 × SeB_1 × ZnO_1.

In the present investigation, the fruiting and yield parameters (number of fruits, fruit set %, fruit yield and yield efficiency) were significantly influenced by AM fungi, selenobacteria and nano zinc oxide. The maximum yield of 611.18 g fruits per plant was obtained with the combined effect of AM fungi, selenobacteria (*Strenotophomonas maltophilia*) and nano zinc oxide applied at a concentration of 100 ppm.

The results of the current study align with the findings of Masrahi et al. (2023), which demonstrated that the utilisation of mycorrhizal fungi led to the attainment of the most elevated yield values. Similar findings were reported by Bona et al. in 2014, in which AMF-inoculated strawberry plants had greater fruit weight (+35.8%) and fruit number (+21%) than control plants. The promotion effect of AMF as bio-fertilizers may be attributed to the impact of non-symbiotic phosphate-solubilizing microorganisms. These microorganisms exert a positive influence on plant growth through the synthesis of phytohormones and enzymes, including ACC deaminase, which regulate the plant's hormonal levels (Lone et al. 2017). Additionally, inorganic phosphate solubilization and organic phosphate mineralization thereby, increasing phosphorus availability to plants (Panhwar et al. 2011). The application of arbuscular mycorrhizal fungi (AMF) inoculation appeared to enhance crop productivity by promoting increased yield and fruit production in strawberry (Todeschini et al. 2018). It was found that inoculation with mycorrhizal preparations increased both the yield and the average fruit weight of the "Rumba" strawberry cultivar. High chlorophyll concentration and CO_2 assimilation intensity were correlated with an increase in strawberry yield and fruit weight after AMF application (Mikiciuk et al. 2019). It has also been reported that AMF inoculation led to an increase in fruit weight in plum (Eswarappa et al. 2002), fruit number and yield in papaya (Vazquez-Hernandez et al. 2011) as well as yield in carrot and green onion (Wang et al. 2011).

The present study that the interaction effect of AM fungi and selenobacterial strain (*Strenotophomonas maltophilia*) have resulted in increase in yield and yield related parameters of strawberry. The obtained outcome aligns with the findings of Jiang et al. (2023), who observed a substantial interaction effect between arbuscular mycorrhizal (AM) fungi and selenobacteria (*Strenotophomonas maltophilia*) on the fresh weight of pak choi (90.05–94.39 g).

The current study demonstrates that the application of nano zinc oxide through foliar treatment resulted in a notable enhancement in fruit yield per plant. The enhanced penetration of zinc nano particles into the leaf surface and subsequent release of Zn^{2+} ions have been observed through foliar application (Bala et al. 2019). The observed increase in fruit yield can be attributed to the positive influence of zinc (Zn) on the formation of flower primordia through its involvement in tryptophan synthesis (Usenik and Stampar 2002 and Davarpanah et al. 2016). Nano ZnO treatment enhances the activity of the nitrate reductase enzyme and facilitates the uptake of NO_3^-. The enhanced fruit yield can be attributed to the increased seedling vigour and early vegetative growth resulting from the promotory effects of nano ZnO. Results are in accordance with Subramanian and Sharmila-Rahale 2012 and Khanm et al. 2018. Sabir et al. (2014) and Kamiab and Zamanibahramabadi (2016) reported a significant increase in crop yield, ranging from 26-30%, by utilising zinc in the form of nanoparticles. Nano ZnO application has been reported to have a positive influence on fruit yield in various crops such as pomegranate (Davarpanah et al. 2016), strawberry (Kumar et al. 2017), mango (Zagzog and Gad 2017), and grapes (El-Said et al. 2019). Also, the increase in the growth of plant is reflected in the yield related parameters (Poornima and Koti 2019). The increase in number of fruits per tree through nano ZnO application has increased the fruit yield in papaya (Jeyakumar et al. 2001) and pomegranate (Davarpanah et al. 2016). Increased efficacy with delayed nutrient release and extended fertilizer effect has also been reported (Mukhopadhyay 2014, Prasad et al. 2013 and Manjunatha et al. 2016). Moreover, Zn acts as an activator of several enzymes such as dehydrogenase, protinease and peptides (Prasad and Kumar 2010). The observed increase in yield can be attributed to the enhanced physiological and biochemical activities resulting from the involvement of zinc as a cofactor for multiple enzymes. The promising effect of Zn on yield related parameters is in accordance with Mousavi et al. (2013) who advocated that the role of Zn in activation of enzymes related to carbohydrate and nitrogen metabolism resulted in proper growth and improved yield.

4.3 EFFECTS OF NANO ZINC, AM FUNGI AND SELENOBACTERIA ON FRUIT QUALITY CHARACTERISTICS

4.3.1 Physical characteristics

4.3.1.1 Fruit length (mm)

The pooled data pertaining to the fruit length (mm) have been depicted in the Table - 4.13 (a and b). A perusal of data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced fruit length of strawberry fruits significantly. However, the interaction, AM × SeB × ZnO was found to be non significant (Appendix- LVII).

Table-4.13a: Effect of nano zinc, AM fungi and selenobacteria on fruit length (mm) in strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	32.04	36.47	**34.26**	32.66	36.70	33.42
ZnO_1	34.02	37.12	**35.57**	35.21	37.90	33.60
ZnO_2	33.38	35.00	**34.19**	33.76	35.82	32.98
Mean	**33.15**	**36.20**		**33.88**	**36.81**	**33.33**
$CD_{0.05}$						
AM	0.40		AM × ZnO	0.70		
SeB	0.49		SeB× ZnO	0.85		
ZnO	0.49					

Table-4.13b: Interactive effects of nano zinc, AM fungi and selenobacteria on fruit length (mm) in strawberry

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	29.40	34.29	32.45	35.93	39.11	34.38
ZnO_1	33.16	35.97	32.93	37.27	39.84	34.26
ZnO_2	32.78	34.16	33.18	34.74	37.47	32.78
Mean	**31.78**	**34.81**	**32.86**	**35.98**	**38.81**	**33.81**
$CD_{0.05}$						
AM × SeB	0.70		AM × SeB × ZnO		NS	

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As regards to AM fungi, maximum fruit length (36.20 mm) of strawberry fruits was observed in AM_1. It was significantly higher to the other fruits from non AM fungi treated plants.

The application of selenobacteria significantly affected the fruit length of strawberry fruits. Maximum fruit length (36.81 mm) of strawberry fruits was observed in SeB_1.

Considering the effect of foliar application of nano zinc oxide applied with different concentrations, the maximum fruit length (35.57 mm) of strawberry fruits was observed with ZnO_1.

The interaction of AM fungi and nano zinc oxide exhibited maximum fruit length (37.12 mm) of strawberry fruits in the interaction, $AM_1 \times ZnO_1$, and it was found to be significantly higher over all the other interactions of AM fungi and nano zinc oxide.

As regards the interaction of selenobacteria and nano zinc oxide, maximum fruit length of strawberry fruits was recorded with a value of 37.90 mm. They were produced in the interaction, $SeB_1 \times ZnO_1$ and found to be significantly higher over all the other interactions of selenobacteria and nano zinc oxide.

The interaction of AM fungi and selenobacteria reveals maximum fruit length (38.81 mm) of strawberry fruits in the interaction, $AM_1 \times SeB_{1.}$ It was significantly superior in comparison to all the other interactions of AM and SeB.

4.3.1.2 Fruit breadth (mm)

The perusal of pooled data pertaining to the fruit breadth (mm) have been presented in the Table – 4.14 (a and b) . The data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced fruit breadth of strawberry fruits significantly (Appendix- LVII).

As regards to AM fungi, maximum fruit breadth with a value of 29.92 mm of strawberry fruits was observed in AM_1. It was significantly higher to the other fruits from non AM fungi treated plants.

The application of selenobacteria significantly affected the fruit breadth of strawberry fruits. Maximum fruit breadth (29.69 mm) of strawberry fruits was observed in SeB_1 i.e. with the application of selenobacteria (*Stenotrophomonas maltophilia*).

Considering the effect of foliar application of nano zinc oxide applied with different concentrations the maximum fruit breadth (29.74 mm) of strawberry fruits was observed when nano zinc oxide was applied @ 100ppm.

Table-4.14a: Effect of nano zinc, AM fungi and selenobacteria on fruit breadth (mm) in strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	26.69	29.70	**28.20**	27.84	28.62	28.13
ZnO_1	28.83	30.65	**29.74**	29.78	30.69	28.76
ZnO_2	28.26	29.41	**28.83**	28.61	29.77	28.13
Mean	**27.93**	**29.92**		**28.74**	**29.69**	**28.34**
$CD_{0.05}$						
AM	0.25		AM × ZnO	0.43		
SeB	0.30		SeB× ZnO	0.52		
ZnO	0.30					

Table-4.14b: Interactive effects of nano zinc, AM fungi and selenobacteria on fruit breadth (mm) in strawberry

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	25.31	27.36	27.40	30.37	29.87	28.86
ZnO_1	28.64	29.12	28.75	30.91	32.27	28.78
ZnO_2	28.48	28.49	27.81	28.73	31.04	28.45
Mean	**27.48**	**28.32**	**27.99**	**30.00**	**31.06**	**28.70**
$CD_{0.05}$						
AM × SeB	0.43		AM × SeB× ZnO	0.74		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

The interaction of AM fungi and nano zinc oxide exhibited maximum fruit breadth (30.65 mm) of strawberry fruits in the interaction, where plants were treated with AM fungi and foliar application of nano zinc oxide @100 ppm and it was found to be significantly higher over all the other interactions of AM fungi and nano zinc oxide.

As regards the interaction of selenobacteria and nano zinc oxide, maximum fruit breadth (30.69 mm) of strawberry fruits were produced in the interaction, with the application of selenobacterial strain *Stenotrophomonas maltophilia* and nano zinc oxide @ 100 ppm and found to be significantly higher over all the other interactions of selenobacteria and nano zinc oxide.

The interaction of AM fungi and selenobacteria reveals maximum fruit breadth (31.06 mm) of strawberry fruits in the interaction, i.e. AM fungi applied at the time of transplanting, 30 and 45 days after transplanting and selenobacteria (*Stenotrophomonas maltophilia*). It was significantly superior in comparison to all the other interactions of AM and SeB.

The interaction of AM fungi × nano zinc oxide × selenobacteria reveals maximum fruit breadth (32.27 mm) of strawberry fruits in the interaction, i.e. when AM fungi was applied along with selenobacteria (*Stenotrophomonas maltophilia*) and nano zinc oxide @100 ppm. This was found to be significantly maximum in comparison to all the other interactions.

4.3.1.3 Fruit weight (g)

The data presented in the Table- 4.15 (a and b) depicts the pooled data pertaining to the fruit weight (g). The data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced fruit weight (g) of strawberry fruits significantly (Appendix- LVII).

As regards to AM fungi, maximum fruit weight (14.78 g) of strawberry fruits was observed in plants that were treated with AM fungi. It was significantly higher to the other fruits from non AM fungi treated plants.

The application of selenobacteria significantly affected the fruit weight of strawberry fruits. Maximum fruit weight (14.66 g) of strawberry fruits was observed with the application of selenobacteria (*Stenotrophomonas maltophilia*).

The effect of foliar application of nano zinc oxide applied with different concentration, the maximum fruit weight (14.82 g) of strawberry fruits was observed with nano zinc oxide applied @ 100ppm.

The interaction of AM and nano ZnO exhibited maximum fruit weight (15.72 g) of strawberry fruits in the interaction, AM_1 × ZnO_1 and it was found to be significantly higher over all the other interactions of AM fungi and nano zinc oxide.

As regards the interaction of SeB and nano ZnO, maximum fruit weight (15.77 g) of strawberry fruits was observed in the interaction, SeB_1 × ZnO_1 and it was found to be significantly higher over all the other interactions of selenobacteria and nano zinc oxide.

Table-4.15a: Effect of nano zinc, AM fungi and selenobacteria on fruit weight (g) of strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	11.36	13.82	**12.59**	11.66	13.15	12.96
ZnO$_1$	13.91	15.72	**14.82**	14.94	15.77	13.74
ZnO$_2$	13.10	14.81	**13.95**	13.79	15.07	13.00
Mean	**12.79**	**14.78**		**13.46**	**14.66**	**13.23**
CD$_{0.05}$						
AM	0.14		AM × ZnO	0.25		
SeB	0.17		SeB× ZnO	0.30		
ZnO	0.17					

Table-4.15b: Interactive effects of nano zinc, AM fungi and selenobacteria on fruit weight (g) of strawberry

Nano Zinc Oxide	**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	10.08	11.81	12.20	13.24	14.50	13.71
ZnO$_1$	13.77	14.58	13.38	16.10	16.97	14.10
ZnO$_2$	12.54	13.98	12.77	15.03	16.16	13.23
Mean	**12.13**	**13.45**	**12.78**	**14.79**	**15.87**	**13.68**
CD$_{0.05}$						
AM × SeB	0.25		AM × SeB× ZnO	0.28		

AM$_0$:without AMF SeB$_0$:without Selenobacteria ZnO$_0$: 0
AM$_1$: with AMF SeB$_1$:*Stenotrophomonas maltophilia* ZnO$_1$: 100 ppm
SeB$_2$:*Alcaligenes faecalis* ZnO$_2$: 200 ppm

The interaction of AM and SeB reveals maximum fruit weight of 15.87 g of strawberry fruits in the interaction, AM$_1$ × SeB$_1$ which was significantly higher.

The interaction of AM × ZnO × SeB reveals maximum fruit weight (16.97 g) of strawberry fruits in the interaction, AM$_1$ × SeB$_1$ × ZnO$_1$. This was found to be significantly maximum in comparison to all the other interactions.

4.3.1.4 Fruit firmness (lb/inch^2)

The pooled data pertaining to the fruit firmness (lb/inch^2) have been depicted in the Table-4.16 (a and b). A perusal of data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced fruit firmness (lb/inch^2) of strawberry fruits significantly (Appendix- LVII).

Table-4.16a: Effect of nano zinc, AM fungi and selenobacteria on fruit firmness (lb/inch^2) in strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	AM_1		SeB_0	SeB_1	SeB_2
ZnO_0	8.90	10.35	**9.62**	9.22	9.77	9.88
ZnO_1	10.23	10.81	**10.52**	10.48	10.67	10.41
ZnO_2	10.07	10.46	**10.27**	10.11	10.38	10.31
Mean	**9.73**	**10.54**		**9.94**	**10.27**	**10.20**
$CD_{0.05}$						
AM	0.09		AM × ZnO	0.16		
SeB	0.11		SeB× ZnO	0.19		
ZnO	0.11					

Table-4.16b: Interactive effects of nano zinc, AM fungi and selenobacteria on fruit firmness (lb/inch^2) in strawberry

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2
ZnO_0	8.05	9.19	9.45	10.38	10.35	10.31
ZnO_1	10.29	10.19	10.22	10.67	11.16	10.59
ZnO_2	9.88	10.29	10.05	10.35	10.47	10.57
Mean	**9.41**	**9.89**	**9.91**	**10.46**	**10.66**	**10.49**
$CD_{0.05}$						
AM × SeB	0.16		AM × SeB× ZnO	0.27		

AM_0:without AMF SeB_0 :without Selenobacteria ZnO_0: 0
AM_1: with AMF SeB_1:*Stenotrophomonas maltophilia* ZnO_1: 100 ppm
SeB_2 :*Alcaligenes faecalis* ZnO_2 : 200 ppm

As regards to AM fungi, maximum fruit firmness with a value of 10.54 lb/inch^2 was observed in strawberry fruits produced from plants to which mycorrhizal treatment was given. It was significantly higher to the other fruits from non AM fungi treated plants.

The application of selenobacteria significantly affected the fruit firmness of strawberry fruits. Maximum fruit firmness (10.27 lb/inch^2) of strawberry fruits was observed with the application of selenobacteria (*Stenotrophomonas maltophilia*).

Considering the effect of foliar application of nano zinc oxide applied with different concentrations the maximum fruit firmness (10.52 lb/inch^2) of strawberry fruits was observed with nano zinc oxide applied @ 100ppm.

The interaction of AM fungi and nano zinc oxide exhibited maximum fruit firmness (10.81 lb/inch^2) of strawberry fruits in the interaction, AM_1 × ZnO_1 and it was found to be significantly higher over all the other interactions of AM fungi and nano zinc oxide.

As regards the interaction of selenobacteria and nano zinc oxide, significantly higher fruit firmness (10.67 lb/inch^2) of strawberry fruits was observed in the interaction, SeB_1 × ZnO_1.

The interaction of AM fungi and selenobacteria reveals maximum fruit firmness (10.66 lb/inch^2) of strawberry fruits in the interaction, AM_1 × SeB_1. It was significantly superior in comparison to all the other interactions of AM and SeB.

The interaction effect of all the three factors revealed that plants treated with AM fungi × nano zinc oxide × selenobacteria produced fruits with maximum fruit firmness (11.16 lb/inch^2) of strawberry fruits in the interaction, AM_1 × SeB_1 × $ZnO_{1.}$ This was found to be significantly maximum in comparison to all the other interactions.

4.3.1.5 Fruit shape index

The perusal of pooled data presented in the Table- 4.17 (a and b) for fruit shape index depicts that nano zinc oxide, selenobacteria individually and the interactions of nano zinc oxide × AM fungi, selenobacteria × AM fungi alongwith nano zinc oxide × AM fungi × selenobacteria significantly affected the fruit shape index. However effect of AM fungi individually and interaction of nano zinc oxide × selenobacteria were non significant (Appendix- LVII).

The application of selenobacteria significantly affected the fruit shape index of strawberry fruits. Maximum fruit shape index (1.24) of strawberry fruits was observed in SeB_1.

Considering the effect of foliar application of nano zinc oxide applied with different concentrations the maximum fruit shape index (1.21) of strawberry fruits was observed with ZnO_0.

The interaction of AM fungi and nano zinc oxide exhibited maximum fruit shape index (1.23) of strawberry fruits in the interaction, AM_1 × ZnO_0.

Table-4.17a: Effect of nano zinc, AM fungi and selenobacteria on fruit shape index in strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM$_0$	AM$_1$		SeB$_0$	SeB$_1$	SeB$_2$
ZnO$_0$	1.20	1.23	**1.21**	1.17	1.28	1.19
ZnO$_1$	1.18	1.21	**1.20**	1.19	1.24	1.17
ZnO$_2$	1.18	1.19	**1.19**	1.18	1.21	1.18
Mean	**1.19**	**1.21**		**1.18**	**1.24**	**1.18**
CD$_{0.05}$						
AM	NS		AM × ZnO	0.03		
SeB	0.02		SeB× ZnO	NS		
ZnO	0.02					

Table-4.17b: Interactive effects of nano zinc, AM fungi and selenobacteria on shape index in strawberry

Nano Zinc Oxide	AM$_0$			AM$_1$		
	SeB$_0$	SeB$_1$	SeB$_2$	SeB$_0$	SeB$_1$	SeB$_2$
ZnO$_0$	1.16	1.25	1.18	1.18	1.31	1.19
ZnO$_1$	1.16	1.24	1.15	1.21	1.23	1.19
ZnO$_2$	1.15	1.20	1.19	1.21	1.21	1.16
Mean	**1.16**	**1.23**	**1.17**	**1.20**	**1.25**	**1.18**
CD$_{0.05}$						
AM × SeB		NS		AM × SeB× ZnO		0.05

AM$_0$:without AMF	SeB$_0$:without Selenobacteria	ZnO$_0$: 0
AM$_1$: with AMF	SeB$_1$:*Stenotrophomonas maltophilia*	ZnO$_1$: 100 ppm
	SeB$_2$:*Alcaligenes faecalis*	ZnO$_2$: 200 ppm

The interaction of AM fungi and selenobacteria reveals maximum fruit shape index (1.25) of strawberry fruits in the interaction, AM$_1$ × SeB$_1$.

The interaction effect of all the three factors revealed that plants treated with AM fungi × nano zinc oxide × selenobacteria produced fruits with maximum fruit shape index (1.31) of strawberry fruits in the interaction, AM$_1$ × SeB$_1$ × ZnO$_0$.

The fruits of the plants treated with the AM fungi, selenobacteria (*Strenotophomonas maltophilia*) and nano zinc oxide @ 100 ppm were observed to have higher physical fruit quality parameters viz., fruit dimensions, weight, firmness.

The present study is in consonance with the findings of Jiang et al. (2023). It states that AM fungi significantly increased the fresh weight of pak choi up to 27.33 g, indicating that the application of AM fungi could stimulate the absorption ability of nutrients in the plant by extending the contact area between plant roots and nutrients,thereby, improving its metabolic activities.

The significant interaction effect of both AM fungi and selenobacteria (*Strenotophomonas maltophilia*) are in confirmation with the findings of Jiang et al. (2023) where they reported that the fresh weight of pak choi significantly increased (90.05–94.39 g) by adding the AM fungi and strain *Strenotophomonas maltophilia.*

Application of ZnO nano particles improved the fruit's physical characteristics, which could be attributed to greater Zn assimilation due to the leaf's increased ability to penetrate it (Rossi et al. 2018). In their study, Prasad et al. (2012) investigated the impact of nano ZnO on bioavailability. They found that the reduced size and increased surface area of ZnO nanoparticles led to enhanced absorption. The researchers observed that ZnO nanoparticles primarily absorbed on the cell surface and effectively translocated towards the sink, which in this case were fruits. The documented studies have shown that the application of nano ZnO has a positive effect on vegetative growth, leading to an increase in the number of flowers and fruits. This ultimately results in an overall increase in fruit weight (Laware and Raskar 2014). The researchers have observed that the presence of Zn, an essential component for various enzymes, correlates with an augmentation in both fruit quantity and fruit weight in strawberries. The increase in fruit diameter can be attributed to the role of Zn in cell division and cell elongation, leading to the synthesis of tryptophan and auxin (Wojcik and Wojcik 2003, Alloway 2004 and Boettcher et al. 2010). The enhanced physical attributes of fruits may be attributed to the increased cell elongation, leading to the accumulation of additional metabolites (Babu and Singh 2001). Lin and Xing (2008) documented similar findings reported in strawberry (Kumar et al. 2017), mango (Zagzog and Gad 2017) and grapes (El-Said et al. 2019). Increase in cellular size and intercellular space due to Zn application in strawberry has also increased fruit weight (Rahman et al. 2016).

4.3.2 Biochemical characteristics

4.3.2.1 Fruit TSS (˚Brix)

The pooled data pertaining to the fruit TSS (˚Brix) have been depicted in the Table - 4.18 (a and b). A perusal of data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced TSS (˚Brix) of strawberry fruits significantly (Appendix- LVII).

Table-4.18a: Effect of nano zinc, AM fungi and selenobacteria on fruit TSS (ºB) of strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	7.67	9.04	**8.35**	8.01	8.68	8.38
ZnO_1	9.36	10.23	**9.79**	9.95	9.89	9.53
ZnO_2	9.20	9.94	**9.57**	9.74	9.57	9.40
Mean	**8.74**	**9.74**		**9.23**	**9.38**	**9.10**
$CD_{0.05}$						
AM	0.09		AM × ZnO	0.16		
SeB	0.12		SeB× ZnO	0.20		
ZnO	0.12					

Table-4.18b: Interactive effects of nano zinc, AM fungi and selenobacteria on fruit TSS (ºB) of strawberry

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	7.03	8.00	7.99	9.00	9.36	8.76
ZnO_1	9.46	9.32	9.29	10.44	10.46	9.77
ZnO_2	9.33	9.10	9.17	10.14	10.05	9.63
Mean	**8.60**	**8.81**	**8.82**	**9.86**	**9.96**	**9.39**
$CD_{0.05}$						
AM × SeB	0.16		AM × SeB× ZnO	0.28		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As regards to AM fungi, significantly higher TSS was recorded with a value of 9.74 ˚Brix of strawberry fruits was observed where, the mycorrhizal treatment was given to the plants and it was significantly higher to the other fruits from non AM fungi treated plants.

The application of selenobacteria significantly affected the fruit TSS of strawberry. Maximum fruit TSS (9.38 ˚Brix) of strawberry fruits was observed with the rhizoinoculation of selenobacteria (*Stenotrophomonas maltophilia*).

The foliar application of nano zinc oxide applied @ 100ppm resulted in production of fruits with significantly higher fruit TSS 9.79 ˚Brix.

The interaction of AM and ZnO, exhibited significantly higher fruit TSS with a value of 10.23 ˚Brix of strawberry fruits in the interaction, where plants were treated with AM fungi and foliar application of nano zinc oxide @100 ppm and it was found to be significantly higher over all the other interactions of AM fungi and nano zinc oxide.

As regards the interaction of SeB and nano ZnO, it recorded maximum fruit TSS (9.95 ˚Brix) of strawberry fruits were produced in the interaction, $SeB_0 \times ZnO_1$. However, the interaction of $SeB_1 \times ZnO_1$ recorded statistically at par fruit TSS (9.89 ˚Brix) with the value of TSS recorded in $SeB_0 \times ZnO_1$.

The interaction of AM and selenobacteria SeB reveals maximum fruit TSS with a value of 9.96 ˚Brix in the interaction, $AM_1 \times SeB_1$. However the interaction effect of $AM_1 \times SeB_0$ i.e. plants treated with only AM fungi observed TSS (9.86 ˚Brix) and it was statistically at par with the interactive effect of $AM_1 \times SeB_1$.

The interaction effect of all the three factors revealed that plants treated with the interaction, $AM_1 \times SeB_1 \times ZnO_1$ produced fruits with maximum TSS (10.46 ˚Brix). However, the interaction of $AM_1 \times SeB_0 \times ZnO_1$ was statistically at par with the above interaction observing fruit TSS value of 10.44 ˚Brix.

4.3.2.2 Fruit titratable acidity (%)

The perusal of pooled data presented in the Table- 4.19 (a and b) for fruit titratable acidity (%) depicts that AM fungi, nano zinc oxide, selenobacteria individually alongwith the interactions significantly affected the fruit titratable acidity (Appendix- LVII).

As regards to AM fungi, maximum fruit titratable acidity (0.71 %) was observed in AM_0 i.e. plants were not treated with AM fungi.

Table-4.19a: Effect of nano zinc, AM fungi and selenobacteria on fruit titratable acidity (%) of strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.76	0.73	**0.75**	0.75	0.75	0.75
ZnO_1	0.68	0.62	**0.65**	0.63	0.63	0.69
ZnO_2	0.69	0.64	**0.66**	0.64	0.65	0.70
Mean	**0.71**	**0.66**		**0.67**	**0.68**	**0.71**
$CD_{0.05}$						
AM SeB ZnO	0.01 0.01 0.01		AM × ZnO SeB× ZnO	0.01 NS		

Table-4.19b: Interactive effects of nano zinc, AM fungi and selenobacteria on fruit titratable acidity (%) of strawberry

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.77	0.75	0.77	0.72	0.74	0.73
ZnO_1	0.67	0.68	0.68	0.59	0.57	0.70
ZnO_2	0.67	0.69	0.70	0.61	0.61	0.69
Mean	**0.70**	**0.71**	**0.72**	**0.64**	**0.64**	**0.71**
$CD_{0.05}$						
AM × SeB	0.01		AM × SeB× ZnO		0.02	

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

The application of selenobacteria significantly affected the titratable acidity of strawberry fruits. Maximum fruit titratable acidity (0.71 %) of strawberry fruits was observed in SeB_2 i.e. with the application of selenobacteria strain *Alcaligenes faecalis*.

The foliar application of nano zinc oxide was observed to reduce the titratable acidity of strawberry fruits applied and thus higher titratable acidity (0.75 %) of strawberry fruits was observed when nano zinc oxide was not applied to plants i.e. ZnO_0.

The interaction of AM fungi and nano zinc oxide at different levels was also observed to decrease the titratable acidity, thus it was recorded that the titratable acidity (0.76 %) of strawberry fruits was maximum in the interaction, $AM_0 \times ZnO_0$.

The interaction of AM fungi and selenobacteria reveals maximum fruit titratable acidity (0.72 %) was observed in the interaction, $AM_0 \times SeB_2$.

The interaction of AM fungi × nano zinc oxide × selenobacteria reveals that the interactions, $AM_0 \times SeB_0 \times ZnO_0$ and $AM_0 \times SeB_2 \times ZnO_0$ observed the maximum fruit titratable acidity (0.77 %) of strawberry fruits.

4.3.2.3 Fruit TSS: Acidity

The perusal of pooled data pertaining to the fruit TSS: acidity have been presented in the Table- 4.20 (a and b). The data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced fruit TSS: acidity significantly (Appendix- LVII).

Table-4.20a: Effect of nano zinc, AM fungi and selenobacteria on fruit TSS/acidity in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	10.07	12.42	**11.25**	10.82	11.66	11.26
ZnO_1	13.84	16.54	**15.19**	15.90	15.96	13.72
ZnO_2	13.35	15.70	**14.53**	15.35	14.79	13.44
Mean	**12.42**	**14.89**		**14.02**	**14.14**	**12.81**
$CD_{0.05}$						
AM	0.20		AM × ZnO	0.34		
SeB	0.24		SeB× ZnO	0.42		
ZnO	0.24					

Table-4.20b: Interactive effects of nano zinc, AM fungi and selenobacteria on fruit TSS/acidity in strawberry

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	9.12	10.66	10.44	12.51	12.65	12.09
ZnO_1	14.22	13.72	13.57	17.57	18.20	13.86
ZnO_2	13.93	13.10	13.02	16.77	16.48	13.86
Mean	**12.43**	**12.50**	**12.34**	**15.62**	**15.78**	**13.27**
$CD_{0.05}$						
AM × SeB	0.34		AM × SeB× ZnO		0.60	

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As regards to AM fungi, maximum fruit TSS: acidity with a value of 14.89 was observed in AM_1. It was significantly higher to the other fruits from non AM fungi treated plants.

The application of selenobacteria significantly affected the fruit TSS: acidity of strawberry fruits. Maximum fruit TSS: acidity with the mean value of 14.14 was observed in SeB_1.

Considering the effect of foliar application of nano zinc oxide applied with different concentrations the maximum TSS: acidity (15.19) of strawberry fruits was observed with ZnO_1 i.e. nano zinc oxide applied @ 100ppm.

The interaction of AM_1 × ZnO_1, significantly maximum TSS: acidity with a value of 16.54 was exhibited and it was found to be significantly higher over all the other interactions of AM fungi and nano zinc oxide.

As regards the interaction of $SeB_1 \times ZnO_1$, maximum TSS: acidity ratio with a value of 15.96 was observed. However, effect of the interaction, $SeB_0 \times ZnO_1$ was statistically at par with the effect of $SeB_1 \times ZnO_1$ for TSS: acidity (15.90).

The interaction of $AM_1 \times SeB_1$, recorded a maximum TSS: acidity (15.78). However, effect of the interaction, $AM_1 \times SeB_0$ was statistically at par with the interaction of $AM_1 \times SeB_1$ for fruit TSS: acidity (15.62).

The interaction of $AM_1 \times SeB_1 \times ZnO_1$ reveals that maximum value 18.20 of fruit TSS: acidity was observed in the interaction.

4.3.2.4 Fruit total sugar (%)

The perusal of pooled data pertaining to the fruit total sugar have been presented in the Table-4.21(a and b). The data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced total sugar (%) of strawberry fruits significantly (Appendix- LVII).

As regards to AM fungi, it significantly affected the total sugar content of strawberry fruits and the maximum value 7.11 % was observed in AM_1. It was significantly higher to the other fruits from non AM fungi treated plants.

Table-4.21a: Effect of nano zinc, AM fungi and selenobacteria fruit total sugar (%) in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	6.62	7.17	**6.88**	6.80	7.02	6.70
ZnO_1	7.00	7.20	**7.11**	7.09	7.31	6.85
ZnO_2	6.83	6.95	**6.89**	6.91	7.14	6.75
Mean	**6.82**	**7.11**		**6.93**	**7.16**	**6.77**
$CD_{0.05}$						
AM	0.07		AM × ZnO	0.13		
SeB	0.09		SeB× ZnO	0.15		
ZnO	0.09					

Table-4.21b: Interactive effects of nano zinc, AM fungi and selenobacteria fruit total sugar (%) in strawberry

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	6.23	6.93	6.69	7.37	7.34	6.66
ZnO_1	6.98	7.13	6.88	7.20	7.61	6.83
ZnO_2	6.84	6.82	6.84	6.98	7.22	6.70
Mean	**6.69**	**6.96**	**6.80**	**7.18**	**7.39**	**6.73**
$CD_{0.05}$						
AM × SeB	0.13		AM × SeB× ZnO	0.22		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

The application of selenobacteria significantly affected the total sugar (%) of strawberry fruits. The maximum total sugar 7.16 % in strawberry fruits was observed in SeB_1.

Considering the effect of foliar application of nano zinc oxide applied with different concentrations the maximum total sugar 7.11 % in strawberry fruits was observed with ZnO_1 and was significantly higher among all the three levels of nano zinc oxide.

The interaction of AM_1 × ZnO_1 exhibited maximum total sugar (7.20 %) of strawberry fruits and it was found to be significantly maximum over all the other interactions of AM fungi and nano zinc oxide.

As regards the interaction of SeB_1 × ZnO_1, maximum total sugar to the value of 7.31 % was observed and it was found to be significantly higher over all the other interactions of selenobacteria and nano zinc oxide.

The interaction of AM_1 × SeB_1 revealed that total sugar to the maximum value of 7.39 % in the strawberry fruits. It was significantly superior in comparison to all the other interactions of AM and SeB.

The interaction AM_1 × SeB_1 × ZnO_1 , reveals total sugar (7.61 %) with significantly increased value in strawberry fruits. This was found to be significantly maximum in comparison to all the other interactions.

4.3.2.5 Fruit reducing sugar (%)

The pooled data pertaining to the reducing sugar of strawberry fruits have been presented in the Table- 4.22 (a and b) .The data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced reducing sugar (%) of strawberry fruits significantly (Appendix- LVII).

As regards to AM fungi, maximum reducing sugar (5.36 %) of strawberry fruits was observed in AM_1. It was significantly higher to the other fruits from non AM fungi treated plants.

The application of selenobacteria significantly affected the reducing sugar of strawberry fruits. Maximum reducing sugar (5.28 %) of strawberry fruits was observed in SeB_1.

Table-4.22a: Effects of nano zinc, AM fungi and selenobacteria on reducing sugar (%) in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.46	5.31	**4.88**	4.79	5.08	4.79
ZnO_1	5.03	5.40	**5.23**	5.20	5.47	5.13
ZnO_2	4.96	5.38	**5.18**	4.92	5.29	5.15
Mean	**4.82**	**5.36**		**4.97**	**5.28**	**5.02**
$CD_{0.05}$						
AM	0.06		AM × ZnO	0.10		
SeB	0.07		SeB× ZnO	0.12		
ZnO	0.07					

Table-4.22b: Interactive effects of nano zinc, AM fungi and selenobacteria on reducing sugar (%) in strawberry

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.31	4.67	4.40	5.26	5.48	5.17
ZnO_1	5.06	5.10	4.94	5.35	5.78	5.32
ZnO_2	4.57	5.16	5.16	5.27	5.49	5.13
Mean	**4.65**	**4.97**	**4.83**	**5.29**	**5.58**	**5.21**
$CD_{0.05}$						
AM × SeB		0.10		AM × SeB× ZnO		0.18

AM_0:without AMF SeB_0 :without Selenobacteria ZnO_0: 0
AM_1: with AMF SeB_1:*Stenotrophomonas maltophilia* ZnO_1: 100 ppm
SeB_2 :*Alcaligenes faecalis* ZnO_2 : 200 ppm

Considering the effect of foliar application of nano zinc oxide applied with different concentrations the maximum reducing sugar (5.23 %) of strawberry fruits was observed with ZnO_1.

The interaction of AM fungi and nano zinc oxide exhibited maximum reducing sugar (5.40 %) of strawberry fruits in the interaction, AM_1 × ZnO_1. However, the reducing sugar (5.38 %) in the interaction, AM_1 × ZnO_2 was significantly at par with AM_1 × ZnO_1.

As regards the interaction of selenobacteria and nano zinc oxide, maximum reducing sugar (5.47 %) of strawberry fruits were produced in the interaction, SeB_1 × ZnO_1 and found to be significantly higher over all the other interactions of selenobacteria and nano zinc oxide.

The interaction of AM fungi and selenobacteria reveals maximum reducing sugar (5.58 %) of strawberry fruits in the interaction, AM_1 × SeB_1. It was significantly superior in comparison to all the other interactions of AM and SeB.

The interaction of AM fungi × nano zinc oxide × selenobacteria reveals maximum reducing sugar (5.78 %) of strawberry fruits in the interaction, AM_1 × SeB_1 × ZnO_1. This was found to be significantly maximum in comparison to all the other interactions.

4.3.2.6 Fruit non reducing sugar (%)

The perusal of pooled data presented in the Table-4.23 (a and b) for fruit non reducing sugar depicts that AM fungi, nano zinc oxide, selenobacteria individually and the interactions significantly affected the non reducing sugar content of the strawberry fruit. However the interaction of AM fungi × nano zinc oxide was non significant (Appendix-LVII).

Table-4.23a: Effect of nano zinc, AM fungi and selenobacteria on non reducing (%) sugar in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	2.05	1.77	**1.91**	1.91	2.05	1.81
ZnO_1	1.87	1.71	**1.78**	1.80	1.75	1.63
ZnO_2	1.78	1.49	**1.64**	1.89	1.64	1.52
Mean	**1.90**	**1.62**		**1.86**	**1.81**	**1.66**
$CD_{0.05}$						
AM 0.10 SeB 0.12 ZnO 0.12			AM × ZnO NS SeB× ZnO 0.22			

Table-4.23b: Interactive effects of nano zinc, AM fungi and selenobacteria on non reducing sugar (%) in strawberry

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	1.82	2.15	2.15	2.18	2.00	1.45
ZnO_1	1.82	1.93	1.93	1.84	1.76	1.43
ZnO_2	2.16	1.58	1.58	1.60	1.62	1.45
Mean	**1.94**	**1.89**	**1.89**	**1.87**	**1.80**	**1.44**
$CD_{0.05}$						
AM × SeB 0.18			AM × SeB× ZnO NS			

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

It was observed that the absence of AM fungi (AM_0), selenobacteria (SeB_0) as well as nano zinc oxide (ZnO_0) exhibited significantly higher non reducing sugar content 1.90 %, 1.86 % and 1.91 %, respectively, compared to the fruits of the plants where treatments were given.

Considering the effect of interaction of foliar application of selenobacteria and nano zinc oxide, the maximum non reducing sugar content (2.05 %) of strawberry fruits was observed with SeB_1 × ZnO_0.

The interaction of AM fungi and selenobacteria reveals maximum non reducing sugar content (1.94 %) of strawberry fruits in the interaction, AM_0 × SeB_0.

The interaction of AM fungi × nano zinc oxide × selenobacteria reveals maximum reducing sugar (2.18 %) of strawberry fruits in the interaction, AM_1 × SeB_0× ZnO_0. However, some of the other interactions were statistically at par with AM_1 × SeB_0× ZnO_0.

4.3.2.7 Fruit ascorbic acid (mg/100g)

The pooled data on fruit ascorbic acid (mg/100g) have been contained in Table- 4.24 (a and b) and closely depicts that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced fruit ascorbic acid significantly. However the interaction effect of nano zinc × selenobacteria was non significant (Appendix- LVII).

As per the effect of AM fungi, maximum fruit ascorbic acid (63.10 mg/100g) was recorded, when the plants were treated with AM fungi and found to be significantly higher in comparison to other plants that were not treated with AM fungi

Table-4.24a: Effect of nano zinc, AM fungi and selenobacteria on ascorbic acid (mg/100 g) in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	59.48	62.36	**60.92**	59.94	61.44	61.38
ZnO$_1$	61.77	63.44	**62.60**	62.03	62.89	62.89
ZnO$_2$	62.31	63.50	**62.90**	62.70	63.15	62.86
Mean	**61.18**	**63.10**		**61.55**	**62.49**	**62.37**
CD$_{0.05}$						
AM	0.60		AM × ZnO	1.04		
SeB	0.74		SeB× ZnO	NS		
ZnO	0.74					

Table-4.24b: Interactive effects of nano zinc, AM fungi and selenobacteria on ascorbic acid (mg/100 g) in strawberry

Nano Zinc Oxide	**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	58.99	58.81	60.62	60.88	63.28	62.14
ZnO$_1$	60.36	61.75	63.19	63.69	64.03	62.58
ZnO$_2$	60.82	63.02	63.09	64.58	64.07	62.62
Mean	**60.06**	**61.19**	**62.30**	**63.05**	**63.80**	**62.45**
CD$_{0.05}$						
AM × SeB	1.04			AM × SeB× ZnO	1.80	

AM$_0$:without AMF
AM$_1$: with AMF
SeB$_0$:without Selenobacteria
SeB$_1$:*Stenotrophomonas maltophilia*
SeB$_2$:*Alcaligenes faecalis*
ZnO$_0$: 0
ZnO$_1$: 100 ppm
ZnO$_2$: 200 ppm

The use of selenobacteria (SeB$_1$) resulted in the maximum fruit ascorbic acid (62.49 mg/100g), while the plants applied with the other strain (*Alcaligenes faecalis*), the fruits produced recorded statistically at par value of fruit ascorbic acid (62.37 mg/100g) with SeB$_1$.

The foliar application of nano zinc oxide @ 200 ppm recorded maximum fruit ascorbic acid (62.90 mg/100g). However, the fruit ascorbic acid (62.60 mg/100g) recorded with the plants treated with nano zinc oxide @ 100 ppm was statistically at par with the effect of nano zinc oxide @ 200 ppm.

The interaction effects of AM fungi and nano zinc oxide indicated that the highest fruit ascorbic acid (63.50 mg/100g) was recorded in the interaction, AM$_1$ × ZnO$_2$. However, the interaction effect of AM$_1$ × ZnO$_1$, recorded fruit ascorbic acid (63.44 mg/100g) which was statistically at par with AM$_1$ × ZnO$_2$.

The interaction effects of AM fungi and selenobacteria revealed maximum fruit ascorbic acid (63.80 mg/100g) in the interaction AM$_1$ × SeB$_1$ and was found to be significantly highest in comparison to all other interactions of AM fungi and selenobacterial applications.

The interaction of AM fungi × nano zinc oxide × selenobacteria exhibited maximum fruit ascorbic acid (64.07 mg/100g) in the interaction, AM$_1$ × SeB$_1$ × ZnO$_2$. However, the fruit ascorbic acid (64.03 mg/100g) produced in the interaction of AM$_1$ × SeB$_1$ × ZnO$_1$ was statistically at par with the effect of the interaction of AM$_1$ × SeB$_1$ × ZnO$_2$.

4.3.2.8 Fruit anthocyanin content (mg/100 ml)

The pooled data on fruit anthocyanin (mg/100 ml) have been contained in Table - 4.25 (a and b) and closely depicts that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced fruit anthocyanin significantly. However the interaction effect of selenobacteria × nano zinc was non significant (Appendix- LVII).

Table-4.25a: Effect of nano zinc, AM fungi and selenobacteria on anthocyanin (mg/100 ml) in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	39.85	43.12	**41.48**	40.74	42.33	41.39
ZnO$_1$	41.44	43.97	**42.71**	42.40	43.27	42.45
ZnO$_2$	42.53	43.91	**43.22**	42.89	43.91	42.86
Mean	**41.27**	**43.67**		**42.01**	**43.17**	**42.23**
CD$_{0.05}$						
AM	0.36		AM × ZnO	0.63		
SeB	0.45		SeB× ZnO	NS		
ZnO	0.45					

Table-4.25b: Interactive effects of nano zinc, AM fungi and selenobacteria on anthocyanin in (mg/100 ml) strawberry

Nano Zinc Oxide	**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	39.15	40.58	39.81	42.33	44.07	42.96
ZnO$_1$	41.00	41.25	42.08	43.81	45.29	42.82
ZnO$_2$	41.13	42.97	43.50	44.65	44.85	42.22
Mean	**40.42**	**41.60**	**41.80**	**43.59**	**44.74**	**42.67**
CD$_{0.05}$						
AM × SeB	0.63		AM × SeB× ZnO	1.09		

AM$_0$:without AMF
AM$_1$: with AMF

SeB$_0$:without Selenobacteria
SeB$_1$:*Stenotrophomonas maltophilia*
SeB$_2$:*Alcaligenes faecalis*

ZnO$_0$: 0
ZnO$_1$: 100 ppm
ZnO$_2$: 200 ppm

As per the effect of AM fungi, maximum fruit anthocyanin (43.67 mg/100 ml) was recorded when the plants were treated with AM fungi and it was found to be significantly higher in comparison to other plants that were not treated with AM fungi.

The use of selenobacteril strain *Stenotrophomonas maltophilia* resulted in the production of maximum fruit anthocyanin (43.17 mg/100 ml), however, the plants applied with the other strain *Alcaligenes faecalis* recorded statistically at par value of anthocyanin (42.23 mg/100 ml).

The foliar application of nano zinc oxide @ 200 ppm recorded maximum fruit anthocyanin (43.22 mg/100 ml) and it was found to be significantly highest.

The interaction effects of AM fungi and nano zinc oxide indicated that the highest fruit anthocyanin (43.97 mg/100 ml) was recorded in the interaction, and it was found to be significantly higher over other interactions of AM fungi and nano zinc oxide. However, the interaction effect of $AM_1 \times ZnO_2$ recorded fruit anthocyanin (43.91 mg/100 ml) which was statistically at par with the $AM_1 \times ZnO_1$.

The interaction effects of AM fungi and selenobacteria revealed maximum fruit anthocyanin (44.74 mg/100 ml) in the interaction $AM_1 \times SeB_1$ and found to be significantly highest in comparison to all other interactions of AM fungi and selenobacterial applications.

The interaction of AM fungi × nano zinc oxide × selenobacteria exhibited maximum fruit anthocyanin content (45.29 mg/100 ml) in the interaction, $AM_1 \times SeB_1 \times ZnO_1$. However, the fruit anthocyanin content (44.85 mg/100 ml) with the interaction of $AM_1 \times SeB_1 \times ZnO_2$ was statistically at par with the effect of the interaction of $AM_1 \times SeB_1 \times ZnO_1$.

The data indicated that the biochemical traits of strawberry fruits were significantly improved with the application of AM fungi. The modification of the sugar/acid ratio in fruit, a crucial factor in determining sweetness perception, is influenced by AM symbiosis (Noceto et al. 2021). A significant increase in the TSS: Acid ratio in the strawberry fruits is in consonance with the work done by various researchers (Sundariyal 2018 and Raturi 2019). Similarly, strawberry plants inoculated with the AM fungi resulted in production of fruits with a higher concentration of sugars and ascorbic acid (Bona et al. 2017). Zeng et al. (2014) found that AM fungi improved the quality of citrus fruits by increasing the ratio of sugar to acid and the amounts of vitamin C. Noceto et al. (2021) reported that AMF inoculation increases the sugar concentration of grape berries by 10% in AMF-inoculated plants. AM symbiosis has been observed to significantly impact the secondary metabolism of plants, leading to an increased production of phytochemicals such as anthocyanins, which possess various health-promoting properties (Basu et al. 2018). The higher concentration of anthocyanins in fruits can be attributed to the activation of a host defence response, specifically through mycorrhizal colonisation (Lingua et al. 2013 and Rouphael et al. 2015). The benefits of mycorrhization for enhancing strawberry anthocyanin content has been reported by various researchers (Castellanos-Morales et al. 2010, Cecatto et al. 2016, Lingua et al. 2013 and Parada et al. 2019).

The enhancement of fruit quality can be ascribed to the functionality of nano Zn as an activator of metabolic enzymes and its involvement in the synthesis of indole-3-acetic acid (IAA), cell division, and cell enlargement (Alamer et al. 2020). The application of nanotechnology in fruit production has been found to have positive effects on enhancing the quality of fruits (Zahedi et al. 2019). Refaai (2014) and Sabir et al. (2014) discovered comparable findings, indicating that nano nutrients exhibited superior efficacy in enhancing the quality of various fruit crops when compared to their bulk counterparts. The study conducted by Hasani et al. (2012) found that the application of Zn foliar sprays in pomegranate resulted in an increase in both total soluble solids (TSS) and the TSS: acid ratio, while simultaneously decreasing titratable acidity. The study conducted by Davarpanah et al. (2016) observed a similar phenomenon in apple, where the increase in TSS was attributed to the impact of zinc (Zn) on the synthesis and translocation of carbohydrates. In addition, zinc (Zn) has been observed to enhance the overall concentration of sugars by influencing starch and nucleic acid metabolism, as well as the activity of various enzymes that participate in biochemical reactions (Alloway 2004). Nano ZnO is a crucial constituent of numerous enzymes, such as proteinases, proteases, dehydrogenases, and phosphohydrolases. Additionally, it plays a significant role in plant metabolism, particularly in carbohydrate metabolism, thereby exerting an influence on the sugar composition of fruits (Carlesso et al. 2018 and Elsheery et al. 2020). Furthermore, the utilisation of ZnO nanoparticles resulted in a decrease in the diffusion rate of oxygen within fruits, consequently leading to a delay in the oxidation process of ascorbic acid present in the samples. Similar observations of the phenomenon were documented in pomegranate (Davarpanah et al. 2016) and strawberry (Carlesso et al. 2018).

4.4 EFFECTS OF NANO ZINC, AM FUNGI AND SELENOBACTERIA ON LEAF AND FRUIT NUTRIENT CONTENT

4.4.1 Leaf nutrient content

4.4.1.1 Leaf nitrogen content (%)

The pooled data pertaining to leaf nitrogen content (%) have been presented in Table–4.26 (a and b) and clearly indicated that only AM fungi and nano zinc oxide individually have influenced leaf nitrogen content (%) significantly .Whereas, the effect of selenobacteria individually and other interactions were found to be non-significant (Appendix- LVII).

Table-4.26a: Effect of nano zinc, AM fungi and selenobacteria on leaf nitrogen (%) content in strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	2.54	3.06	**2.80**	2.90	2.89	2.62
ZnO$_1$	2.92	3.22	**3.07**	3.08	3.14	3.00
ZnO$_2$	2.87	3.25	**3.06**	3.14	3.08	2.96
Mean	**2.78**	**3.18**		**3.04**	**3.04**	**2.86**
CD$_{0.05}$						
AM SeB ZnO	0.14 NS 0.17		AM × ZnO SeB× ZnO	NS NS		

Table-26b: Interactive effects of nano zinc, AM fungi and selenobacteria on leaf nitrogen (%) content in strawberry

Nano Zinc Oxide	AM$_0$			AM$_1$		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	2.70	2.62	2.31	3.11	3.15	2.93
ZnO$_1$	2.94	2.94	2.88	3.21	3.34	3.11
ZnO$_2$	3.03	2.95	2.62	3.25	3.22	3.29
Mean	**2.89**	**2.84**	**2.61**	**3.19**	**3.24**	**3.11**
CD$_{0.05}$						
AM × SeB	NS		AM × SeB× ZnO		NS	

AM$_0$:without AMF SeB$_0$:without Selenobacteria ZnO$_0$: 0
AM$_1$: with AMF SeB$_1$:*Stenotrophomonas maltophilia* ZnO$_1$: 100 ppm
SeB$_2$:*Alcaligenes faecalis* ZnO$_2$: 200 ppm

As regards the effects of AM fungi (AM$_1$), maximum leaf nitrogen content (3.18 %) was recorded, when the plants were treated with AM fungi and it was found to be significantly higher in comparison to other plants that were not treated with AM fungi.

Considering the effect of foliar application of nano zinc oxide applied with different concentrations the maximum leaf nitrogen content was observed with ZnO_1 (3.07 %). However, effect of nano zinc oxide applied @ 200 ppm (ZnO_2) also showed similar trend with leaf nitrogen content (3.06 %) which was statistically at par with ZnO_1.

4.4.1.2 Leaf phosphorus content (%)

The perusal of pooled data presented in Table- 4.27 (a and b) indicated that nano zinc, AM fungi and selenobacteria applications alone have influenced leaf phosphorus content (%) of strawberry leaves significantly individually as well as with their interactions. However the interaction of AM fungi and nano zinc oxide was found to be non-significant (Appendix- LVII).

Table-4.27a: Effect of nano zinc, AM fungi and selenobacteria on leaf phosphorus (%) content in strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.27	0.45	**0.36**	0.37	0.36	0.36
ZnO_1	0.27	0.44	**0.35**	0.35	0.37	0.35
ZnO_2	0.26	0.43	**0.35**	0.34	0.35	0.35
Mean	**0.27**	**0.44**		**0.35**	**0.36**	**0.35**
$CD_{0.05}$						
AM SeB ZnO	0.01 0.01 0.01		AM × ZnO SeB× ZnO	NS 0.01		

Table-4.27b: Interactive effects of nano zinc, AM fungi and selenobacteria leaf phosphorus (%) content in strawberry

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.28	0.28	0.26	0.45	0.44	0.45
ZnO_1	0.27	0.27	0.26	0.43	0.46	0.43
ZnO_2	0.26	0.26	0.26	0.42	0.44	0.43
Mean	**0.27**	**0.27**	**0.26**	**0.43**	**0.45**	**0.44**
$CD_{0.05}$						
AM × SeB	0.01		AM × SeB× ZnO	0.02		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As regards the effects of AM fungi, maximum leaf phosphorus content (0.44 %) was recorded in $AM_1$and it was found to be significantly higher in comparison to other plants that were not treated with AM fungi.

The use of selenobacteria (SeB_1) resulted in higher leaf phosphorus content (0.36 %) and it was observed to be significantly higher over the other SeB treatments.

The effect of foliar application of nano zinc oxide recorded a decrease in leaf phosphorus content, where maximum leaf phosphorus content (0.36 %) was recorded in the control i.e. when no application of nano zinc oxide was given.

The interaction of SeB and ZnO reveals maximum leaf phosphorus content (0.37 %) in the interaction, $SeB_1 \times ZnO_1$ and it was observed to be significantly higher.

The interaction between AM and SeB exhibited maximum leaf phosphorus content (0.45 %) in the interaction, $AM_1 \times SeB_1$ and it was found significantly higher.

The interaction of AM × SeB × ZnO application reveals that maximum leaf phosphorus content (0.46 %) in the interaction, $AM_1 \times SeB_1 \times ZnO_1$.

4.4.1.3 Leaf potassium content (%)

The pooled data presented in Table- 4.28 (a and b) indicated that nano zinc, AM fungi and selenobacteria applications alone have influenced leaf potassium content (%) of strawberry leaves significantly individually as well as with their interactions. However the interaction of AM fungi × selenobacteria as well as the overall interaction effect of all the three factors were non-significant (Appendix- LVII).

As regards the effects of AM fungi, maximum leaf potassium content (2.14 %) was recorded in AM_1, and found to be significantly higher in comparison to other plants that were not treated with AM fungi.

Table-28a: Effect of nano zinc, AM fungi and selenobacteria on leaf potassium (%) content in strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	AM_1		SeB_0	SeB_1	SeB_2
ZnO_0	1.25	2.04	**1.65**	1.69	1.60	1.65
ZnO_1	1.54	2.24	**1.89**	1.92	1.97	1.84
ZnO_2	1.55	2.16	**1.86**	1.86	1.92	1.83
Mean	**1.45**	**2.14**		**1.82**	**1.83**	**1.77**
$CD_{0.05}$						
AM	0.04		AM × ZnO	0.06		
SeB	0.04		SeB× ZnO	0.08		
ZnO	0.04					

Table-28b: Interactive effects of nano zinc, AM fungi and selenobacteri on leaf potassium (%) content in strawberry

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	1.21	1.32	1.24	2.00	2.07	2.06
ZnO_1	1.59	1.50	1.54	2.25	2.33	2.13
ZnO_2	1.66	1.52	1.53	2.29	2.19	2.13
Mean	**1.48**	**1.45**	**1.44**	**2.18**	**2.20**	**2.11**
$CD_{0.05}$						
AM × SeB	NS		AM × SeB× ZnO	NS		

AM_0:without AMF SeB_0 :without Selenobacteria ZnO_0: 0
AM_1: with AMF SeB_1:*Stenotrophomonas maltophilia* ZnO_1: 100 ppm
SeB_2 :*Alcaligenes faecalis* ZnO_2 : 200 ppm

The use of selenobacteria did show significant effect on increasing leaf potassium content, therefore the plants treated with selenobacteria (*Stenotrophomonas maltophilia*) were found to have significantly higher leaf potassium content (1.83 %). However the treatment SeB_0 i.e. no selenobacterial application was found to be statistically at par with SeB_1 recording a value of 1.82 % for leaf potassium.

The effect of foliar application of nano zinc oxide recorded a significant increase in leaf potassium content, where maximum leaf potassium content (1.89 %) was recorded with ZnO_1. However, effect of nano zinc oxide @ 200 ppm on leaf potassium content (1.86 %) was statistically at par with ZnO_1

The interaction effects of AM fungi and nano zinc oxide indicated that the highest leaf potassium (2.24 %) content was recorded in the interaction, AM_1 × ZnO_1 and it was found to be significantly higher over other interactions of AM fungi and nano zinc oxide

Considering the interaction of selenobacteria and nano zinc oxide reveals a maximum leaf potassium content (1.97 %) in the interaction, SeB_1 × ZnO_1. However, the interaction effect of SeB_0 × ZnO_1 and SeB_1 × ZnO_2 registered similar value of leaf potassium content 1.92 % which was statistically at par with the interactive effect SeB_1 × ZnO_1.

4.4.1.4 Leaf iron content (ppm)

The perusal of pooled data presented in Table- 4.29 (a and b) indicated that AM fungi applications alone have influenced leaf iron content (ppm) of strawberry leaves significantly.

However the nano zinc, selenobacteria individually as well as with their interactions with AMfungi was found to be non-significant (Appendix- LVII).

It was observed that the plants treated with AM fungi at the time of transplanting, 30 and 45 days after transplanting were found to be have significantly higher leaf iron content (150.05 ppm) in comparison to other plants that were not treated with AM fungi

Table-4.29a: Effect of nano zinc, AM fungi and selenobacteria on leaf iron (ppm) content in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	142.30	149.70	**146.00**	145.5	145.5	147.0
ZnO$_1$	146.77	150.61	**148.69**	149.3	149.3	147.6
ZnO$_2$	146.20	149.84	**148.02**	148.0	148.3	147.8
Mean	**145.09**	**150.05**		**147.6**	**147.7**	**147.5**
CD$_{0.05}$						
AM	2.30		AM × ZnO	NS		
SeB	NS		SeB× ZnO	NS		
ZnO	NS					

Table-4.29b: Interactive effects of nano zinc, AM fungi and selenobacteria on leaf iron (ppm) content in strawberry

Nano Zinc Oxide	**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	141.04	141.40	144.45	150.00	149.50	149.60
ZnO$_1$	147.50	147.40	145.40	151.00	151.11	149.72
ZnO$_2$	145.65	146.44	146.50	150.30	150.11	149.10
Mean	**144.73**	**145.08**	**145.45**	**150.44**	**150.24**	**149.47**
CD$_{0.05}$						
AM × SeB	NS		AM × SeB× ZnO	NS		

AM$_0$:without AMF	SeB$_0$:without Selenobacteria	ZnO$_0$: 0
AM$_1$: with AMF	SeB$_1$:*Stenotrophomonas maltophilia*	ZnO$_1$: 100 ppm
	SeB$_2$:*Alcaligenes faecalis*	ZnO$_2$: 200 ppm

4.4.1.5 Leaf copper content (ppm)

The perusal of pooled data presented in Table- 4.30 (a and b) indicated that AM fungi applications alone have significantly influenced leaf copper content (ppm) of the plant. However the nano zinc, selenobacteria individually as well as with their interactions with AMfungi was found to be non-significant (Appendix- LVII).

Table-4.30a: Effect of nano zinc, AM fungi and selenobacteria on leaf copper (ppm) content in strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.90	6.98	**5.94**	5.86	6.01	5.95
ZnO_1	5.26	7.15	**6.21**	6.09	6.20	6.33
ZnO_2	5.24	7.14	**6.19**	6.16	6.24	6.18
Mean	**5.14**	**7.09**		**6.04**	**6.15**	**6.15**
$CD_{0.05}$						
AM `	0.24		AM × ZnO	NS		
SeB	NS		SeB× ZnO	NS		
ZnO	NS					

Considering the effect of AM fungi on the accumulation of copper content in plant leaves it was observed that the plants treated with AM fungi were found to be have significantly higher leaf copper content with a mean value of 7.09 ppm in comparison to other plants that were not treated with AM fungi.

Table-4.30b: Interactive effects of nano zinc, AM fungi and selenobacteria on leaf copper (ppm) content in strawberry

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.65	5.08	4.98	7.08	6.95	6.91
ZnO_1	5.21	5.14	5.42	6.96	7.25	7.25
ZnO_2	5.16	5.30	5.27	7.15	7.18	7.10
Mean	**4.65**	**5.08**	**4.98**	**7.08**	**6.95**	**6.91**
$CD_{0.05}$						
AM × SeB	NS		AM × SeB× ZnO	NS		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

4.4.1.6 Leaf zinc content (ppm)

The Table-4.31 (a and b) presents the pooled data for the effects of nano zinc, AM fungi and selenobacteria applications on the leaf zinc content (ppm). It is evident that nano zinc, AM fungi and selenobacterial doses have significantly affected the zinc content in leaves individually and also the interaction of AM fungi and nano zinc oxide, while rest of the interactions were found to be non significant (Appendix- LVII).

It was observed that the rhizoinoculztion of AM fungi had significantly improved the leaf zinc content (35.02 ppm) compared to the plants not applied with AM fungi.

Table-4.31a: Effect of nano zinc, AM fungi and selenobacteria on leaf zinc (ppm) content in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	24.39	28.88	**26.64**	26.50	27.75	25.66
ZnO$_1$	31.87	37.49	**34.68**	35.20	35.15	33.69
ZnO$_2$	35.65	38.69	**37.17**	37.60	37.57	36.33
Mean	**30.64**	**35.02**		**33.10**	**33.49**	**31.89**
CD$_{0.05}$						
AM	0.67		AM × ZnO	1.15		
SeB	0.82		SeB× ZnO	NS		
ZnO	0.82					

Table-4.31b: Interactive effects of nano zinc, AM fungi and selenobacteria on leaf zinc (ppm) content in strawberry

Nano Zinc Oxide	**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	24.70	26.12	22.37	28.29	29.38	28.96
ZnO$_1$	32.22	32.03	31.37	38.18	38.27	36.02
ZnO$_2$	36.31	36.28	34.35	38.90	38.86	38.30
Mean	**24.70**	**26.12**	**22.37**	**28.29**	**29.38**	**28.96**
CD$_{0.05}$						
AM × SeB	NS			AM × SeB× ZnO	NS	

AM$_0$:without AMF SeB$_0$:without Selenobacteria ZnO$_0$: 0
AM$_1$: with AMF SeB$_1$:*Stenotrophomonas maltophilia* ZnO$_1$: 100 ppm
SeB$_2$:*Alcaligenes faecalis* ZnO$_2$: 200 ppm

Similar findings were observed with the rhizoinoculation of selenobacteria (*Stenotrophomonas maltophilia*) which significantly enabled the increase of leaf zinc content (33.49 ppm) compared to the other selenobacterial strain (*Alcaligenes faecalis*) and also the plants that were not rhizoinoculated with any selenobacterial strain.

The folair application of nano zinc oxide @ 200 ppm recorded a significantly higher leaf zinc content (37.17 ppm) compared to other treatments of the same.

The interaction effect of AM fungi and nano zinc oxide was also helpful in improving the leaf zinc content (38.69 ppm) when the plants were administered with rhizo inoculation of AM fungi and foliar applications of nano zinc oxide @ 200 ppm.

4.4.1.7 Leaf manganese content (ppm)

The pooled data pertaining to the leaf manganese content (ppm) have been depicted in the Table-4.32 (a and b). A perusal of data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as the interaction between nano zinc and AM fungi have influenced leaf manganese content (ppm) in strawberry plants significantly. However the interaction effect of selenobacteria × nano zinc oxide was non significant (Appendix- LVII).

As regards to AM fungi, maximum leaf manganese content (30.23 ppm) was observed in AM_1. It was significantly highest in comparison to the other non AM fungi treated plants.

The application of selenobacteria significantly affected the leaf manganese content in strawberry plants. Maximum leaf manganese content (28.02 ppm) was observed with SeB_1.

Table-4.32a: Effect of nano zinc, AM fungi and selenobacteria on leaf manganese (ppm) content in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	21.78	29.63	**25.71**	25.44	26.65	25.03
ZnO_1	23.22	30.71	**26.96**	26.18	28.60	26.10
ZnO_2	24.28	30.36	**27.32**	26.98	28.81	26.17
Mean	**23.09**	**30.23**		**26.20**	**28.02**	**25.77**
$CD_{0.05}$						
AM	0.46		AM × ZnO	0.80		
SeB	0.55		SeB× ZnO	NS		
ZnO	0.55					

Table-4.32b: Interactive effects of nano zinc, AM fungi and selenobacteria on leaf manganese (ppm) content in strawberry

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	21.22	23.09	21.03	29.66	30.21	29.03
ZnO_1	21.78	26.17	21.70	30.58	31.04	30.51
ZnO_2	23.29	27.53	22.03	30.68	30.09	30.31
Mean	**22.10**	**25.60**	**21.59**	**30.31**	**30.45**	**29.95**
$CD_{0.05}$						
AM × SeB		0.80	AM × SeB× ZnO		1.39	

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

Considering the effect of foliar application of nano zinc oxide applied with different concentrations the maximum leaf manganese content was observed with ZnO_2 (27.32 ppm). However, effect of nano zinc oxide applied @ 100 ppm also showed similar trend with leaf manganese content (26.96 ppm) which was statistically at par with ZnO_2.

The interaction of AM fungi and nano zinc oxide exhibited maximum leaf manganese content (30.71 ppm) with the interaction, AM_1 × ZnO_1. However, the interaction effect of AM_1 × ZnO_2 on leaf manganese content (30.36 ppm) was found to be significantly at par with the interaction effect of AM_1 × ZnO_1.

The interaction effects of AM fungi and selenobacteria revealed maximum leaf manganese content (30.45 ppm) in the interaction AM_1 × SeB_1. However, the interactions, AM_1 × SeB_0 and AM_1 × SeB_2 recorded leaf manganese content 30.01 ppm and 29.95 ppm respectively, which followed a similar trend and were statistically at par with AM_1 × SeB_1.

The interaction of AM fungi × selenobacteria × nano zinc oxide exhibited maximum leaf manganese content (31.04 ppm) in the interaction, AM_1 × SeB_1 × ZnO_1. While the all the interactions with the presence of AM fungi were statistically at par with AM_1 × SeB_1 × ZnO_1 except AM_1 × SeB_2 × ZnO_0.

4.4.1.8 Leaf selenium content (µg/g)

The Table-4.33 (a and b) presents the pooled data for the effects of nano zinc, AM fungi and selenobacteria applications on the leaf selenium content (µg/g). It is evident that AM fungi and selenobacterial doses have significantly affected the leaf selenium content individually, but the effect nano zinc oxide alone and also the interaction of AM fungi and nano zinc oxide and selenobacteria were found to be non significant (Appendix- LVII).

Table-4.33a: Effect of nano zinc, AM fungi and selenobacteria on leaf selenium (µg/g) content in strawberry

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	1.40	1.46	**1.43**	1.31	1.57	1.41
ZnO_1	1.38	1.45	**1.42**	1.29	1.56	1.41
ZnO_2	1.37	1.44	**1.40**	1.29	1.53	1.40
Mean	**1.38**	**1.45**		**1.29**	**1.55**	**1.41**

$CD_{0.05}$			
AM	0.02	AM × ZnO	NS
SeB	0.03	SeB× ZnO	NS
ZnO	NS		

Table-4.33b: Interactive effects of nano zinc, AM fungi and selenobacteria on leaf selenium (µg/g) content in strawberry

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	1.27	1.53	1.40	1.35	1.60	1.43
ZnO_1	1.25	1.53	1.37	1.32	1.58	1.44
ZnO_2	1.24	1.49	1.37	1.34	1.56	1.43
Mean	**1.25**	**1.52**	**1.38**	**1.33**	**1.58**	**1.43**
$CD_{0.05}$						
AM × SeB	NS		AM × SeB× ZnO		NS	

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

It was observed that the AM fungi applied had significantly improved the uptake and accumulation of leaf selenium content upto a value of 1.45 µg/g compared to the plants not applied with AM fungi.

Similar findings were observed with the rhizoinoculation of selenobacteria (*Stenotrophomonas maltophilia*) which significantly increased the leaf selenium content upto a value of 1.55 µg/g while the leaf selenium content recorded with the other selenobacterial strain *Alcaligenes faecalis* was 1.41 µg/g. While the plants that were not rhizoinoculated with any selenobacterial strain were observed to have the lowest leaf selenium content (1.29 µg/g).

The results of the present study indicate an increased levels of leaf nutrients in the strawberry plants inoculated with AM fungi. Mycorrhizal plants are capable of taking up more metal nutrients via extraradical hyphae, which thereby, provide larger surface area than the roots alone and reduce the distance for diffusion, thus, enhancing the absorption of immobile metal nutrients (Jakobsen et al. 1992). It has been reported that the mycorrhizal plants have a higher P acquisition than the control plants (Duran et al. 2016). The mycorrhizal community exhibited elevated concentrations of nitrogen and phosphorus in the aboveground portion of strawberry plants, as demonstrated by Trentin et al. (2022). Moreover, in this study leaf selenium content was also influenced with AMF application. The enhanced root development of mycorrhizal wheat during the jointing stage may contribute to its ability to absorb a greater amount of selenium (Se) for transportation to aboveground tissues. As a result, the stalks of mycorrhizal wheat exhibit significantly higher levels of Se content (Wu et al. 2022). These findings are also in accordance with Baslam et al. (2013) who concluded that fungal inoculation can improve the mineral nutrients of plants.

In the present study the plants inoculated with selenobacteria witnessed an improved levels of micronutrients in plants. The findings of the present study is in accordance with the results, which showed a positive effect of endophytic selenobacteria on foliar macronutrient and micronutrient concentrations in lettuce shoots. Moreover, these nutrient levels were higher in plants inoculated with bacteria than in the single-colonized mycorrhizal plants. The interaction of plants co-inoculated with selenobacteria plus AMF showed the highest Se content (Duran et al. 2016).

The current study observed a positive influence of nano ZnO treatment on the levels of leaf K, Mn, and Zn. The foliar application of zinc (Zn) has been found to effectively increase the zinc (Zn) and potassium (K) content in mandarin leaves, as demonstrated by Khan et al. (2012). The application of Zn in soil leads to enhanced nutrient absorption by plants through the regulation of auxin effects, chlorophyll formation, and various metabolic processes. Foliar application of zinc has been shown to have positive effects on carbohydrate metabolism and the translocation of photosynthates within plants, resulting in an increase in nutrient content (Verma 2016). Zhou et al. (2011) have postulated that the enhancement of nutrient status can be achieved through the foliar application of nano ZnO, primarily attributed to the augmented accumulation and translocation of Zn. Zinc oxide nanoparticles exhibit a high affinity for the cell surface, resulting in rapid uptake and subsequent translocation to the sink (Lin and Xing 2008). The enhanced absorption capacity and reduced water solubility of nano ZnO contribute to the elevated leaf nutrient content (Prasad et al. 2012). The study conducted by Kaya and Higgs (2002) found that foliar application of Zn led to a decrease in translocation of Zn from shoots to roots, which in turn resulted in an increase in leaf Zn content. Nano fertilisers have been found to enhance leaf nutrient content in comparison to bulk fertilisers, as reported by Naderi and Danesh-Shahraki in 2013. Previous studies have reported similar positive interactions in pomegranate (Davarpanah et al. 2016), date palm (El-Sayed et al. 2017), mango (Zagzog and Gad 2017) and grapes (El-Said et al. 2019).

4.4.2 Fruit Nutrient

4.4.2.1 Fruit phosphorus content (%)

The perusal of pooled data presented in Table- 4.34 (a and b) indicated that AM fungi alone and its interaction with selenobacteria have influenced fruit phosphorus content (%) of strawberry leaves significantly. However the nano zinc and selenobacteria alone and their interactions were found to be non-significant (Appendix- LVII).

As regards the effects of AM fungi, maximum fruit phosphorus content (0.36 %) was recorded, when the plants were treated with AM fungi and found to be significantly higher in comparison to other plants that were not treated with AM fungi.

The interaction between AM fungi and selenobacteria exhibited maximum fruit phosphorus content (0.37 %) in the interaction, AM_1 × SeB_1 and it was found to be significantly higher. However the interaction, AM_1 × SeB_0 recorded fruit phosphorus content (0.36 %) which was statistically at par with AM_1 × SeB_1.

Table-4.34a: Effect of nano zinc, AM fungi and selenobacteria on fruit phosphorus (%) content in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.20	0.37	**0.29**	0.28	0.30	0.28
ZnO_1	0.20	0.36	**0.28**	0.29	0.29	0.27
ZnO_2	0.19	0.35	**0.27**	0.27	0.28	0.26
Mean	**0.20**	**0.36**		**0.28**	**0.29**	**0.27**
$CD_{0.05}$						
AM	0.01		AM × ZnO	NS		
SeB	NS		SeB× ZnO	NS		
ZnO	NS					

Table-4.34b: Interactive effects of nano zinc, AM fungi and selenobacteria on fruit phosphorus (%) content in strawberry

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.19	0.21	0.21	0.36	0.38	0.36
ZnO_1	0.21	0.21	0.19	0.36	0.37	0.34
ZnO_2	0.18	0.20	0.18	0.35	0.36	0.33
Mean	**0.19**	**0.21**	**0.19**	**0.36**	**0.37**	**0.34**
$CD_{0.05}$						
AM × SeB	0.01		AM × SeB × ZnO	NS		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

4.4.2.2 Fruit zinc content (ppm)

The perusal of pooled data of two years given in Table- 4.35 (a and b) indicated that nano zinc, AM fungi and selenobacteria levels not only had significant effect individually but their interactions also had significant results (Appendix- LVII).

Table-4.35a: **Effect of nano zinc, AM fungi and selenobacteria on fruit zinc (ppm) content in strawberry**

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	20.26	27.22	**23.74**	24.77	24.45	22.00
ZnO_1	27.67	31.32	**29.49**	30.51	31.07	26.90
ZnO_2	31.21	32.09	**31.65**	31.56	33.24	30.16
Mean	**26.38**	**30.21**		**28.95**	**29.58**	**26.35**
CD$_{0.05}$						
AM	0.44		AM × ZnO	0.77		
SeB	0.54		SeB× ZnO	0.94		
ZnO	0.54					

Table-4.35b: **Interactive effects of nano zinc, AM fungi and selenobacteria on fruit zinc (ppm) content in strawberry**

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	21.19	21.15	18.45	28.40	27.70	25.55
ZnO_1	28.01	27.79	27.20	33.23	34.12	26.59
ZnO_2	30.08	31.01	32.55	32.11	36.40	27.77
Mean	**26.43**	**26.65**	**26.07**	**31.25**	**32.74**	**26.64**
CD$_{0.05}$						
AM × SeB	0.77		AM × SeB× ZnO	1.33		

AM_0:without AMF SeB_0 :without Selenobacteria ZnO_0: 0
AM_1: with AMF SeB_1:*Stenotrophomonas maltophilia* ZnO_1: 100 ppm
SeB_2 :*Alcaligenes faecalis* ZnO_2 : 200 ppm

Considering the data pertaining to the effect of AMF on fruit zinc content showed significant increase in fruit zinc content (30.21 ppm) with the application of AM fungi.

As per the effect of the selenobacteria, the significantly higher increase in fruit zinc content (29.58 ppm) was observed with SeB_1 (*Stenotrophomonas maltophilia*) compared to the other selebacterial strain (*Alcaligenes faecalis*).

Similarly, the effect of foliar application of nano zinc oxide, the highest increase in fruit zinc content (31.65 ppm) was recorded with the nano zinc oxide applied @ 200 ppm.

As regards the interaction of AM fungi and nano zinc oxide, the fruits with maximum zinc content (32.09 ppm) were produced in the interaction, AM_1 x ZnO_2. It was observed to be significantly higher in fruit zinc content over all other interactions of AM fungi and nano zinc oxide sprays.

The interaction of selenobacteria and nano zinc oxide reveals maximum fruit zinc content (33.24 ppm) in the interaction, $SeB_1 \times ZnO_2$. They were found to be significantly superior in comparison to all the other interactions of selenobacteria and nano zinc oxide sprays.

The interaction between AM fungi and selenobacteria exhibited maximum fruit zinc content (32.74 ppm) with the interaction, $AM_1 \times SeB_1$ and it was recorded to be significantly higher over all the other interactions of AM fungi and selenobacteria.

The interaction of AM fungi × selenobacteria × nano zinc oxide application reveals that maximum fruit zinc content (36.40 ppm) with the interaction, $AM_1 \times SeB_1 \times ZnO_2$. This was found to be significantly maximum in comparison to all the other interactions.

4.4.2.3 Fruit selenium content (µg/g)

The Table-4.36 (a and b) presents the pooled data for the effects of nano zinc, AM fungi and selenobacteria applications on the fruit selenium content (µg/g). It is evident that AM fungi and selenobacterial doses have significantly affected the fruit selenium content individually as well as with their interaction, but the effect nano zinc oxide alone and also the interaction of AM fungi and nano zinc oxide and selenobacteria were found to be non significant (Appendix- LVII).

It was observed that the AM fungi applied as rhizoinoculation had significantly improved the uptake and accumulation of fruit selenium content (0.67 µg/g) compared to the plants not applied with AM fungi.

Table-4.36a: Effect of nano zinc, AM fungi and selenobacteria on fruit selenium (µg/g) content in strawberry

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.59	0.67	**0.63**	0.48	0.77	0.64
ZnO_1	0.59	0.68	**0.64**	0.49	0.77	0.64
ZnO_2	0.59	0.67	**0.63**	0.50	0.76	0.63
Mean	**0.59**	**0.67**		**0.49**	**0.77**	**0.64**
$CD_{0.05}$						
AM	0.02		AM × ZnO	NS		
SeB	0.03		SeB× ZnO	NS		
ZnO	NS					

Table-4.36b: Interactive effects of nano zinc, AM fungi and selenobacteria on fruit selenium (µg/g) of strawberry

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.41	0.75	0.61	0.55	0.79	0.66
ZnO_1	0.43	0.74	0.61	0.56	0.81	0.67
ZnO_2	0.44	0.72	0.60	0.57	0.79	0.66
Mean	**0.43**	**0.73**	**0.61**	**0.56**	**0.80**	**0.67**
$CD_{0.05}$						
AM × SeB	0.04		AM × SeB× ZnO		NS	

AM_0:without AMF SeB_0 :without Selenobacteria ZnO_0: 0
AM_1: with AMF SeB_1:*Stenotrophomonas maltophilia* ZnO_1: 100 ppm
SeB_2 :*Alcaligenes faecalis* ZnO_2 : 200 ppm

Similar findings were observed with the rhizoinoculation of selenobacteria (*Stenotrophomonas maltophilia*) significantly increased of fruit selenium content (0.77 µg/g) compared to the fruit selenium content (0.64 µg/g) with other selenobacterial strain (*Alcaligenes faecalis*).

Regards to the interaction of AM fungi and selenobacteria, it was observed that significantly higher fruit selenium content (0.80 µg/g) was observed with the interaction of AM_1 × SeB_1 and it was found higher over all the other interactions of AM fungi and selenobacteria.

The results of this study demonstrate that plants inoculated with arbuscular mycorrhizal fungi exhibited increased accumulation of P, Zn and Se in their fruits. The increase in nutrient levels can be attributed to the inoculation with AMF (Ndoye et al. 2015). The enhanced uptake of metal nutrients in mycorrhizal plants is facilitated by extraradical hyphae, which offer a greater surface area compared to the roots alone. This increased surface area reduces the diffusion distance, leading to improved absorption of immobile metal nutrients (Jakobsen et al. 1992). The study conducted by Nogueira et al. (2007) highlights the significant contribution of AMF in facilitating nutrient uptake through an indirect symbiotic relationship with plants. The treatment involving AMF resulted in enhanced nutrient uptake, specifically phosphorus and other micronutrients, through the augmentation of hyphal presence on the root surface. This finding is supported by various studies conducted by Nogueira et al. (2007), Khan et al. (2010), Heidari and Karami (2014) and Wali et al. (2018). Previous studies have also suggested that mycorrhizal colonisation has the potential to enhance the phosphorus status of plants (Goicoechea et al. 2014 and He et al. 2021). Golubkina et al. (2019) reported that colonization by AMF increased Se content of shallot bulbs (*Allium cepa* L.) by increasing the antioxidant activity of ascorbic acid. Larsen et al. (2006) and Yu et al. (2011) reported that AMF inoculation increased Se content in garlic, alfalfa and maize. Castellanos-Morales et al. (2010) and the study conducted by Bona et al. (2015) demonstrated that the fungal inoculation had a significant impact on the mineral nutrient composition of strawberries, which aligns with the findings of our own research. The study conducted by Arcand and Schneider (2006) revealed that fungal inoculation has the ability to enhance the mobilisation and availability of various mineral nutrient elements, leading to an increased uptake of micronutrients.

Results of present investigation reveals that the plants treated with selenobacteria (*Strenotophomonas maltophilia*) produced fruits with higher selenium content. These results are in accordance with those of Duran et al. (2013) demonstrated that bacterial inoculation improved the translocation of selenium to shoots and ultimately increased the selenium content of wheat grain. Compared to non-inoculated plants, plants inoculated with endophytic selenobacteria acquired significantly more macronutrients (P, K, Ca and Mg) (Duran et al. 2014).

The data reveals that the rhizoinoculation of both AM fungi and selenobacteria together significantly affected the nutrient uptake and its increment in the total fruit nutrient content. The application of AM fungi agent plus strain *Strenotophomonas maltophilia* vastly increased pak choi total Se content relative to the individual application of AM fungi agent or *Strenotophomonas maltophilia* (Jiang et al. 2023).

The preceding findings regarding fruit nutrient analysis demonstrate the enhanced efficacy of ZnO nanoparticles treatment compared to other forms of Zn application. This superiority is attributed to the increased absorption of Zn facilitated by the nano-sized structure of ZnO. Nutrient uptake is influenced by various factors, including soil composition, pH levels, cation exchange capacity (CEC) and the presence of soil microbes. The positive impact of nano ZnO on fruit nutrients has been extensively studied and reported by multiple researchers (Prasad et al. 2012, Zhao et al. 2014, Subbaiah et al. 2016 and Astafurova et al. 2017). The nutritional quality of fruits was enhanced by the application of nanofertilizers due to an increase in nutrient uptake and the accumulation of sugars in the fruits (Sharma et al. 2013). The enhanced nutrient content can be attributed to the heightened absorption of zinc resulting from the high surface area to volume ratio of zinc oxide nanoparticles (Khanm et al. 2018). The nutrient elements have a tendency to move to metabolically active sites after absorption. Using nano Zn foliar application, Garcia- Lopez et al. (2019) observed the movement of Zn from leaf tissues to fruits via phloem during the fruit's development and ripening. Likewise, Bahadur et al. (1998) reported that foliar application of zinc increased the zinc content of pomegranate fruit, with the fruit pulp acting as a stronger sink for zinc. Aside from this, it was reported that the Zn content of fruits increased linearly with increasing Zn concentration (Sharma et al. 2013).

4.5 EFFECTS OF NANO ZINC, AM FUNGI AND SELENOBACTERIA ON SOIL PROPERTIES

4.5.1 Chemical properties

4.5.1.1 Soil pH

The perusal of pooled data presented in Table-4.37 (a and b) indicated that nano zinc, AM fungi and selenobacteria applications alone have influenced soil pH of strawberry field significantly individually as well as with their interactions. However the interaction of SeB × ZnO and AM × SeB × ZnO were found to be non-significant (Appendix- LVII).

Table-4.37a: Effect of nano zinc, AM fungi and selenobacteria on soil pH of strawberry field

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	AM_1		SeB_0	SeB_1	SeB_2
ZnO_0	6.54	6.72	**6.63**	6.72	6. 49	6.67
ZnO_1	6.61	6.73	**6.67**	6.74	6. 60	6.68
ZnO_2	6.77	6.84	**6.81**	6.79	6. 75	6.69
Mean	**6.64**	**6.76**		**6.75**	**6.61**	**6.55**
$CD_{0.05}$						
AM	0.07		AM × ZnO	0.11		
SeB	0.08		SeB× ZnO	NS		
ZnO	0.08					

Table-4.37b: Interactive effects of nano zinc, AM fungi and selenobacteria on soil pH of strawberry field

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2
ZnO_0	6.58	6.60	6.83	6.73	6.63	6.19
ZnO_1	6.80	6.67	6.54	6.81	6.78	6.59
ZnO_2	6.85	6.79	6.65	6.91	6.86	6.82
Mean	**6.74**	**6.69**	**6.67**	**6.82**	**6.76**	**6.53**
$CD_{0.05}$						
AM × SeB	0.11		AM × SeB× ZnO	NS		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As regards the effects of AM fungi, soil pH of strawberry field was recorded with a value of 6.76 and found to be significantly higher in comparison to other plants that were not treated with AM fungi.

The use of selenobacteria did not seem to contribute in affecting the soil pH significantly, thus maximum soil pH (6.75) was recorded in the strawberry field where no selenobacterial application was given.

The nano zinc oxide also has significant effect in improving the soil pH recording a value of 6.81 when nano zinc was applied @ 200 ppm.

Regards to the interaction of AM fungi and nano zinc oxide, the highest soil pH (6.84) was observed in the interaction of $AM_1 \times ZnO_2$ which was at par with the interactions, $AM_0 \times ZnO_2$ and $AM_1 \times ZnO_1$ having a pH value 6.77 and 6.73 respectively.

The interaction between AM fungi and selenobacteria exhibited maximum soil pH of strawberry field (6.82) in the interaction, $AM_1 \times SeB_0$ and it was at par with $AM_1 \times SeB_1$ with soil pH 6.76.

4.5.1.2 Soil EC (dS/m)

The perusal of pooled data given in Table- 4.38(a and b) indicated that nano zinc, AM fungi and selenobacteria levels did not have significant effect individually as well as in their interactions on soil EC values of strawberry fields (Appendix- LVII).

Table-4.38a: **Effect of nano zinc, AM fungi and selenobacteria on soil EC (dS/m) of strawberry field**

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.27	0.24	**0.25**	0.26	0.25	0.25
ZnO_1	0.25	0.24	**0.24**	0.25	0.24	0.24
ZnO_2	0.26	0.25	**0.26**	0.25	0.25	0.27
Mean	**0.26**	**0.24**		**0.26**	**0.25**	**0.25**
$CD_{0.05}$						
AM SeB ZnO	NS NS NS		AM × ZnO SeB× ZnO	NS NS		

Table-4.38b: **Interactive effects of nano zinc, AM fungi and selenobacteria on soil EC (dS/m) of strawberry field**

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.29	0.28	0.25	0.23	0.22	0.26
ZnO_1	0.26	0.26	0.23	0.25	0.22	0.24
ZnO_2	0.27	0.24	0.27	0.24	0.25	0.27
Mean	**0.27**	**0.26**	**0.25**	**0.24**	**0.23**	**0.25**
$CD_{0.05}$						
AM × SeB	NS		AM × SeB× ZnO	NS		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

4.5.1.3 Soil organic carbon (%)

The pooled data for the soil organic carbon of strawberry field is presented in the Table. 4.39 (a and b), indicated that only AM fungi significantly affected soil organic carbon while, rest all the factors and their interaction were non significant (Appendix- LVII).

It was observed that AM_1 significantly impacted the soil organic carbon (0.61 %) in the strawberry field where the plants were treated with AM fungi.

Table-4.39a: Effect of nano zinc, AM fungi and selenobacteria on soil organic carbon (%) of strawberry field

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.44	0.60	**0.52**	0.53	0.52	0.52
ZnO_1	0.47	0.60	**0.53**	0.53	0.54	0.53
ZnO_2	0.46	0.61	**0.53**	0.55	0.53	0.53
Mean	**0.46**	**0.61**		**0.54**	**0.53**	**0.53**
$CD_{0.05}$						
AM	0.01		AM × ZnO	NS		
SeB	NS		SeB× ZnO	NS		
ZnO	NS					

Table-4.39b: Interactive effects of nano zinc, AM fungi and selenobacteria on soil organic carbon (%) of strawberry

Nano Zinc Oxide	**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	0.42	0.45	0.45	0.64	0.58	0.59
ZnO$_1$	0.46	0.47	0.47	0.61	0.60	0.59
ZnO$_2$	0.47	0.45	0.45	0.62	0.61	0.60
Mean	**0.45**	**0.46**	**0.46**	**0.62**	**0.60**	**0.60**
CD$_{0.05}$						
AM × SeB	NS		AM × SeB× ZnO	NS		

AM$_0$:without AMF SeB$_0$:without Selenobacteria ZnO$_0$: 0
AM$_1$: with AMF SeB$_1$:*Stenotrophomonas maltophilia* ZnO$_1$: 100 ppm
SeB$_2$:*Alcaligenes faecalis* ZnO$_2$: 200 ppm

4.5.1.4 Available nitrogen (kg/ha)

The pooled data pertaining to soil nitrogen content (kg/ha) have been presented in Table- 4.40 (a and b) and clearly indicated that only AM fungi and nano zinc oxide individually have influenced available nitrogen content significantly. Whereas, the effect of selenobacteria individually and other interactions were found to be non-significant (Appendix- LVII).

As regards the effects of AM fungi (AM), maximum soil nitrogen content (394.66 kg/ha) was recorded, when the plants were treated with AM fungi and found to be significantly higher in comparison to other plants that were not treated with AM fungi where, minimum soil nitrogen content (369.35 kg/ha) was observed.

Table-4.40a: Effect of nano zinc, AM fungi and selenobacteria on available nitrogen (kg/ha) content of strawberry field

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	364.59	388.19	**376.39**	374.96	378.19	376.02
ZnO$_1$	370.22	395.28	**382.75**	382.01	388.51	377.73
ZnO$_2$	373.25	400.50	**386.88**	390.24	389.73	380.66
Mean	**369.35**	**394.66**		**382.40**	**385.48**	**378.13**
CD$_{0.05}$						
AM	5.62		AM × ZnO	NS		
SeB	NS		SeB× ZnO	NS		
ZnO	6.88					

Table-4.40b: Interactive effects of nano zinc, AM fungi and selenobacteria on available nitrogen (kg/ha) content of strawberry field

Nano Zinc Oxide	AM$_0$			AM$_1$		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	360.46	367.64	365.67	389.46	388.75	386.37
ZnO$_1$	372.78	371.75	366.13	391.24	405.28	389.32
ZnO$_2$	377.32	371.67	370.77	403.16	407.80	390.55
Mean	**370.19**	**370.35**	**367.52**	**394.62**	**400.61**	**388.74**
CD$_{0.05}$						
AM × SeB	NS		AM × SeB× ZnO	NS		

AM$_0$:without AMF SeB$_0$:without Selenobacteria ZnO$_0$: 0
AM$_1$: with AMF SeB$_1$:*Stenotrophomonas maltophilia* ZnO$_1$: 100 ppm
SeB$_2$:*Alcaligenes faecalis* ZnO$_2$: 200 ppm

Considering the effect of foliar application of nano zinc oxide applied with different concentrations the maximum soil nitrogen content was observed with ZnO$_2$ (386.88 kg/ha) i.e. nano zinc oxide applied @ 200ppm. However, effect of nano zinc oxide applied @ 100 ppm also showed similar results with soil nitrogen content (382.75 kg/ha) which was statistically at par with ZnO$_2$.

4.5.1.5 Available phosphorus (kg/ha)

The perusal of pooled data of two years given in Table-4.41 (a and b) indicated that nano zinc, AM fungi and selenobacteria levels not only had significant effect individually but their interactions also had significant results on the available phosphorus (kg/ha) (Appendix-LVII).

Considering the data pertaining to the effect of AMF on soil phosphorus showed significant higher available phosphorus content (45.82 kg/ha) in soil with the application of AM fungi.

Table-4.41a: Effect of nano zinc, AM fungi and selenobacteria on available phosphorus (kg/ha) content of strawberry field

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	38.16	46.09	**42.12**	39.26	44.52	42.59
ZnO$_1$	40.56	46.14	**43.35**	43.40	43.32	43.34
ZnO$_2$	40.29	45.23	**42.76**	41.80	43.56	43.37
Mean	**39.67**	**45.82**		**41.49**	**43.80**	**43.10**
CD$_{0.05}$						
AM	0.47		AM × ZnO	0.81		
SeB	0.57		SeB× ZnO	0.99		
ZnO	0.57					

Table-4.41b: Interactive effects of nano zinc, AM fungi and selenobacteria on available phosphorus (kg/ha) content of strawberry field

Nano Zinc Oxide	AM$_0$			AM$_1$		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	34.12	37.91	42.45	44.40	47.28	46.59
ZnO$_1$	40.51	39.58	41.60	46.28	47.10	45.04
ZnO$_2$	37.71	41.24	41.91	45.85	45.49	45.21
Mean	**37.45**	**39.58**	**41.99**	**45.51**	**46.62**	**45.61**
CD$_{0.05}$						
AM × SeB	0.81		AM × SeB× ZnO		1.40	

AM$_0$:without AMF SeB$_0$:without Selenobacteria ZnO$_0$: 0
AM$_1$: with AMF SeB$_1$:*Stenotrophomonas maltophilia* ZnO$_1$: 100 ppm
SeB$_2$:*Alcaligenes faecalis* ZnO$_2$: 200 ppm

As per the effect of the selenobacteria, the significantly higher increase in available phosphorus (43.80 kg/ha) was observed with SeB$_1$.

Similarly, the effect of foliar application of nano zinc oxide, the highest increase in available phosphorus (43.35 kg/ha) was recorded with the nano zinc oxide applied @ 100 ppm.

As regards the interaction of AM fungi and nano zinc oxide the soil having maximum available phosphorus (46.14 kg/ha) was observed with the interaction, AM$_1$ × ZnO$_1$. They were found to have significantly higher soil available phosphorus over all other interactions of AM fungi and nano zinc oxide sprays. However the effect of interaction, AM$_1$ × ZnO$_0$ recorded soil available phosphorus content (46.09 kg/ha) which was statistically at par with AM$_1$ × ZnO$_1$.

The interaction of selenobacteria and nano zinc oxide reveals maximum available soil phosphorus (44.52 kg/ha) in the interaction, SeB$_1$ × ZnO$_0$. It was found to be significantly superior in comparison to all the other interactions of selenobacteria and nano zinc oxide sprays.

The interaction between AM fungi and selenobacteria exhibited maximum available soil phosphorus (46.62 kg/ha) in the interaction, AM$_1$ × SeB$_1$ and it was found statistically higher over all the other interactions of AM fungi and selenobacteria.

The interaction of AM fungi × selenobacteria × nano zinc oxide application reveals that maximum available soil phosphorus (47.28 kg/ha) in the interaction, AM$_1$ × SeB$_1$ ×

ZnO_0. However the interactions, $AM_1 \times SeB_0 \times ZnO_1$, $AM_1 \times SeB_1 \times ZnO_1$ and $AM_1 \times SeB_2 \times ZnO_0$ observed the available phosphorus to the value 46.28 kg/ha, 47.10 kg/ha and 46.59 kg/ha, respectively, . They were found to be statistically at par with $AM_1 \times SeB_1 \times ZnO_0$.

4.5.1.6 Available potassium (kg/ha)

The perusal of pooled data available potassium (kg/ha) in soil, given in Table- 4.42(a and b) indicated that nano zinc, AM fungi and selenobacteria levels not only had significant effect individually but their interactions also had significant results (Appendix- LVII).

Considering the data pertaining to the effect of AMF on plant height showed significant increase in available soil potassium (356.75 kg/ha) with the application of AM fungi.

Table- 4.42a: **Effect of nano zinc, AM fungi and selenobacteria on available potassium (kg/ha) content of strawberry field**

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	323.51	349.10	**336.31**	317.77	342.08	331.26
ZnO_1	321.24	359.88	**340.56**	326.75	346.97	352.85
ZnO_2	330.38	361.28	**345.83**	332.24	359.89	358.29
Mean	**325.04**	**356.75**		**325.59**	**349.64**	**347.46**
$CD_{0.05}$						
AM	3.69		AM × ZnO	6.40		
SeB	4.52		SeB× ZnO	7.83		
ZnO	4.52					

Table- 4.42b: Interactive effects of nano zinc, AM fungi and selenobacteria on available potassium (kg/ha) content of strawberry field

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	301.52	317.34	351.67	334.03	365.70	345.18
ZnO_1	311.37	333.90	318.45	342.13	371.79	367.88
ZnO_2	319.07	346.01	326.05	345.40	370.56	368.10
Mean	**310.65**	**332.42**	**332.06**	**340.52**	**369.02**	**360.39**
$CD_{0.05}$						
AM × SeB	NS		AM × SeB× ZnO	11.08		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As per the effect of the selenobacteria, the significant increase in available soil potassium (349.64 kg/ha) was observed with SeB_1 (*Stenotrophomonas maltophilia*).

Similarly, the effect of foliar application of nano zinc oxide, the highest available soil potassium (345.83 kg/ha) was recorded with the nano zinc oxide applied @ 200 ppm.

As regards the interaction of AM fungi and nano zinc oxide, maximum soil potassium (361.28 kg/ha) were produced in the interaction, AM_1 x ZnO_2. It was found to be statistically at par with AM_1 x ZnO_1 with available potassium 359.88 kg/ha.

The interaction of selenobacteria and nano zinc oxide reveals maximum available soil potassium (359.89 kg/ha) in the interaction, $SeB_1 \times ZnO_2$. It was found to be statistically at par with SeB_2 x ZnO_2 and $SeB_2 \times ZnO_1$.

The interaction of AM fungi × selenobacteria × nano zinc oxide application reveals that soil potassium (371.79 kg/ha) was maximum in the interaction, $AM_1 \times SeB_1 \times ZnO_1$. However, the soil potassium content (370.56 kg/ha) was recorded with interaction, $AM_1 \times SeB_1 \times ZnO_2$ was found to be statistically at par with to $AM_1 \times SeB_1 \times ZnO_1$. It was also at par with others.

4.5.1.7 Exchangeable calcium [cmol (p^+) kg^{-1}]

The perusal of pooled data of two years given in Table- 4.43 (a and b) indicated that nano zinc and AM fungi levels had significant effect individually on exchangeable soil calcium content. However, all the interactions were non significant except AM × SeB (Appendix- LVII).

Table-4.43a: Effect of nano zinc, AM fungi and selenobacteria on exchangeable calcium [cmol (p^+) kg^{-1}] content of strawberry field

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.26	5.68	**4.97**	4.95	4.89	5.07
ZnO_1	4.45	5.72	**5.08**	5.13	5.06	5.06
ZnO_2	4.42	5.77	**5.09**	5.09	5.11	5.08
Mean	**4.38**	**5.72**		**5.06**	**5.02**	**5.07**
$CD_{0.05}$						
AM	0.07		AM × ZnO	NS		
SeB	NS		SeB× ZnO	NS		
ZnO	0.08					

Table-4.43b: Interactive effects of nano zinc, AM fungi and selenobacteria on exchangeable calcium [cmol (p^+) kg^{-1}] content of strawberry field

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2
ZnO_0	4.11	4.22	4.45	5.78	5.56	5.70
ZnO_1	4.43	4.45	4.47	5.83	5.66	5.66
ZnO_2	4.34	4.47	4.45	5.84	5.75	5.71
Mean	**4.29**	**4.38**	**4.46**	**5.82**	**5.66**	**5.69**
$CD_{0.05}$						
AM × SeB	0.11		AM × SeB× ZnO		NS	

AM_0:without AMF SeB_0 :without Selenobacteria ZnO_0: 0
AM_1: with AMF SeB_1:*Stenotrophomonas maltophilia* ZnO_1: 100 ppm
SeB_2 :*Alcaligenes faecalis* ZnO_2 : 200 ppm

Considering the data pertaining to the effect of AMF on calcium content [5.72 cmol (p^+) kg^{-1}], it showed significant increase in soil calcium with the application of AM fungi (AM_1).

Similarly, the effect of foliar application of nano zinc oxide, the highest increase in calcium [5.09 cmol (p^+) kg^{-1}] was recorded with the nano zinc oxide applied @ 200 ppm. However, it was statistically at par with nano zinc oxide applied @ 100 ppm with a value of exchangeable calcium 5.08 cmol (p^+) kg^{-1}

The interaction between AM fungi and selenobacteria exhibited maximum calcium with a value of 5.82 cmol (p^+) kg^{-1} in the interaction, AM_1 × SeB_1 and it was significantly higher compared to rest of the interactions.

4.5.1.8 Exchangeable magnesium [cmol (p^+) kg^{-1}]

The perusal of pooled data of two years given in Table- 4.44 (a and b) indicated that nano zinc, AM fungi and selenobacteria levels had significant effect individually but their interactions were non significant for exchangeable soil magnesium (Appendix- LVII).

Table-4.44a: Effect of nano zinc, AM fungi and selenobacteria on exchangeable magnesium [cmol (p^+) kg^{-1}] content of strawberry field

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	AM_1		SeB_0	SeB_1	SeB_2
ZnO_0	1.67	2.02	**1.85**	1.83	1.90	1.87
ZnO_1	1.70	2.07	**1.89**	1.88	1.90	1.89
ZnO_2	1.71	2.11	**1.91**	1.89	1.96	1.89
Mean	**1.70**	**2.07**		**1.87**	**1.92**	**1.88**
$CD_{0.05}$						
AM SeB ZnO	0.03 0.04 0.04		AM × ZnO SeB× ZnO	NS NS		

Table-4.44b: Interactive effects of nano zinc, AM fungi and selenobacteria on exchangeable magnesium [cmol (p^+) kg^{-1}] content of strawberry field

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	1.61	1.69	1.72	2.04	2.11	2.02
ZnO_1	1.71	1.67	1.73	2.05	2.12	2.04
ZnO_2	1.72	1.71	1.71	2.06	2.21	2.08
Mean	**1.68**	**1.69**	**1.72**	**2.05**	**2.15**	**2.05**
$CD_{0.05}$						
AM × SeB	0.05		AM × SeB× ZnO	NS		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

Considering the data pertaining to the effect of AMF on exchangeable magnesium showed significant increase in soil magnesium upto a value of 2.07 cmol (p^+) kg^{-1} with the application of AM fungi.

As per the effect of the selenobacteria, the significantly higher levels of exchangeable magnesium with a mean value of 1.92 cmol (p^+) kg^{-1} was observed with (*Stenotrophomonas maltophilia*). However, effect of the other strain (*Alcaligenes faecalis*) was statistically at par with SeB_1.

Similarly, the effect of foliar application of nano zinc oxide, the significantly higher exchangeable magnesium [1.91 cmol (p^+) kg^{-1}] was recorded with foliar application of the nano zinc oxide applied @ 200 ppm while, the effect of nano zinc oxide applied @ 100 ppm was statistically at par recording a value of 1.89 cmol (p^+) kg^{-1}.

As regards the interaction of AM fungi and selenobacteria, maximum exchangeable magnesium [2.15 cmol (p^+) kg^{-1}] was observed in the interaction, AM_1 x SeB_1.

4.5.1.9 Soil iron (ppm)

The Table-4.45 (a and b) presents that AM fungi and selenobacteria levels had significant effect individually along with their interactions. the overall interaction of all the three factors was also significant. However, nano zinc oxide alone as well as its interaction with AM fungi and selenobacteria were non significant (Appendix- LVII).

Table-45a: Effects of nano zinc, AM fungi and selenobacteria on soil iron (ppm) content of strawberry field

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	63.13	69.59	**66.36**	63.42	69.29	66.37
ZnO_1	67.25	68.17	**67.71**	67.46	69.72	65.95
ZnO_2	64.46	68.55	**66.50**	65.01	69.27	65.23
Mean	**64.95**	**68.77**		**65.30**	**69.43**	**65.85**
$CD_{0.05}$						
AM	1.00		AM × ZnO	NS		
SeB	1.22		SeB× ZnO	NS		
ZnO	NS					

Table-45b: Interactive effects of nano zinc, AM fungi and selenobacteria on soil iron (ppm) content of strawberry field

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	59.32	65.58	64.49	67.53	73.00	68.25
ZnO_1	67.19	67.63	66.92	67.73	71.80	64.97
ZnO_2	60.90	68.59	63.88	69.12	69.95	66.58
Mean	**62.47**	**67.27**	**65.10**	**68.13**	**71.58**	**66.60**
$CD_{0.05}$						
AM × SeB	1.73		AM × SeB× ZnO	3.00		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As regards the effect of AMF on soil iron content, it was observed that soil iron content (68.77 ppm) was significantly increased with the application of AM fungi.

As per the effect of the selenobacteria, the significantly higher levels of soil iron (69.43 ppm) was observed with the rhizoinoculation of *Stenotrophomonas maltophilia*.

The interaction between AM fungi and selenobacteria exhibited maximum soil iron content (71.58 ppm) in the interaction, $AM_1 \times SeB_1$ and it was found significantly higher over all the other interactions of AM fungi and selenobacteria.

The interaction of AM fungi × selenobacteria × nano zinc oxide application reveals that maximum soil iron (73.00 ppm) in the interaction, $AM_1 \times SeB_1 \times ZnO_0$. However, the soil iron content (71.80 ppm) was recorded with interaction, $AM_1 \times SeB_1 \times ZnO_1$, was found to be statistically at par with $AM_1 \times SeB_1 \times ZnO_0$.

4.5.1.10 Soil copper (ppm)

The perusal of pooled data of two years given in Table- 4.46 (a and b) indicated that nano zinc, AM fungi and selenobacteria levels not only had significant effect individually but their interactions also had significant results on the soil copper (ppm) (Appendix- LVII).

Considering the data pertaining to the effect of AMF on soil copper showed significant increase in soil copper content (9.85 ppm) with the application of AM fungi (AM_1).

As per the effect of the selenobacteria, the significantly higher increase in soil copper (10.12 ppm) was observed with *Stenotrophomonas maltophilia*.

Table-4.46a Effect of nano zinc, AM fungi and selenobacteria on soil copper (ppm) content of strawberry field

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	7.71	9.52	**8.61**	7.59	9.38	8.52
ZnO_1	8.62	10.08	**9.35**	9.12	10.41	8.88
ZnO_2	9.64	9.95	**9.79**	8.57	10.58	10.24
Mean	**8.66**	**9.85**		**8.43**	**10.12**	**9.21**
$CD_{0.05}$						
AM	0.09		AM × ZnO	0.16		
SeB	0.11		SeB× ZnO	0.20		
ZnO	0.11					

Table-4.46b: Interactive effects of nano zinc, AM fungi and selenobacteria on soil copper (ppm) content of strawberry field

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	5.92	9.00	7.04	9.26	9.76	9.55
ZnO_1	8.62	10.10	8.21	9.63	10.62	9.99
ZnO_2	7.42	10.14	8.96	9.72	10.61	9.51
Mean	**7.32**	**9.75**	**8.07**	**9.54**	**10.33**	**9.68**
$CD_{0.05}$						
AM × SeB	0.16		AM × SeB× ZnO	0.28		

AM_0:without AMF
AM_1: with AMF
SeB_0 :without Selenobacteria
SeB_1:*Stenotrophomonas maltophilia*
SeB_2 :*Alcaligenes faecalis*
ZnO_0: 0
ZnO_1: 100 ppm
ZnO_2 : 200 ppm

Similarly, the effect of foliar application of nano zinc oxide, the highest soil copper value 9.79 ppm was recorded with the nano zinc oxide (ZnO_2) applied @ 200 ppm.

As regards the interaction of AM fungi and nano zinc oxide, the soil having maximum copper content (10.08 ppm) was observed with the interaction, $AM_1 \times ZnO_1$. It was found that the interaction effect of $AM_1 \times ZnO_2$, recorded soil copper value 9.95 and was statistically at par with $AM_1 \times ZnO_1$.

The interaction of selenobacteria and nano zinc oxide reveals maximum soil copper (10.58 ppm) in the interaction, $SeB_1 \times ZnO_2$. It was found that the interaction effect of $SeB_1 \times ZnO_1$, recorded soil copper value 10.41 and was statistically at par with $SeB_1 \times ZnO_2$.

The interaction between AM fungi and selenobacteria exhibited soil copper content (10.33 ppm) which was maximum in the interaction, $AM_1 \times SeB_1$ and it was found significantly higher over all the other interactions of AM fungi and selenobacteria.

The interaction of $AM_1 \times SeB_1 \times ZnO_1$ application , reveals that maximum soil copper content with a value of 10.62 ppm was recorded. However the interaction, $AM_1 \times SeB_1 \times ZnO_2$, with the soil copper content upto a value of 10.61 ppm was found to be statistically at par with $AM_1 \times SeB_1 \times ZnO_1$.

4.5.1.11 Soil zinc (ppm)

The pooled data on production of soil zinc (ppm) have been contained in Table- 4.47 (a and b) and closely depicts that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced the soil zinc content of strawberry field significantly (Appendix- LVII).

Table-4.47a: Effect of nano zinc, AM fungi and selenobacteria on soil zinc (ppm) content of strawberry field

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	AM_1		SeB_0	SeB_1	SeB_2
ZnO_0	13.84	15.23	**14.53**	13.54	15.26	14.79
ZnO_1	16.67	17.30	**16.99**	16.64	17.39	16.43
ZnO_2	17.34	17.94	**17.64**	17.44	17.98	17.15
Mean	**15.95**	**16.82**		**15.87**	**16.87**	**16.12**
$CD_{0.05}$						
AM 0.23 SeB 0.28 ZnO 0.28			AM × ZnO 0.40 SeB× ZnO 0.49			

Table-4.47b: Interactive effects of nano zinc, AM fungi and selenobacteria on soil zinc (ppm) content of strawberry

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2
ZnO_0	12.07	15.03	14.41	15.01	15.49	15.17
ZnO_1	16.30	17.02	16.69	16.57	17.76	16.72
ZnO_2	17.14	17.68	17.21	17.04	18.27	17.21
Mean	**15.17**	**16.58**	**16.10**	**16.21**	**17.17**	**16.37**
$CD_{0.05}$						
AM × SeB	0.40		AM × SeB× ZnO		0.69	

AM_0:without AMF
AM_1: with AMF

SeB_0 :without Selenobacteria
SeB_1:*Stenotrophomonas maltophilia*
SeB_2 :*Alcaligenes faecalis*

ZnO_0: 0
ZnO_1: 100 ppm
ZnO_2 : 200 ppm

As regards the effects of AM fungi (AM), maximum soil zinc content (16.82 ppm) of strawberry field was recorded, when the plants were treated with AM fungi and found to be significantly higher in comparison to other plants that were not treated with AM fungi.

The use of selenobacteria *Stenotrophomonas maltophilia* resulted in the zinc content (16.87 ppm) of strawberry field was recorded maximum and found to be significantly highest.

The foliar application of nano zinc oxide @ 200 ppm recorded maximum zinc content in soil (17.64 ppm) of strawberry field and it was found to be significantly higher over the other dose of nano zinc oxide.

The interaction effects of AM fungi and nano zinc oxide indicated that the highest zinc content (17.94 ppm) in soil of strawberry field was recorded in the interaction, AM_1 × ZnO_2 and it was found to be significantly higher over all other interactions of AM fungi and nano zinc oxide.

As regards the interaction effects of selenobacteria and nano zinc oxide, soil zinc content (17.98 ppm) of strawberry field was recorded maximum in the interaction, SeB_1 × ZnO_2 and observed to be significantly higher as compared to all other interactions of selenobacteria and nano zinc oxide doses.

The interaction effects of AM fungi and selenobacteria revealed soil zinc content (17.17 ppm) of strawberry field was higher in the interaction AM_1 × SeB_1 and it was found to be significantly highest in comparison to all the interactions of AM fungi and selenobacterial applications.

The interaction of AM fungi × nano zinc oxide × selenobacteria exhibited maximum soil zinc content (18.27 ppm) of strawberry field in the interaction, $AM_1 \times SeB_1 \times ZnO_1$ i.e. when AM fungi was applied along with selenobacteria (*Stenotrophomonas maltophilia*) and nano zinc oxide @ 100 ppm. This was found to be significantly superior in comparison to all other interactions.

4.5.1.12 Soil manganese (ppm)

The pooled data for the soil manganese content of strawberry field is presented in the Table- 4.48(a and b) and it was observed that only AM fungi significantly increased the soil manganese content (55.93 ppm) of the strawberry field as well as nano zinc oxide with both the concentration of 100 and 200 ppm significantly influenced the soil manganese content (54.19 ppm and 54.49 ppm, respectively) and were statistically at par with each other when compared to the control. Whereas, the application of selenobacteria individually as well as in their interactions with AM fungi and nano zinc oxide were non significant (Appendix- LVII).

Table-4.48a: **Effect of nano zinc, AM fungi and selenobacteria on soil manganese (ppm) content of strawberry field**

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	AM_1		SeB_0	SeB_1	SeB_2
ZnO_0	49.72	53.90	**51.81**	51.78	52.19	51.47
ZnO_1	51.54	56.85	**54.19**	53.50	54.96	54.12
ZnO_2	51.87	57.06	**54.46**	55.20	54.38	53.81
Mean	**51.04**	**55.93**		**53.49**	**53.84**	**53.13**
$CD_{0.05}$						
AM	0.86		AM × ZnO	NS		
SeB	NS		SeB× ZnO	NS		
ZnO	1.06					

Table-48b: Interactive effects of nano zinc, AM fungi and selenobacteria on soil manganese (ppm) content of strawberry field

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2
ZnO_0	49.14	50.40	49.63	54.42	53.97	53.31
ZnO_1	51.13	51.85	51.62	55.86	58.06	56.62
ZnO_2	52.17	51.96	51.49	58.22	56.81	56.14
Mean	**50.81**	**51.40**	**50.91**	**56.17**	**56.28**	**55.35**
$CD_{0.05}$						
AM × SeB	NS		AM × SeB× ZnO	NS		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

4.5.1.13 Soil selenium (ppm)

The perusal of pooled data presented in Table- 4.49(a and b) indicated that nano zinc, AM fungi and selenobacteria applications alone have influenced soil selenium (ppm) of strawberry field significantly individually as well as with their interactions. However the interaction of AM fungi and nano zinc oxide was found to be non-significant (Appendix-LVII).

As regards the effects of AM fungi (AM_1), maximum soil selenium content (3.72 ppm) was recorded, when the plants were treated with AM fungi and found to be significantly higher in comparison to other plants that were not treated with AM fungi where minimum soil selenium content (3.55 ppm) was observed.

Table-4.49a: **Effect of nano zinc, AM fungi and selenobacteria on soil selenium (ppm) content of strawberry field**

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	3.57	3.77	**3.67**	3.13	4.29	3.58
ZnO_1	3.57	3.76	**3.67**	3.13	4.49	3.38
ZnO_2	3.53	3.62	**3.57**	3.06	4.25	3.42
Mean	**3.55**	**3.72**		**3.11**	**4.34**	**3.46**
$CD_{0.05}$						
AM SeB ZnO	0.06 0.07 NS		AM × ZnO SeB× ZnO	NS 0.12		

Table-4.49b: **Interactive effects of nano zinc, AM fungi and selenobacteria on soil selenium (ppm) content of strawberry field**

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	3.03	4.12	3.55	3.23	4.46	3.61
ZnO_1	3.05	4.10	3.56	3.21	4.87	3.21
ZnO_2	2.90	4.06	3.62	3.22	4.43	3.22
Mean	**2.99**	**4.09**	**3.58**	**3.22**	**4.59**	**3.35**
$CD_{0.05}$						
AM × SeB	0.10		AM × SeB× ZnO	0.17		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

With the use of selenobacteria *Stenotrophomonas maltophilia*, the soil selenium content (4.34 ppm) was recorded maximum and found to be significantly higher over the applications of selenobacteria.

The interaction of selenobacteria and nano zinc oxide recorded significantly higher value of soil selenium content (4.49 ppm) in the interaction, SeB_1 × ZnO_1.

The interaction between AM fungi and selenobacteria exhibited maximum soil selenium content (4.59 ppm) in the interaction, AM_1 × SeB_1 and it was found significantly higher as compared to rest of the interactions of AMF and selenobacteria.

The interaction of AM fungi × selenobacteria × nano zinc oxide application reveals that soil selenium content (4.87 ppm) was observed to be maximum in the interaction, AM_1 × SeB_1 × ZnO_1.

The results pertaining to soil nutrient content indicates that the AMF application significantly improved the soil pH, organic carbon and other soil nutrient N, P, K, Ca, Mg, Cu, Fe, Zn, Mn as well as soil Se. The findings of the present study for soil pH and organic carbon are in consonance with the observations of Cheng et al. (2012) that the AMF significantly increased the pH and soil organic carbon in the soybean rhizosphere compared to non-AMF treatment. This could be linked to the increased root colonization and AMF hyphae in the soil. This result supported the fact that AMF play a major role in improving organic C through secretions, from their extraradical hyphae loaded into the rhizosphere. Thus, rhizodeposition of organic C by the roots of host plant helps AMF activities in soil aggregate formation (Rillig and Mummey 2006).

Arbuscular Mycorrhizae Fungi is known for its phosphorus mobilizing ability thus, symbionts are recognised as significant microbial contributors to the formation of the major biogeochemical cycles of soils (P and N). Consequently, the proliferation of mycorrhizal plants is enhanced (Fall et al. 2022). AMF performs a crucial role in enhancing soil P availability. In fact, it is a P activator that can speed up the transformation of P into bio-available forms through a variety of chemical reactions and biological interactions (Zhu et al. 2018). It was proven that the double inoculation of *R. irregularis and Rahnella aquatilis* improves solubilization of inorganic P by the increased production of phosphatase released by the bacteria that is also stimulated by AMF exuded fructose (Zhang et al. 2018). It is known that AMF allows better absorption of low mobile trace elements in soils, such as potassium (K), calcium (Ca), magnesium (Mg), copper (Cu), zinc (Zn), iron (Fe), manganese (Mn) and cobalt (Co) (Garcia et al. 2016 and Hashem et al. 2018). For instance, according to Krishna and Bagyaraj (1984), the level of Zn, Fe and Mn is twice in mycorrhizal peanut plants compared to non-mycorrhizal plants. It has also been revealed that mycorrhizal inoculation improved Zn and Cu nutrition in crops. However, when some of these elements are present in high quantities and therefore possess a toxic character, the mycorrhization can play a role in the protection of the plant, by strong retention of these elements (Liu et al. 2000). The addition of 150 spores/kg·soil AM fungi was reported to increase the available Se content (by 43.02 μg/kg) in soil (Jiang et al. 2023).

In the findings of the present study it was found that selenobacteria was helpful in improving soil nutrient status. Similar findings were reported by few researchers that Selenobacteria (Se-tolerant bacteria) isolated from different ecological niches have been explored and studied for their potential in the bioremediation and biofortification of soils (Eswayah et al. 2016). It can reduce inorganic Se to elemental Se nanospheres (NanoSe) and other important organic Se forms (Acuna et al. 2013, Duran et al. 2013, Duran et al. 2014 and Duran et al. 2015).

Plants inoculated with selenobacteria showed significant micronutrient concentrations compared to plants without the strain. Two possible reasons may explain the phenomenon observed in the present study. One is that the Se adsorbed onto the surface of oxides and clay minerals was more likely to combine with peptides and amino acids secreted by the strain and released into the soil (Fernandez-Martínez and Charlet 2009). The other likely reason is that the strain secreted extracellular phosphatase to dissolve the insoluble phosphorus in the soil, and the release of phosphorus was accompanied by the activation and release of Se (Lee et al. 2011).

The results regarding the soil's chemical properties were also positively affected by the foliar spray of nano ZnO, which coincided with the findings of Liu (2006), who reported improved soil physical properties through the interaction of nanoparticles with natural organic minerals. Romero-Freire et al. (2017) found that the application of ZnO nanoparticles led to an increase in the soil's pH, which may have been caused by an increase in the amount of dissolved Zn in water over time due to the soil's exposure to the nanoparticles. In addition, this exposure increased the amount of Zn extracted with DTPA. In other studies (Waalewijn-Kool et al. 2011, Zhao et al. 2013 and Garcia- Gomez et al. 2014) the increase in soil pH due to ZnO as compared to nano ZnO was also documented. In addition, the increased population of resident microorganisms may be involved in mineralization and organic acid synthesis, resulting in a neutralisation of the soil's pH (Nithya 2017). Similarly, a decrease in EC level has been reported for both nano ZnO and conventional (bulk) ZnO due to an increase in oxide solubilization (Garcia-Gomez et al. 2014). The increased decomposition of organic matter with Zn treatment results in increased soil organic carbon content (Babu and Sharma 2005). The significant difference observed may be attributed to the FYM application in addition to recommended dose of fertilizers. Apart from this, available N content was also found to show increment with nano ZnO which might be due to the complete degradation of the organic matter resulting in increased availability of nutrients (Shashidhar et al. 2009). Similar to the findings of Depar et al. (2011), it is reported that foliar spraying of ZnO nano particles improves the available N content. Lonergan et al. (2009) observed a decrease in available P due to the interaction between P and Zn, which reduces translocation and results in an imbalanced P:Zn ratio in the plant system. The DTPA extractable Zn content was also affected by nano ZnO application, as these nano particles significantly affect the translocation and localization of Zn. According to Linehan et al. (1989), the increased mobilisation of Zn from insoluble to soluble forms by biologically produced chelators led to an increase in soil Zn levels. In addition, an increase in dissolved Zn was observed with increasing nano ZnO application rates (Rousk et al. 2012). The observed results are consistent with those of Ghoneim (2016) and Bala et al. (2019).

4.5.2 Microbiological

4.5.2.1 Total bacterial count (×10^5 cfu/g)

The perusal of pooled data pertaining to the total bacterial count have been depicted in the Table - 4.50 (a and b). A perusal of data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced total bacterial count (×10^5 cfu/g) of strawberry field significantly (Appendix- LVII).

Table-4.50a: Effect of nano zinc, AM fungi and selenobacteria on total bacterial count (×10^5 cfu/g) in strawberry field

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	AM_1		SeB_0	SeB_1	SeB_2
ZnO_0	58.75	62.12	**60.44**	60.82	61.29	60.96
ZnO_1	61.38	67.71	**64.55**	61.08	66.80	63.23
ZnO_2	62.25	63.70	**62.98**	61.78	65.58	62.35
Mean	**60.79**	**64.51**		**61.23**	**64.56**	**62.18**
$CD_{0.05}$						
AM	0.93		AM × ZnO	1.62		
SeB	1.14		SeB× ZnO	1.98		
ZnO	1.14					

Table-4.50b: Interactive effects of nano zinc, AM fungi and selenobacteria on total bacterial count (×10^5 cfu/g) in strawberry field

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_0**	**SeB_1**	**SeB_0**	**SeB_1**
ZnO_0	53.42	59.16	58.67	60.12	61.10	56.14
ZnO_1	62.03	61.48	62.28	68.22	70.44	66.03
ZnO_2	60.81	63.57	65.79	62.76	67.60	64.18
Mean	**58.75**	**61.40**	**62.25**	**63.70**	**66.38**	**62.12**
$CD_{0.05}$						
AM × SeB		1.62		AM × SeB× ZnO		2.80

AM_0:without AMF SeB_0 :without Selenobacteria ZnO_0: 0
AM_1: with AMF SeB_1:*Stenotrophomonas maltophilia* ZnO_1: 100 ppm
SeB_2 :*Alcaligenes faecalis* ZnO_2 : 200 ppm

As regards to AM fungi, maximum total bacterial count (64.51 × 10^5 cfu/g) of was observed in strawberry field in which mycorrhizal treatment was given to the plants. It was significantly higher in comparison to the other non AM fungi treated plants.

The application of selenobacteria significantly increased the phosphorus solubilizing bacteria of strawberry field. Maximum total bacterial count (64.56 × 10^5 cfu/g) was observed in strawberry field where *Stenotrophomonas maltophilia* strain was applied.

Considering the effect of foliar application of nano zinc oxide applied with different concentrations, the maximum total bacterial count (64.55 × 10^5 cfu/g) within the strawberry field was observed with ZnO_2.

The interaction of AM_1 × ZnO_1 was observed to have total bacterial count with a mean value of 67.71 × 10^5 cfu/g of strawberry field and it was found to be significantly higher over the other interactions of AM fungi and nano zinc oxide.

As regards the interaction of SeB_1 × ZnO_2, total bacterial count (66.80 × 10^5 cfu/g) in the strawberry field was recorded maximum and found to be significantly higher over the other interactions of selenobacteria and nano zinc oxide.

Similarly, the interaction effect of AM_1 × SeB_1, recorded the total bacterial count with a value of 66.38 × 10^5 cfu/g in the strawberry field. It was significantly superior in comparison to the other interactions of AM and SeB.

The interaction of $AM_1 \times SeB_1 \times ZnO_1$, revealed total bacterial count (70.44×10^5 cfu/g) of strawberry field was maximum in this interaction. This was found to be significantly maximum in comparison to all the other interactions.

4.5.2.2 Selenobacterial count ($\times 10^5$ cfu/g)

The pooled data pertaining to the selenobacterial count have been depicted in the Table - 4.51 (a and b). A perusal of data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced selenobacterial count ($\times 10^5$cfu/g) of strawberry field significantly. However, the interaction of selenobacteria and nano zinc oxide was non significant (Appendix- LVII).

Table-4.51a: **Effect of nano zinc, AM fungi and selenobacteria on selenobacterial count ($\times 10^5$ cfu/g) in strawberry field**

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.67	7.14	**5.91**	0.92	10.20	6.60
ZnO_1	4.22	9.21	**6.72**	1.08	12.83	6.23
ZnO_2	5.67	8.57	**7.12**	1.08	12.17	8.10
Mean	**4.85**	**8.31**		**1.03**	**11.73**	**6.98**
$CD_{0.05}$						
AM	0.78		AM × ZnO	1.36		
SeB	0.96		SeB× ZnO	NS		
ZnO	0.96					

Table-4.51b: **Interactive effects of nano zinc, AM fungi and selenobacteria on Selenobacterial ($\times 10^5$ cfu/g) in strawberry field**

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	1.00	6.00	7.00	0.83	14.40	6.20
ZnO_1	0.67	9.67	2.33	1.50	16.00	10.13
ZnO_2	1.00	11.00	5.00	1.17	13.33	11.20
Mean	**0.89**	**8.89**	**4.78**	**1.17**	**14.58**	**9.18**
$CD_{0.05}$						
AM × SeB	1.36		AM × SeB× ZnO	2.35		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As regards to AM fungi, maximum selenobacterial count (8.31 $\times 10^5$ cfu/g) of strawberry field were observed in AM_1. It was significantly higher in comparison to the other non AM fungi treated plants.

The application of selenobacteria significantly increased the selenobacterial count of strawberry field. Maximum selenobacterial count (11.73 $\times 10^5$ cfu/g) in strawberry field were observed with the application of selenobacteria (*Stenotrophomonas maltophilia*).

Considering the effect of foliar application of nano zinc oxide applied with different concentrations, the maximum selenobacterial count (7.12 $\times$ 10^5 cfu/g) in strawberry field were observed with nano zinc oxide applied @ 200ppm. However, effect of nano zinc oxide applied @ 100 ppm also showed similar trend and the selenobacterial count (6.72 $\times 10^5$ cfu/g) in strawberry field was statistically at par with ZnO_2.

The interaction of AM and ZnO exhibited selenobacterial count (9.21 $\times$ 10^5 cfu/g) of strawberry field which was maximum in the interaction, $AM_1 \times ZnO_1$. However, the interaction effect of $AM_1 \times ZnO_2$ also showed similar trend, i.e. observing selenobacterial count (8.57 $\times 10^5$ cfu/g) in strawberry field which was statistically at par with $AM_1 \times ZnO_1$.

The interaction of AM fungi and selenobacteria reveals maximum selenobacterial count (14.58 $\times$ 10^5 cfu/g) of strawberry field in the interaction, $AM_1 \times SeB_1$. It was significantly superior in comparison to all the other interactions of AM and SeB.

The interaction of AM fungi × nano zinc oxide × selenobacteria reveals that the interaction, $AM_1 \times SeB_1 \times ZnO_1$ recorded higher selenobacterial count (16.00 $\times$ 10^5 cfu/g) in strawberry field. This was found to be significantly maximum in comparison to all the other interactions.

4.5.2.3 Phosphorus solubilizing bacteria ($\times 10^5$ cfu/g)

The perusal of pooled data pertaining to the phosphorus solubilizing bacteria have been depicted in the Table - 4.52 (a and b). A perusal of data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced phosphorus solubilizing bacteria ($\times 10^5$ cfu/g) of strawberry field significantly. However the interaction of selenobacteria and nano zinc oxide was non significant (Appendix- LVII).

As regards to AM fungi, maximum phosphorus solubilizing bacteria (6.05 $\times 10^5$ cfu/g) were observed in the strawberry field where mycorrhizal treatment was given to the plants. It was significantly higher in comparison to the other non AM fungi treated plants.

Table-4.52a: Effect of nano zinc, AM fungi and selenobacteria on phosphorus solubilizing bacteria ($\times 10^5$ cfu/g) in strawberry field

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	2.34	5.62	**3.98**	3.89	4.29	3.77
ZnO$_1$	3.82	6.32	**5.07**	5.05	5.46	4.70
ZnO$_2$	3.57	6.22	**4.90**	5.22	5.08	4.40
Mean	**3.24**	**6.05**		**4.72**	**4.94**	**4.29**
CD$_{0.05}$						
AM	0.17		AM × ZnO	0.29		
SeB	0.21		SeB× ZnO	NS		
ZnO	0.21					

Table-4.52b: Interactive effects of nano zinc, AM fungi and selenobacteria on phosphorus solubilizing bacteria ($\times 10^5$ cfu/g) in strawberry field

Nano Zinc Oxide	**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	2.05	2.79	2.17	5.72	5.79	5.36
ZnO$_1$	4.21	3.70	3.54	5.88	7.22	5.85
ZnO$_2$	4.03	3.31	3.38	6.41	6.84	5.42
Mean	**3.43**	**3.27**	**3.03**	**6.00**	**6.62**	**5.54**
CD$_{0.05}$						
AM × SeB	0.29		AM × SeB× ZnO	0.51		

AM$_0$:without AMF　SeB$_0$:without Selenobacteria　ZnO$_0$: 0
AM$_1$: with AMF　SeB$_1$:*Stenotrophomonas maltophilia*　ZnO$_1$: 100 ppm
SeB$_2$:*Alcaligenes faecalis*　ZnO$_2$: 200 ppm

The application of selenobacteria significantly increased the phosphorus solubilizing bacteria of strawberry field. Maximum phosphorus solubilizing bacterial count (4.94$\times 10^5$ cfu/g) in strawberry field was observed with the application of selenobacteria (*Stenotrophomonas maltophilia*).

Considering the effect of foliar application of nano zinc oxide applied with different concentrations the maximum phosphorus solubilizing bacterial count (5.07$\times 10^5$ cfu/g) in the strawberry field was observed with ZnO$_1$. However, effect of nano zinc oxide applied @ 200 ppm also showed similar trend observing PSB count with a value of 4.90 $\times 10^5$ cfu/g , which was statistically at par with ZnO$_1$.

The interaction of AM fungi and nano zinc oxide exhibited maximum phosphorus solubilizing bacterial count (6.32×10^5 cfu/g) in the strawberry field with the interaction, $AM_1 \times ZnO_1$ and it was found to be significantly higher over the other interactions of AM fungi and nano zinc oxide. However, the interaction effect of $AM_1 \times ZnO_2$ also showed similar trend with phosphorus solubilizing bacterial count (6.22×10^5 cfu/g) in strawberry field and was statistically at par with $AM_1 \times ZnO_1$.

The interaction of AM fungi and selenobacteria reveals maximum phosphorus solubilizing bacterial count (6.62×10^5 cfu/g) of strawberry field in the interaction, $AM_1 \times SeB_1$. It was significantly superior in comparison to all the other interactions of AM and SeB.

The interaction of AM fungi × nano zinc oxide × selenobacteria reveals maximum phosphorus solubilizing bacterial count (7.22×10^5 cfu/g) within the strawberry field in the interaction, $AM_1 \times SeB_1 \times ZnO_1$. However, the interaction effect of $AM_1 \times SeB_1 \times ZnO_2$, also showed results for phosphorus solubilizing bacterial count (6.84×10^5 cfu/g) within the strawberry field which was statistically at par with $AM_1 \times SeB_1 \times ZnO_1$.

4.5.2.4 AM spores count (per 50g soil)

The pooled data pertaining to the AM spores count have been depicted in the Table - 4.53(a and b). A perusal of data clearly reveals that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced AM spores count (per 50g soil) of strawberry field significantly (Appendix- LVII).

Table-4.53a: Effect of nano zinc, AM fungi and selenobacteria on AM spores count (per 50g soil) in strawberry field

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	176.86	538.28	**357.57**	299.06	394.84	378.81
ZnO_1	201.98	549.29	**375.63**	327.02	452.89	346.99
ZnO_2	210.76	539.15	**374.96**	355.94	386.17	382.76
Mean	**196.53**	**542.24**		**327.34**	**411.30**	**369.52**
$CD_{0.05}$						
AM	4.94		AM × ZnO	8.56		
SeB	6.05		SeB× ZnO	10.48		
ZnO	6.05					

Table-4.53b: Interactive effects of nano zinc, AM fungi and selenobacteria on AM spores count (per 50g soil) in strawberry field

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2
ZnO_0	123.01	165.35	242.22	475.11	624.33	515.40
ZnO_1	139.06	261.70	205.17	514.98	644.07	488.82
ZnO_2	185.14	162.20	284.95	526.74	610.15	480.58
Mean	**149.07**	**196.42**	**244.11**	**505.61**	**626.18**	**494.93**
$CD_{0.05}$						
AM × SeB	8.56		AM × SeB× ZnO	14.82		

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

As regards to AM fungi, maximum AM spores count (542.24 per 50g soil) of strawberry field were observed in AM_1. It was significantly higher in comparison to the other non AM fungi treated plants.

The application of selenobacteria recorded that AM spores count (411.30 per 50g soil) in strawberry field was significantly impacted with the application of *Stenotrophomonas maltophilia*.

Considering the effect of foliar application of nano zinc oxide applied with different concentrations, it was observed that the AM spores count with a value of 375.63 per 50g soil in strawberry field was significantly increased with ZnO_1 . However, effect of nano zinc oxide applied @ 200 ppm also showed similar trend, where, the AM spores count was observed with a value of 374.96 per 50g soil in strawberry field and it was statistically at par with ZnO_1.

The interaction of AM and nano ZnO exhibited maximum AM spores count (549.29 per 50g soil) in strawberry field in the interaction, $AM_1 \times ZnO_1$ and it was found to be significantly higher over the other interactions of AM fungi and nano zinc oxide. However, the interaction effect of $AM_1 \times ZnO_2$, also showed similar trend with AM spores count (539.15 per 50g soil) of strawberry field which was statistically at par with $AM_1 \times ZnO_1$.

As regards the interaction of selenobacteria and nano zinc oxide, maximum AM spores count (452.89 per 50g soil) in strawberry field were produced in the interaction, $SeB_1 \times ZnO_1$ and found to be significantly higher over the other interactions of selenobacteria and nano zinc oxide.

The interaction of AM fungi and selenobacteria recorded the maximum AM spores count (626.18 per 50g soil) in strawberry field in the interaction, $AM_1 \times SeB_1$. It was significantly superior in comparison to all the other interactions of AM and SeB.

The interaction of AM fungi × nano zinc oxide × selenobacteria reveals maximum AM spores count (644.07 per 50g soil) of strawberry field in the interaction, $AM_1 \times SeB_1 \times ZnO_1$. This was found to be significantly maximum in comparison to all the other interactions.

The application of AM fungi to the plants led to an increase in the microbiological content of the soil, as indicated by the test results. It may be because AMF releases organic compounds, thereby increasing bacterial density, accelerating microbial metabolic activity, and enhancing nutrient cycling in the rhizosphere (Barea et al. 2005). The number of AMF spores in the soil increased by 126% to 150% when plants were inoculated with AMF (Jabborova et al. 2021). Budi et al. (1999) reported that a high number of bacteria associated with AMF structures and the establishment of complex bacteria-mycorrhiza interactions can contribute to greater bacterial diversity.

The effect of nanoparticles is related to the role of released metal ions, which are essential for the development of microorganisms due to their structural, regulatory, and catalytic functions in enzymes (Wyszkowska et al. 2013). The bioavailability of these metal ions from the nanoparticles is dependent on the diverse soil properties, such as pH and organic carbon, which may have accounted for the abundance of resident microbial population (Fierer and Jackson 2006 and Simonin and Richaume 2015). Ge et al. (2011) observed changes in rhizosphere bacterial population that were attributed to the pronounced effect of nano ZnO application. Through foliar application of ZnO nano particles, an increase in the resident microbial population was also observed (Raliya and Tarafdar 2013, Yadav et al. 2014 and Bala et al. 2019). Additionally, this may be a result of the elevated dehydrogenase enzyme activity in the rhizosphere zone. However, the positive or negative effect of nanoparticles depended on their application rate and their exposure to microbes, which, at higher concentrations, could reduce the microbial population (Yadav et al. 2014).

4.5.3 Soil enzymes

4.5.3.1 Acid phosphatase enzyme (µg pNPP/g/ha soil)

The pooled data on the presence of acid phosphatase enzyme in the soil of strawberry field have been contained in Table- 4.54 (a and b) and closely depicts that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced production of acid phosphatase enzyme (µg pNPP/g/ha soil) in the soil significantly except for the interaction of AM fungi and nano zinc oxide (Appendix- LVII).

As per the effect of AM fungi on the amount of acid phosphatase enzyme in the soil (AM), maximum acid phosphatase enzyme (133.32 µg pNPP/g/ha soil) was recorded, when rhizoinoculation of AM fungi and found to be significantly higher in comparison to other soil samples around plants that were not treated with AM fungi.

The use of selenobacteria *Stenotrophomonas maltophilia* resulted in the production of maximum acid phosphatase enzyme (123.87 µg pNPP/g/ha soil) and found to be significantly highest over the plants which were rhizoinoculated with the other strain (*Alcaligenes faecalis*) and also where no selenobacteria was applied.

Table-4.54a: Effect of nano zinc, AM fungi and selenobacteria on acid phosphatase enzyme (µg pNPP/g/ha soil) in strawberry field

Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	98.50	127.31	**112.91**	109.74	112.99	116.00
ZnO_1	110.50	137.20	**123.85**	120.66	130.43	120.46
ZnO_2	108.46	135.43	**121.94**	119.00	128.19	118.64
Mean	**105.82**	**133.32**		**116.47**	**123.87**	**118.36**
$CD_{0.05}$						
AM	2.61		AM × ZnO	NS		
SeB	3.20		SeB× ZnO	5.54		
ZnO	3.20					

Table-4.54b: Interactive effects of nano zinc, AM fungi and selenobacteria on acid phosphtase enzyme (µg pNPP/g/ha soil) in strawberry field

Nano Zinc Oxide	**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	97.14	100.37	97.99	122.33	125.60	134.00
ZnO_1	116.65	109.83	105.00	124.67	151.03	135.91
ZnO_2	114.67	107.39	103.33	123.33	149.00	133.95
Mean	**109.49**	**105.86**	**102.11**	**123.44**	**141.88**	**134.62**
$CD_{0.05}$						
AM × SeB	4.53		AM × SeB× ZnO	7.84		

AM_0:without AMF SeB_0 :without Selenobacteria ZnO_0: 0
AM_1: with AMF SeB_1:*Stenotrophomonas maltophilia* ZnO_1: 100 ppm
SeB_2 :*Alcaligenes faecalis* ZnO_2 : 200 ppm

The foliar application of nano zinc oxide @ 100 ppm recorded maximum acid phosphatase enzyme (123.85 µg pNPP/g/ha soil). However, the acid phosphatase enzyme (121.94 µg pNPP/g/ha soil) recorded in strawberry field where the plants were treated with nano zinc oxide @ 200 ppm observed similar trend and was statistically at par with the effect of nano zinc oxide @ 100 ppm.

As regards the interaction effects of selenobacteria and nano zinc oxide, maximum acid phosphatase enzyme (130.43 µg pNPP/g/ha soil) was observed in the interaction, SeB_1 × ZnO_1. However the interaction effect of SeB_1 × ZnO_2 , the acid phosphatase enzyme (128.19 µg pNPP/g/ha soil) content observed was statistically at par with the effect of the interaction of SeB_1 × ZnO_1.

The interaction effects of AM fungi and selenobacteria observed acid phosphatase enzyme (141.88 µg pNPP/g/ha soil) and it revealed an increase in its amount in the interaction AM_1 × SeB_1 and found to be significantly highest in comparison to all other interactions of AM fungi and selenobacterial applications.

The interaction of AM fungi × nano zinc oxide × selenobacteria exhibited maximum acid phosphatase enzyme (151.03 µg pNPP/g/ha soil) in the interaction, AM_1 × SeB_1 × ZnO_1. However, acid phosphatase enzyme (149.00 µg pNPP/g/ha soil) observed with the interaction of AM_1 × SeB_1 × ZnO_2 was statistically at par with the effect of the interaction of AM_1 × SeB_1 × ZnO_1.

4.5.3.2 Alkaline phosphatase enzyme (µg pNPP/g/ha soil)

The pooled data on the presence of alkaline phosphatase enzyme in the soil of strawberry field have been contained in Table- 4.55(a and b) and closely depicts that nano zinc, AM fungi and selenobacteria applications as well as their interactions have influenced production of alkaline phosphatase enzyme (µg pNPP/g/ha soil) in the soil significantly except for the interaction of AM fungi and nano zinc oxide (Appendix- LVII).

As per the effect of AM fungi on the amount of alkaline phosphatase enzyme in the soil, maximum alkaline phosphatase enzyme (203.28 µg pNPP/g/ha soil) was recorded, when rhizoinoculation of AM fungi was given to the plants and it was found to be significantly higher in comparison to other soil samples around plants that were not treated with AM fungi.

Table-4.55a: Effect of nano zinc, AM fungi and selenobacteria on alkaline phosphatase (µg pNPP/g/ha soil) in strawberry field

Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria		
	AM_0	AM_1		SeB_0	SeB_1	SeB_2
ZnO_0	133.06	190.79	**161.92**	161.01	162.09	162.67
ZnO_1	142.80	211.28	**177.04**	187.29	179.44	164.39
ZnO_2	141.29	207.77	**174.53**	183.64	177.88	162.08
Mean	**139.05**	**203.28**		**177.31**	**173.14**	**163.05**
$CD_{0.05}$						
AM SeB ZnO	2.93 3.59 3.59		AM × ZnO SeB× ZnO	5.08 6.22		

Table-4.55b: Interactive effects of nano zinc, AM fungi and selenobacteria on alkaline phsophtase (µg PNP/g/ha soil) in strawberry field

Nano Zinc Oxide	AM_0			AM_1		
	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2
ZnO_0	133.51	134.00	131.67	188.51	190.18	193.67
ZnO_1	159.07	136.33	133.00	215.51	222.55	195.77
ZnO_2	155.37	135.67	132.83	211.91	220.08	191.33
Mean	**149.32**	**135.33**	**132.50**	**205.31**	**210.94**	**193.59**
$CD_{0.05}$						
AM × SeB	5.08		AM × SeB× ZnO		8.79	

AM_0:without AMF	SeB_0 :without Selenobacteria	ZnO_0: 0
AM_1: with AMF	SeB_1:*Stenotrophomonas maltophilia*	ZnO_1: 100 ppm
	SeB_2 :*Alcaligenes faecalis*	ZnO_2 : 200 ppm

The use of SeB_1 (*Stenotrophomonas maltophilia*) resulted in the production of alkaline phosphatase enzyme (177.31 µg pNPP/g/ha soil) and found to be significantly highest over the observed values recorded with other treatments of SeB.

The foliar application of nano zinc oxide @ 100 ppm recorded alkaline phosphatase enzyme (177.04 µg pNPP/g/ha soil) and it was observed to be significantly highest. However, the alkaline phosphatase enzyme (174.53 µg pNPP/g/ha soil) recorded with the plants treated with nano zinc oxide @ 200 ppm was statistically at par with the effect of nano zinc oxide @ 100 ppm.

The interaction of AM fungi and nano zinc oxide exhibited alkaline phosphatase enzyme (211.28 µg pNPP/g/ha soil) of strawberry field in the interaction, $AM_1 \times ZnO_1$ and it was found to be significantly higher over the other interactions of AM fungi and nano zinc oxide. However, the interaction effect of $AM_1 \times ZnO_2$ also showed similar trend with alkaline phosphatase enzyme (207.77 µg pNPP/g/ha soil) in strawberry field and was statistically at par with $AM_1 \times ZnO_1$.

As regards the interaction effects of $SeB_0 \times ZnO_1$, significantly higher alkaline phosphatase enzyme (187.29 µg pNPP/g/ha soil) was observed in the interaction. However the interaction effect of $SeB_0 \times ZnO_2$, the alkaline phosphatase enzyme (183.64 µg pNPP/g/ha soil) observed was statistically at par with the effect of the interaction of $SeB_1 \times ZnO_1$.

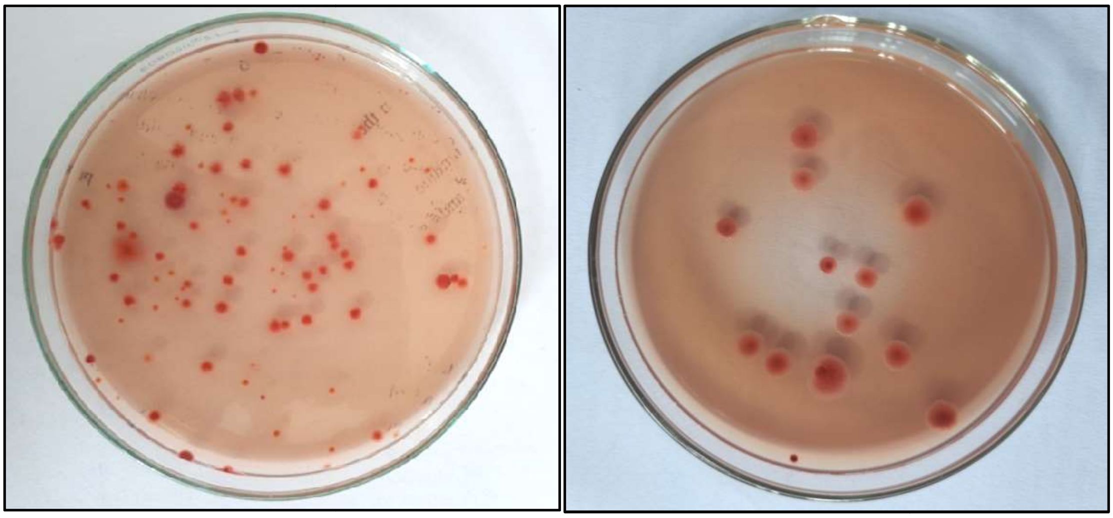
The interaction effects of AM fungi and selenobacteria revealed maximum alkaline phosphatase enzyme (210.94 µg pNPP/g/ha soil) in the interaction $AM_1 \times SeB_1$ and it was significantly highest in comparison to all the other interactions of AM fungi and selenobacterial applications.

With the interaction effect of $AM_1 \times SeB_1 \times ZnO_1$, alkaline phosphatase enzyme (222.55 µg pNPP/g/ha soil) was observed to be maximum in the interaction. However, alkaline phosphatase enzyme (220.08 µg pNPP/g/ha soil) recorded with the interaction of $AM_1 \times SeB_1 \times ZnO_2$, was statistically at par with the effect of the interaction of $AM_1 \times SeB_1 \times ZnO_1$.

In the present study it was observed that AM fungi profoundly affected the soil enzyme content. AMF treatment alone increased acidic phosphatase as well as alkaline phosphatase content of the soil. Similar findings confirming that the activity of soil acid phosphatase was positively increased by the application of AMF (170.54 %) was reported by Ndoye et al. (2015). Alkaline phosphatase content of the soil was reported to be significantly higher in +AMF treatment than in −AMF treatment (Peng et al. 2020).

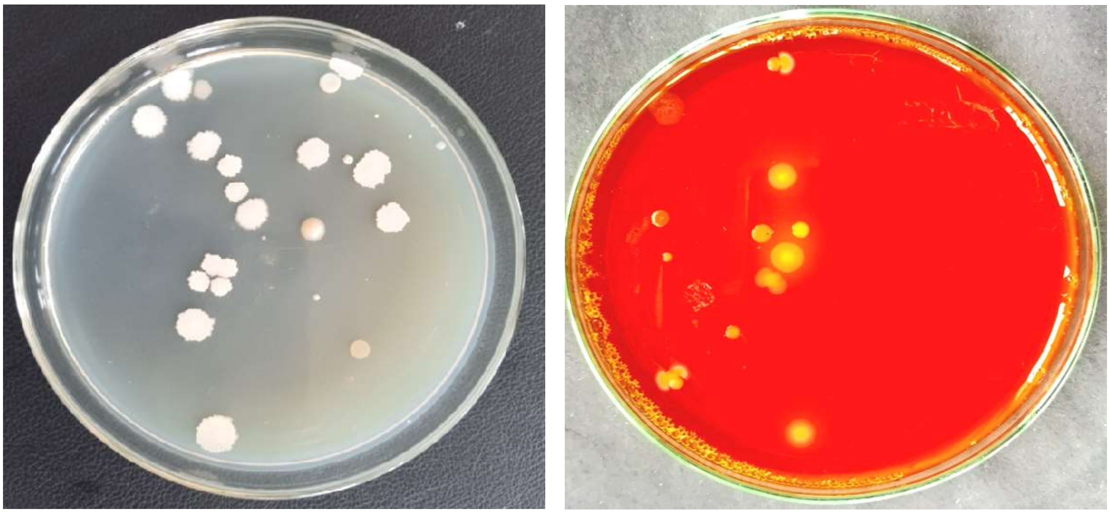
The presence of selenobacteria in the soil was found to have a significant impact on enzyme levels, resulting in an observed increase in enzyme content. The probable cause can be attributed to the secretion of extracellular phosphatase by the strain Stenotrophomonas maltophilia in order to dissolve insoluble phosphorus present in the soil. This process leads to the release of phosphorus, which is accompanied by the activation and subsequent release of Se, as reported by Lee et al. (2011).

Plate 2. Effect of nano zinc, AM fungi and selenobacteria on number of flowers and cumulative fruit number in strawberry



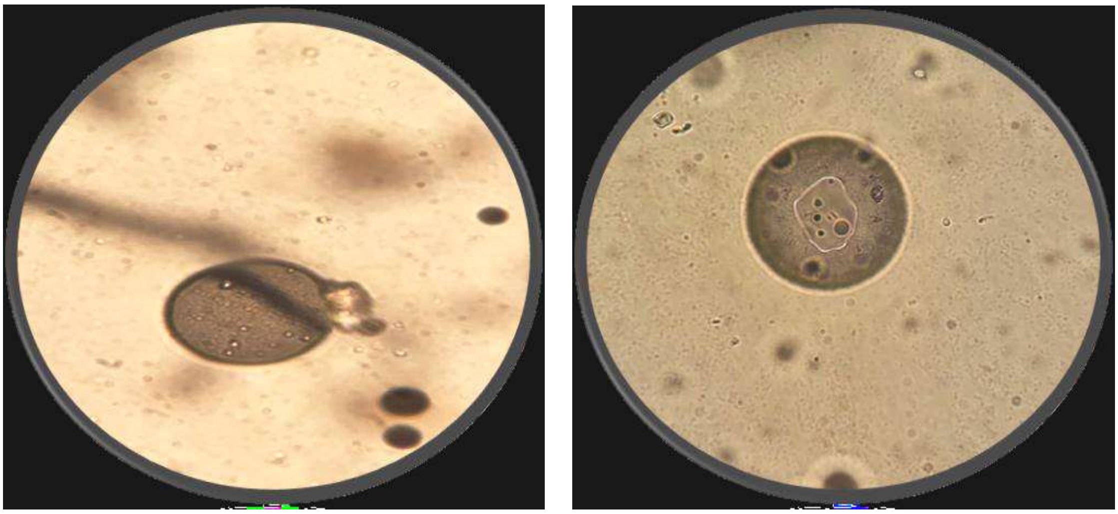
SeB$_1$: *Stenotrophomonas maltophilia* **SeB$_2$: *Alcaligenes faecalis***

(A) Selenobacterial strains in strawberry field



Total bacterial count **Phosphorus solubilizing bacteria**

(B) Total bacterial count and phosphorus solubilizing bacteria in strawberry field



AM spores

(C) AM spore in strawberry field

Plate 3. Microbiological properties in strawberry field

Chapter-5

SUMMARY AND CONCLUSION

The present study entitled "**Interactive effects of nano zinc, AM fungi and selenobacteria for selenium biofortification in strawberry (*Fragaria* × *ananassa* Duch.)**" was carried out in the experimental farm of Department of Fruit Science, Dr. Y S Parmar University of Horticulture and Forestry during two consecutive years between 2020 and 2021 under protected conditions. The results obtained during the course of study are briefly summarized and concluded as under:

5.1 Effects of nano zinc, AM fungi and selenobacteria on cropping behaviour

5.1.1 Vegetative growth parameters

The nano zinc, AM fungi and selenobacteria levels significantly impacted the plant vegetative growth parameters. Among AMF levels, the plants inoculated with AM spores (10 g/plant) showed significantly higher plant height (21.97 cm), maximum number of leaves (24.16), leaf area (76.70 cm^2), number of crowns per plant (6.52) and number of runners per plant (32.32). As per the effect of the selenobacteria, the plants inoculated with the strain *Stenotrophomonas maltophilia*, observed significantly higher plant height (21.90 cm), number of leaves (23.44), leaf area (75.20 cm^2), number of crowns per plant (6.10) and number of runners per plant (28.72). As far as the effect of foliar application of nano zinc oxide is concerned, the highest increase in plant height (22.15 cm) and number of runners per plant (28.69) were recorded with the nano zinc oxide applied @ 200 ppm while, number of leaves (23.80), leaf area (76.96 cm^2) and number of crowns per plant (6.15) were recorded with the nano zinc oxide applied @ 100 ppm.

The interaction of AM fungi × selenobacteria × nano zinc oxide application reveals that maximum height of plants (25.31 cm) and maximum number of runners per plant (36.75) were recorded in the interaction, $AM_1 \times SeB_1 \times ZnO_2$ i.e. plants rhizoinoculated with AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* and foliar application of nano zinc oxide @ 200 ppm. Whereas, the maximum number of leaves (26.76) and maximum leaf area (83.36 cm^2) were produced in the interaction, $AM_1 \times SeB_1 \times ZnO_1$ (AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* and foliar application of nano zinc oxide @ 100ppm).

5.1.2 Flowering traits

The presence of arbuscular mycorrhizal fungi in the rhizosphere significantly influenced the flowering traits of the rhizoinoculated plants. The study demonstrates that the treated plants exhibited a minimum time of 52.45 days for initial flowering, a maximum duration (144.64 days) of flowering and a maximum number of 34.14 flowers. The use of selenobacteria (*Stenotrophomonas maltophilia*) has led to the shortest days for initiation of flowering (53 days), the longest duration of flowering (143.62 days), and the highest number of flowers (32.25). The application of nano zinc oxide at a concentration of 100 ppm demonstrated significant reduction in the time taken for the first flowering event (50.95 days), an increase in the duration of flowering (146.48 days) and an increase in the number of flowers produced (32.05).

The study investigated the impact of the interaction, AM fungi × nano zinc oxide × selenobacteria on the flowering process. The results demonstrate that the interaction, $AM_1 \times SeB_1 \times ZnO_1$ i.e. plants treated with AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* and foliar application of nano zinc oxide @ 100ppm led to the shortest duration until the first flowering (50.29 days) and produced highest number of flowers (41.18).

5.2 Effects of nano zinc, AM fungi and selenobacteria on yield and fruit quality related traits

5.2.1 Yield Parameters

The study observed that the inoculation of arbuscular mycorrhizal (AM) fungi had significant impact on various parameters including maximum cumulative fruit number (27.91 per plant), fruit set (81.44%), fruit yield per plant (415.77 g), and yield efficiency (5.39 g/cm2 LA). The utilisation of selenobacterial strain *Stenotrophomonas maltophilia*, led to the attainment of optimal outcomes in terms of cumulative fruit number per plant (25.87 per plant), fruit set (79.29%), fruit yield per plant (389.75 g) and yield efficiency (5.08 g/cm^2 LA). With the foliar application of nano zinc oxide @ 100 ppm, the maximum cumulative fruit number (25.89 per plant), fruit set (80.12%), fruit yield per plant (389.38 g) and yield efficiency (5.01g/cm^2 LA) were recorded.

The interaction, $AM_1 \times SeB_1 \times ZnO_1$ i.e. rhizoinoculation of AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* and foliar application of nano zinc oxide @ 100ppm exhibited maximum cumulative fruit number (36.02 per plant), fruit yield per plant (611.18 g) and yield efficiency (7.34 g/cm^2 LA) in the strawberry plants.

5.2.2 Physical characteristics of fruits

The study observed that the mycorrhizal treatment, resulted in the maximum fruit length (36.20 mm), fruit breadth (29.92 mm), fruit weight (14.78 g) and maximum fruit firmness (10.54 lb/$inch^2$) in the strawberry fruits. Maximum fruit length (36.81 mm), fruit breadth (29.69 mm), fruit weight (14.66 g) and fruit firmness (10.27 lb/$inch^2$) were significantly higher with the application of selenobacteria (*Stenotrophomonas maltophilia*). Foliar application of nano zinc oxide @ 100 ppm, gave maximum length (35.57 mm), breadth (29.74 mm), weight (14.82 g) and firmness (10.52 lb/$inch^2$) of fruits.

The study concludes the synergistic effects of AM fungi, nano zinc oxide and selenobacteria on strawberry fruits and demonstrated that the interaction, $AM_1 \times SeB_1 \times ZnO_1$ (AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* and foliar application of nano zinc oxide @ 100ppm) led to the highest fruit breadth (32.27 mm), fruit weight (16.97 g) and fruit firmness (11.16 lb/$inch^2$) in strawberry fruits.

5.2.3 Biochemical characteristics of fruits

The study observed that the mycorrhizal treatment resulted in the highest levels of TSS (9.74 ˚Brix), maximum titratable acidity (0.71%), total sugar content (7.11%), ascorbic acid (63.10 mg/100g) and anthocyanin (43.67 mg/100 ml). The application of selenobacteria had a substantial impact on fruit biochemical parameters with maximum TSS (9.38 ˚Brix), titratable acidity (0.71%), total sugar (7.19%), ascorbic acid (62.49 mg/100g) and anthocyanin (43.17 mg/100 ml) observed in SeB_1 i.e. *Stenotrophomonas maltophilia*. Effect of foliar application of nano zinc oxide applied @ 100 ppm gave the maximum fruit TSS (9.79 ˚Brix) and total sugar (7.11 %) while nano zinc oxide @ 200 ppm recorded maximum fruit ascorbic acid (62.90 mg/100g) and maximum anthocyanin (43.22 mg/100 ml).

The interaction effect of all the three factors revealed that plants treated with the $AM_1 \times SeB_1 \times ZnO_1$ viz., AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* and foliar application of nano zinc oxide @ 100ppm produced strawberry fruits with maximum

TSS (10.46 °Brix), titratable acidity (0.77 %), total sugars (7.54 %) and anthocyanin content (45.29 mg/100 ml). However, the cumulative effect of AM_1 × SeB_1 × ZnO_2 (AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* and foliar application of nano zinc oxide @ 200ppm) exhibited maximum fruit ascorbic acid (64.07 mg/100g).

5.3 Effects of nano zinc, AM fungi and selenobacteria on leaf and fruit nutrient content

5.3.1 Leaf nutrient content

Maximum leaf nitrogen content (3.18%), phosphorus content (0.44%), potassium content (2.16%), iron content (150.05 ppm), copper content (7.09 ppm), zinc content (35.02 ppm), manganese content (30.23 ppm), and selenium content (1.45 g/100 g) were measured as a result of the effects of AM fungi inoculation in strawberry plants. The use of selenobacteria strain *Stenotrophomonas maltophilia*, resulted in the production of significantly higher leaf phosphorus content (0.36 %), zinc content (33.49 ppm), manganese content (28.02 ppm), and selenium content (1.55 g/100 g). Moreover, foliar application of nano zinc oxide at 200 ppm increased leaf zinc (37.17 ppm) and manganese (27.7 ppm) content.

The interaction, AM_1 × SeB_1 × ZnO_1 (AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* and foliar application of nano zinc oxide @ 100ppm) revealed maximum leaf phosphorus (0.46 %) and manganese content (31.04 ppm). However, the interaction of AM_1 × ZnO_2 i.e. AM fungi and foliar nano zinc oxide @ 200ppm, was helpful in improving the leaf zinc content (38.69 ppm).

5.3.2 Fruit nutrient content

Arbuscular mycorrhizal fungi played a crucial role in enhancing the phosphorus content (0.36%), as well as zinc (30.21 ppm) and selenium (0.67 µg/100 g) in fruits. The treatment of SeB_1 i.e. *Stenotrophomonas maltophilia* led to a significant increase in the phosphorus content (0.29%), zinc content (29.58 ppm) and selenium content (0.77 µg/g) of fruits compared to control plants. With the nano zinc oxide applied @ 200 ppm, the highest content of fruit zinc (31.65 ppm) was observed.

The interaction, AM_1 × SeB_1 × ZnO_2 (AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* and foliar application of nano zinc oxide @ 200ppm) exhibited maximum fruit zinc content (36.40 ppm). The interaction, $AM_1 \times SeB_1$ (AM fungi and selenobacterial strain *Stenotrophomonas maltophilia*) resulted in a notable increase in fruit phosphorus and selenium content, with a measured value of 0.37 % and 0.80 µg/g, respectively.

5.4 Effects of nano zinc, AM fungi and selenobacteria on soil properties

5.4.1 Chemical properties

The strawberry field's soil organic carbon level (0.61 %) and pH (6.76) both witnessed a significant increase due to AM fungi. It also recorded the highest levels of soil nitrogen (394.66 kg/ha), phosphorus (45.92 kg/ha) and potassium (356.75 kg/ha). As per the effect of the selenobacteria, the significantly higher soil phosphorus (43.80 kg/ha) and potassium (349.64 kg/ha) were observed with *Stenotrophomonas maltophilia*.

The maximum soil potassium (361.28 kg/ha) was recorded in the interaction, AM_1 x ZnO_2 (AM fungi and foliar application of nano zinc oxide @ 200ppm). However, the maximum soil phosphorus (47.28 kg/ha) was observed in the interaction, $AM_1 \times SeB_1 \times ZnO_0$ i.e. plants were treated with AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* while no foliar application of nano zinc oxide was given.

Considering the data, it was concluded that AMF inoculation resulted in maximum soil calcium [5.72 cmol (p^+) kg^{-1}], magnesium [2.07 cmol (p^+) kg^{-1}], iron (68.77 ppm), copper (9.85 ppm), zinc (16.82 ppm), manganese (55.93 ppm) and selenium (3.72 ppm). As per the effect of the selenobacteria, the significantly higher values of soil magnesium [1.92 cmol (p^+) kg^{-1}], iron (69.43 ppm), zinc (16.87 ppm) and selenium (4.34 ppm) were observed with the rhizoinoculation of *Stenotrophomonas maltophilia*.

The interaction, $AM_1 \times SeB_1 \times ZnO_1$ (AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* and foliar application of nano zinc oxide @ 100ppm) exhibited maximum zinc (18.27 ppm) and selenium (4.87 ppm) contents in strawberry growing soils.

5.4.2 Microbiological properties

The study observed the highest recorded counts of total bacterial count (64.51×10^5 cfu/g), selenobacteria (8.31×10^5 cfu/g), phosphorus solubilizing bacteria (6.05×10^5 cfu/g) and AM spores (542.24 per 50g soil) in the strawberry field, rhizoinoculated with AMF. The rhizoinoculation of *Stenotrophomonas maltophilia*, impacted the microbial count. It thereby, increased the total bacterial count, selenobacterial count, phosphorus solubilizing bacterial count and AM spores count with values of 64.56 $\times 10^5$ cfu/g, 11.73$\times 10^5$ cfu/g, 4.94$\times 10^5$ cfu/g, and 411.30 per 50g soil respectively.

The interaction, $AM_1 \times SeB_1 \times ZnO_1$ (AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* and foliar application of nano zinc oxide @ 100ppm) recorded a higher total bacterial count (70.44 $\times 10^5$ cfu/g), selenobacterial count (16.00 $\times 10^5$ cfu/g), phosphorus solubilizing bacterial count (7.22 $\times 10^5$ cfu/g) and AM spores count (644.07 per 50g soil) in strawberry field.

5.4.3 Soil enzymes

AM fungi had a significant impact on the amount of phosphatase enzyme in the soil; the highest levels of acid phosphatase enzyme (133.32 g pNPP/g/ha soil) and alkaline phosphatase enzyme (203.28 g pNPP/g/ha soil) were recorded. The use of *Stenotrophomonas maltophilia*, resulted in the production of maximum acid phosphatase enzyme (123.87 µg pNPP/g/ha soil) and alkaline phosphatase enzyme (177.31 µg pNPP/g/ha soil).

The interaction, $AM_1 \times SeB_1 \times ZnO_1$ (AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* and foliar application of nano zinc oxide @ 100ppm) exhibited maximum value of acid phosphatase enzyme (151.03 µg pNPP/g/ha soil) and alkaline phosphatase enzyme (222.55 µg pNPP/g/ha soil) in the strawberry field.

CONCLUSION

Based on the results, it can be concluded that foliar application of nano ZnO @ 100 ppm alongwith soil application of selenobacterial strain (*Stenotrophomonas maltophilia*) and AM fungi (10 g per plant) is the most effective treatment for improved vegetative growth, flowering, fruit yield and quality of strawberry grown under protected conditions. The treatment also had significant impact on the chemical and microbiological characteristics of the rhizosphere soil. The AM fungi and strain *Stenotrophomonas maltophilia* improved the bioavailability of soil selenium by increasing the activity of soil acid phosphatase and promoted the absorption ability of selenium by strawberry plants primarily by stimulating root activity. These findings offer a new perspective of the microbiological mechanism underlying the various types of selenium transformations in soil and open the way to the production of Se-rich horticultural products.

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Appendix I (a): Effect of nano zinc, AM fungi and selenobacteria on plant height (cm) in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	17.05	19.37	18.21	16.64	18.89	19.11	17.70	21.45	19.57	17.65	21.50	19.57
ZnO_1	19.39	21.66	20.53	19.82	21.44	20.32	21.18	22.47	21.82	21.15	23.18	21.14
ZnO_2	20.39	23.32	21.86	21.83	23.02	20.72	21.31	23.55	22.43	22.15	23.39	21.75
Mean	18.95	21.45		19.43	21.12	20.05	20.06	22.49		20.32	22.69	20.82
$CD_{0.05}$							$CD_{0.05}$					
AM 0.38 SeB 0.47 ZnO 0.47			AM × ZnO NS SeB× ZnO 0.81				AM 0.31 SeB 0.38 ZnO 0.38		AM × ZnO 0.53 SeB× ZnO 0.65			

Appendix I (b): Interactive effects of nano zinc, AM fungi and selenobacteria on plant height (cm) in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	15.82	16.63	18.70	17.45	21.15	19.52	15.60	18.70	18.80	19.70	24.30	20.34
ZnO_1	18.67	19.78	19.72	20.97	23.11	20.91	20.66	21.70	21.18	21.64	24.66	21.10
ZnO_2	20.18	20.71	20.30	23.48	25.33	21.15	21.10	21.49	21.34	23.20	25.30	22.16
Mean	18.22	19.04	19.57	20.63	23.20	20.52	19.12	20.63	20.44	21.51	24.75	21.20
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB 0.66				AM × SeB× ZnO NS			AM × SeB 0.53		AM × SeB× ZnO NS			

Appendix II (a): Effect of nano zinc, AM fungi and selenobacteria on number of leaves in strawberry plant

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	17.80	21.67	19.74	19.82	20.45	18.95	19.63	23.66	21.64	22.27	22.18	20.48
ZnO$_1$	20.82	24.25	22.54	22.21	23.30	22.11	23.70	26.43	25.06	25.49	26.31	23.39
ZnO$_2$	21.46	24.04	22.75	22.12	23.28	22.85	24.36	24.92	24.64	24.49	25.15	24.29
Mean	20.03	23.32		21.38	22.34	21.30	22.56	25.00		24.08	24.55	22.72
CD$_{0.05}$							CD$_{0.05}$					
AM SeB ZnO	0.49 0.60 0.60	AM × ZnO SeB× ZnO			NS NS		AM 0.39 SeB 0.47 ZnO 0.47		AM × ZnO 0.67 SeB× ZnO 0.82			

Appendix II (b): Interactive effects of nano zinc, AM fungi and selenobacteria on number of leaves in strawberry plant

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	18.29	17.89	17.23	21.35	23.00	20.67	19.83	19.97	19.09	24.71	24.39	21.87
ZnO$_1$	19.91	21.33	21.22	24.50	25.26	23.00	23.36	24.36	23.37	27.62	28.25	23.41
ZnO$_2$	20.04	22.00	22.34	24.20	24.55	23.36	22.10	25.07	25.91	26.87	25.23	22.67
Mean	19.41	20.41	20.26	23.35	24.27	22.34	21.76	23.14	22.79	26.40	25.96	22.65
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB 0.85				AM × SeB× ZnO NS			AM × SeB 0.67			AM × SeB× ZnO 1.16		

Appendix III (a): Effect of nano zinc, AM fungi and selenobacteria on leaf area (cm^2) in strawberry plant

2020-21							2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	63.79	73.88	68.84	67.19	68.48	70.83	64.30	74.60	69.45	67.88	68.92	71.55
ZnO$_1$	73.86	79.35	76.60	76.58	78.33	74.89	74.58	80.08	77.33	77.30	79.06	75.62
ZnO$_2$	75.23	75.93	75.58	75.28	77.83	73.63	75.95	76.39	76.17	76.00	78.56	73.96
Mean	70.96	76.39		73.02	74.88	73.12	71.61	77.02		73.73	75.51	73.71
CD$_{0.05}$							CD$_{0.05}$					
AM 0.65 SeB 0.79 ZnO 0.79			AM × ZnO 1.12 SeB× ZnO 1.37				AM 1.00 SeB 1.22 ZnO 1.22		AM × ZnO 1.73 SeB× ZnO 2.12			

Appendix III (b): Interactive effects of nano zinc, AM fungi and selenobacteria on leaf area (cm^2) in strawberry plant

2020-21							2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	60.31	63.07	68.00	74.07	73.90	73.67	60.98	63.21	68.72	74.79	74.62	74.39
ZnO$_1$	73.33	73.67	74.57	79.83	83.00	75.21	74.05	74.39	75.28	80.55	83.72	75.96
ZnO$_2$	75.10	75.33	75.27	75.47	80.33	72.00	75.82	76.06	75.99	76.19	81.05	71.94
Mean	69.58	70.69	72.61	76.46	79.08	73.62	70.28	71.22	73.33	77.18	79.80	74.10
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB 1.12				AM × SeB× ZnO 1.94			AM × SeB 1.73			AM × SeB× ZnO NS		

Appendix IV (a): Effect of nano zinc, AM fungi and selenobacteria on number of crowns in strawberry plant

2020-21							2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.34	6.13	5.24	5.23	5.38	5.10	4.32	6.31	5.32	5.24	5.65	5.07
ZnO_1	5.56	6.91	6.24	6.16	6.50	6.05	5.38	6.72	6.05	6.01	6.22	5.93
ZnO_2	5.49	6.60	6.05	6.35	6.49	5.31	5.62	6.46	6.04	6.25	6.38	5.50
Mean	5.13	6.55		5.91	6.13	5.49	5.11	6.50		5.83	6.08	5.50
$CD_{0.05}$							$CD_{0.05}$					
AM	0.36		AM × ZnO		NS		AM 0.36		AM × ZnO 0.62			
SeB	0.44		SeB× ZnO		NS		SeB 0.44		SeB× ZnO NS			
ZnO	0.44						ZnO 0.44					

Appendix IV (b): Interactive effects of nano zinc, AM fungi and selenobacteria on number of crowns in strawberry plant

2020-21							2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.17	4.67	4.19	6.29	6.09	6.01	4.10	4.66	4.21	6.38	6.64	5.92
ZnO_1	5.65	5.80	5.24	6.66	7.20	6.87	5.55	5.37	5.23	6.47	7.07	6.63
ZnO_2	5.69	5.84	4.96	7.01	7.15	5.66	5.65	5.96	5.25	6.85	6.79	5.74
Mean	5.17	5.44	4.80	6.65	6.81	6.18	5.10	5.33	4.90	6.57	6.83	6.10
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB	NS		AM × SeB× ZnO		NS		AM × SeB		AM × SeB× ZnO		NS	

Appendix V (a): Effect of nano zinc, AM fungi and selenobacteria on number of runners in strawberry plant

2020-21							**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	18.00	30.32	24.16	21.59	24.54	26.35	19.58	30.65	25.11	24.57	25.93	24.85
ZnO_1	22.37	31.63	27.00	24.47	28.48	28.06	27.99	34.96	31.48	29.58	33.70	31.16
ZnO_2	22.02	33.75	27.88	25.90	30.02	27.73	27.33	33.33	30.33	29.09	32.00	29.89
Mean	20.80	31.90		23.99	27.68	27.38	24.97	32.98		27.74	30.54	28.63
$CD_{0.05}$							$CD_{0.05}$					
AM SeB ZnO	0.63 0.77 0.77	AM × ZnO SeB× ZnO			1.09 1.34		AM SeB ZnO	0.97 1.19 1.19	AM × ZnO SeB× ZnO	1.68 NS		

Appendix V (b): Interactive effects of nano zinc, AM fungi and selenobacteria on number of runners in strawberry plant

2020-21							**2021-22**					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	16.85	18.78	18.37	26.33	30.29	34.33	18.50	20.59	19.67	30.63	31.27	30.04
ZnO_1	22.17	22.71	22.24	26.77	34.24	33.87	27.15	28.33	28.50	32.00	39.07	33.81
ZnO_2	22.69	23.04	20.33	29.11	37.00	35.13	25.92	27.50	28.57	32.26	36.50	31.22
Mean	20.57	21.51	20.31	27.40	33.84	34.45	23.86	25.47	25.58	31.63	35.61	31.69
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB	1.09		AM × SeB× ZnO	1.89			AM × SeB	1.68		AM × SeB× ZnO	NS	

Appendix VI (a): Effect of nano zinc, AM fungi and selenobacteria on days taken to first flowering in strawberry

2020-21							2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	58.44	55.53	56.99	58.33	55.72	56.92	58.28	55.60	56.94	58.50	55.29	57.04
ZnO$_1$	53.89	49.92	51.90	51.31	50.72	53.68	51.32	48.68	50.00	49.08	49.87	51.06
ZnO$_2$	55.75	52.35	54.05	52.82	53.69	55.65	54.42	52.59	53.51	52.08	52.72	55.72
Mean	56.03	52.60		54.15	53.37	55.42	54.67	52.29		53.22	52.62	54.61
CD$_{0.05}$							CD$_{0.05}$					
AM 0.71 SeB 0.87 ZnO 0.87			AM × ZnO NS SeB× ZnO 1.50				AM 0.73 SeB 0.89 ZnO 0.89		AM × ZnO NS SeB× ZnO 1.54			

Appendix VI (b): Interactive effects of nano zinc, AM fungi and selenobacteria on days taken to first flowering in strawberry

2020-21							2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	59.01	57.26	59.06	57.65	54.17	54.78	58.94	55.09	60.81	58.06	55.48	53.26
ZnO$_1$	53.14	54.32	54.21	49.47	47.12	53.16	50.53	52.73	50.70	47.62	47.00	51.42
ZnO$_2$	55.50	55.92	55.83	50.15	51.45	55.46	53.48	54.77	55.00	50.67	50.66	56.45
Mean	55.88	55.83	56.37	52.42	50.91	54.47	54.32	54.20	55.50	52.12	51.05	53.71
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB 1.50			AM × SeB× ZnO 2.12				AM × SeB NS		AM × SeB× ZnO 2.18			

Appendix VII (a): Effect of nano zinc, AM fungi and selenobacteria on duration of flowering (days) in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	131.63	141.85	136.74	135.10	138.25	136.88	131.88	142.59	137.23	134.70	140.21	136.79
ZnO_1	141.13	144.92	143.02	141.85	144.36	142.87	143.63	148.04	145.83	144.56	148.89	144.05
ZnO_2	139.91	143.14	141.53	140.15	142.78	141.65	143.95	147.29	145.62	144.64	147.23	144.99
Mean	137.56	143.30		139.03	141.79	140.47	139.82	145.97		141.30	145.44	141.94
$CD_{0.05}$							$CD_{0.05}$					
AM 1.41 SeB 1.72 ZnO 1.72			AM × ZnO 2.43 SeB× ZnO NS				AM 2.06 SeB 2.52 ZnO 2.52		AM × ZnO 3.56 SeB× ZnO NS			

Appendix VII (b): Interactive effects of nano zinc, AM fungi and selenobacteria duration of flowering (days) in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	130.42	131.60	132.88	139.77	144.89	140.89	130.64	133.42	131.58	138.77	147.00	142.00
ZnO_1	139.88	141.58	141.92	143.82	147.13	143.81	141.69	145.98	143.22	147.44	151.79	144.88
ZnO_2	138.14	140.22	141.38	142.16	145.33	141.92	140.58	144.83	146.45	148.70	149.63	143.53
Mean	136.15	137.80	138.73	141.92	145.78	142.21	137.63	141.41	140.42	144.97	149.47	143.47
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB 2.43			AM × SeB× ZnO NS				AM × SeB NS		AM × SeB× ZnO NS			

Appendix VIII (a): Effect of nano zinc, AM fungi and selenobacteria on number of flowers per plant in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria			AM Fungi		Mean	Selenobacteria		
	AM_0	AM_1		SeB_0	SeB_1	SeB_2	AM_0	AM_1		SeB_0	SeB_1	SeB_2
ZnO_0	21.74	32.45	27.10	24.43	28.97	27.90	22.09	33.77	27.93	26.54	29.98	27.27
ZnO_1	27.57	34.98	31.28	29.98	34.29	29.56	28.83	36.83	32.83	32.41	35.67	30.41
ZnO_2	26.37	32.55	29.46	28.58	31.84	27.96	27.72	34.25	30.99	31.32	32.77	28.87
Mean	25.23	33.33		27.66	31.70	28.47	26.21	34.95		30.09	32.81	28.85
$CD_{0.05}$							$CD_{0.05}$					
AM	0.48		AM × ZnO	0.83			AM	0.52	AM × ZnO	0.89		
SeB	0.58		SeB× ZnO	1.01			SeB	0.63	SeB× ZnO	1.09		
ZnO	0.58						ZnO	0.63				

Appendix VIII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on number of flowers per plant in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	AM_0			AM_1			AM_0			AM_1		
	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2
ZnO_0	19.80	23.30	22.13	29.06	34.63	33.66	20.86	23.30	22.10	32.22	36.66	32.43
ZnO_1	28.07	28.44	26.20	31.89	40.14	32.92	30.48	29.12	26.89	34.34	42.22	33.92
ZnO_2	27.04	26.95	25.11	30.12	36.72	30.81	29.87	27.33	25.98	32.78	38.21	31.77
Mean	24.97	26.23	24.48	30.36	37.16	32.46	27.07	26.58	24.99	33.11	39.03	32.71
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB	0.83		AM × SeB× ZnO	1.43			AM × SeB	0.89	AM × SeB× ZnO	1.55		

Appendix IX (a): Effect of nano zinc, AM fungi and selenobacteria on cumulative fruit number in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	14.60	25.94	20.27	17.99	22.06	20.76	15.42	27.30	21.36	19.69	23.72	20.67
ZnO_1	21.22	29.31	25.26	24.72	28.31	22.76	21.87	31.02	26.45	25.84	29.86	23.65
ZnO_2	19.25	25.72	22.49	21.38	25.03	21.06	20.27	27.83	24.05	23.71	26.25	22.19
Mean	18.36	26.99		21.36	25.13	21.53	19.19	28.72		23.08	26.61	22.17
$CD_{0.05}$							$CD_{0.05}$					
AM 0.74 SeB 0.90 ZnO 0.90			AM × ZnO 1.27 SeB× ZnO 1.56				AM 0.76 SeB 0.93 ZnO 0.93		AM × ZnO 1.32 SeB× ZnO 1.62			

Appendix IX (b): Interactive effects of nano zinc, AM fungi and selenobacteria on cumulative fruit number in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	12.38	16.12	15.30	23.59	28.00	26.22	13.15	17.77	15.33	26.23	29.68	26.00
ZnO_1	22.67	21.68	19.30	26.77	34.93	26.22	23.23	22.60	19.78	28.44	37.11	27.52
ZnO_2	20.11	19.66	18.00	22.65	30.40	24.12	21.30	20.74	18.78	26.12	31.76	25.60
Mean	18.39	19.15	17.53	24.34	31.11	25.52	19.23	20.37	17.96	26.93	32.85	26.37
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB 1.27			AM × SeB× ZnO 2.21				AM × SeB 1.32		AM × SeB× ZnO 2.29			

Appendix X (a): Effect of nano zinc, AM fungi and selenobacteria on fruit set (%) in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	67.01	79.72	73.36	71.52	75.02	73.55	69.62	80.90	75.26	72.32	78.64	74.82
ZnO$_1$	76.13	83.56	79.85	81.21	81.67	76.66	75.84	83.97	79.90	79.58	82.78	77.34
ZnO$_2$	73.03	80.98	77.01	78.13	77.91	74.98	73.21	81.14	77.18	75.57	79.50	76.47
Mean	72.06	81.42		76.95	78.20	75.06	72.89	82.00		75.82	80.31	76.21
CD$_{0.05}$							CD$_{0.05}$					
AM 1.46 SeB 1.79 ZnO 1.79	AM × ZnO 2.54 SeB× ZnO 3.10						AM 1.62 SeB 1.99 ZnO 1.99		AM × ZnO NS SeB× ZnO NS			

Appendix X (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit set (%) in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	62.71	69.19	69.13	80.32	80.85	77.98	63.15	76.28	69.43	81.50	81.00	80.21
ZnO$_1$	78.38	76.34	73.66	84.03	87.00	79.66	76.27	77.67	73.56	82.89	87.89	81.12
ZnO$_2$	74.42	72.97	71.70	81.84	82.85	78.25	71.45	75.88	72.30	79.68	83.12	80.63
Mean	71.84	72.84	71.50	82.06	83.57	78.63	70.29	76.61	71.77	81.36	84.00	80.65
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB NS			AM × SeB× ZnO NS				AM × SeB NS		AM × SeB× ZnO 4.87			

Appendix XI (a): Effect of nano zinc, AM fungi and selenobacteria on fruit yield (g/plot) of strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	163.10	351.02	257.06	215.24	282.74	273.20	181.17	387.41	284.29	244.20	336.91	271.77
ZnO_1	285.88	451.35	368.61	357.99	443.22	304.64	314.51	505.80	410.16	403.53	490.71	336.22
ZnO_2	244.53	373.15	308.84	287.57	375.73	263.21	273.94	425.87	349.90	339.73	409.17	300.81
Mean	231.17	391.84		286.93	367.23	280.35	256.54	439.69		329.15	412.27	302.93
$CD_{0.05}$							$CD_{0.05}$					
AM 11.17 SeB 13.68 ZnO 13.68			AM × ZnO 19,34 SeB× ZnO 23.69				AM 13.05 SeB 15.98 ZnO 15.98		AM × ZnO 22.60 SeB× ZnO 27.68			

Appendix XI (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit yield (g/plot) of strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	124.50	182.60	182.22	305.99	382.89	364.19	133.13	218.94	191.45	355.27	454.89	352.08
ZnO_1	297.26	306.92	253.46	418.71	579.51	355.81	335.68	338.58	269.27	471.38	642.84	403.18
ZnO_2	241.95	274.41	217.24	333.19	477.06	309.19	278.72	290.10	252.99	400.74	528.24	348.62
Mean	221.24	254.64	217.64	352.63	479.82	343.06	249.18	282.54	237.90	409.13	541.99	367.96
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB 19.34			AM × SeB× ZnO 33.50				AM × SeB 22.60		AM × SeB× ZnO 39.14			

Appendix XII (a): Effect of nano zinc, AM fungi and selenobacteria on yield efficiency (g/cm^2 LA) in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	2.55	4.75	3.65	3.10	4.04	3.81	2.81	5.20	4.00	3.47	4.78	3.76
ZnO_1	3.88	5.65	4.77	4.65	5.58	4.07	4.22	6.28	5.25	5.19	6.12	4.44
ZnO_2	3.25	4.88	4.07	3.82	4.79	3.59	3.61	5.54	4.57	4.47	5.17	4.09
Mean	3.23	5.10		3.86	4.80	3.83	3.55	5.67		4.38	5.36	4.10
$CD_{0.05}$							$CD_{0.05}$					
AM SeB ZnO	0.16 0.20 0.20		AM × ZnO SeB× ZnO			0.28 0.35	AM SeB ZnO	0.18 0.22 0.22	AM × ZnO SeB× ZnO	NS 0.37		

Appendix XII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on yield efficiency (g/cm^2 LA) in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	2.06	2.90	2.68	4.13	5.18	4.95	2.19	3.46	2.79	4.75	6.10	4.74
ZnO_1	4.06	4.17	3.40	5.25	6.98	4.73	4.53	4.56	3.58	5.86	7.69	5.31
ZnO_2	3.22	3.64	2.89	4.41	5.94	4.30	3.67	3.82	3.33	5.26	6.51	4.84
Mean	3.11	3.57	2.99	4.60	6.03	4.66	3.46	3.95	3.23	5.29	6.77	4.96
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB	0.28		AM × SeB× ZnO		0.49		AM × SeB	0.30	AM × SeB× ZnO	0.53		

Appendix XIII (a): Effect of nano zinc, AM fungi and selenobacteria on fruit length (mm) in strawberry

2020-21							2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	30.35	35.28	32.81	32.08	33.69	32.68	33.74	37.66	35.70	33.25	39.71	34.16
ZnO_1	33.12	37.28	35.20	34.22	37.52	33.86	34.92	36.97	35.95	36.21	38.29	33.34
ZnO_2	32.43	35.47	33.95	33.05	35.75	33.05	34.33	34.53	34.43	34.48	35.88	32.92
Mean	31.96	36.01		33.12	35.65	33.19	34.33	36.39		34.64	37.96	33.47
$CD_{0.05}$							$CD_{0.05}$					
AM 0.50 SeB 0.62 ZnO 0.62			AM × ZnO 0.87 SeB× ZnO 1.07				AM 0.53 SeB 0.65 ZnO 0.65		AM × ZnO 0.91 SeB× ZnO 1,12			

Appendix XIII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit length (mm) in strawberry

2020-21							2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	29.02	30.77	31.25	35.13	36.60	34.10	29.77	37.80	33.65	36.72	41.61	34.66
ZnO_1	32.10	35.14	32.12	36.34	39.90	35.60	34.22	36.80	33.74	38.20	39.78	32.93
ZnO_2	31.33	33.40	32.55	34.77	38.10	33.55	34.23	34.92	33.82	34.72	36.84	32.02
Mean	30.82	33.10	31.97	35.41	38.20	34.42	32.74	36.51	33.74	36.55	39.41	33.20
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB 0.87				AM × SeB× ZnO NS			AM × SeB NS			AM × SeB× ZnO NS		

Appendix XIV (a): Effect of nano zinc, AM fungi and selenobacteria on fruit breadth (mm) in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	26.08	28.84	27.46	27.07	27.90	27.41	27.31	30.56	28.93	28.61	29.34	28.85
ZnO$_1$	28.15	30.32	29.24	29.16	30.23	28.33	29.52	30.98	30.25	30.39	31.16	29.20
ZnO$_2$	27.35	28.79	28.07	27.62	28.88	27.72	29.17	30.03	29.60	29.60	30.65	28.54
Mean	27.19	29.32		27.95	29.00	27.82	28.67	30.52		29.54	30.38	28.86
CD$_{0.05}$							CD$_{0.05}$					
AM 0.29 SeB 0.35 ZnO 0.35			AM × ZnO 0.50 SeB× ZnO 0.61				AM 0.48 SeB 0.59 ZnO 0.59		AM × ZnO 0.84 SeB× ZnO NS			

Appendix XIV (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit breadth (mm) in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	25.04	26.60	26.60	29.10	29.20	28.22	25.58	28.13	28.21	31.64	30.55	29.49
ZnO$_1$	28.11	28.23	28.11	30.20	32.22	28.55	29.17	30.00	29.39	31.61	32.32	29.00
ZnO$_2$	27.06	27.55	27.44	28.17	30.20	28.00	29.90	29.44	28.17	29.30	31.87	28.91
Mean	26.74	27.46	27.38	29.16	30.54	28.26	28.22	29.19	28.59	30.85	31.58	29.13
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB 0.50				AM × SeB× ZnO 0.86			AM × SeB 0.84			AM × SeB× ZnO 1.45		

Appendix XV (a): Effect of nano zinc, AM fungi and selenobacteria on fruit weight (g) of strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	11.09	13.51	12.30	11.50	12.49	12.90	11.63	14.13	12.88	11.83	13.82	13.01
ZnO_1	13.47	15.27	14.37	14.38	15.39	13.35	14.35	16.17	15.26	15.50	16.15	14.13
ZnO_2	12.69	14.41	13.55	13.38	14.82	12.45	13.51	15.21	14.36	14.20	15.31	13.55
Mean	12.42	14.39		13.08	14.23	12.90	13.16	15.17		13.84	15.09	13.56
$CD_{0.05}$							$CD_{0.05}$					
AM 0.18 SeB 0.21 ZnO 0.21			AM × ZnO 0.30 SeB× ZnO 0.37				AM 0.22 SeB 0.27 ZnO 0.27		AM × ZnO 0.39 SeB× ZnO 0.47			

Appendix XV (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit weight (g) of strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	10.04	11.31	11.92	12.96	13.67	13.89	10.12	12.30	12.47	13.53	15.33	13.54
ZnO_1	13.11	14.18	13.13	15.64	16.60	13.57	14.43	14.98	13.63	16.56	17.33	14.63
ZnO_2	12.03	13.96	12.07	14.72	15.68	12.82	13.06	13.99	13.47	15.35	16.63	13.64
Mean	11.73	13.15	12.37	14.44	15.31	13.43	12.54	13.76	13.19	15.15	16.43	13.93
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB 0.30				AM × SeB× ZnO 0.53			AM × SeB 0.39		AM × SeB× ZnO NS			

Appendix XVI (a): Effect of nano zinc, AM fungi and selenobacteria on fruit firmness (lb/inch^2) in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	8.55	9.88	9.22	8.88	9.33	9.44	9.25	10.81	10.03	9.56	10.21	10.32
ZnO_1	9.81	10.47	10.14	10.10	10.32	10.01	10.65	11.14	10.90	10.87	11.02	10.81
ZnO_2	9.62	10.11	9.86	9.72	9.99	9.88	10.52	10.82	10.67	10.50	10.77	10.74
Mean	9.33	10.16		9.57	9.88	9.78	10.14	10.92		10.31	10.66	10.62
$CD_{0.05}$							**$CD_{0.05}$**					
AM 0.11 SeB 0.13 ZnO 0.13			AM × ZnO 0.19 SeB× ZnO 0.23				AM 0.13 SeB 0.16 ZnO 0.16		AM × ZnO 0.23 SeB× ZnO 0.28			

Appendix XVI (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit firmness (lb/inch^2) in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	7.89	8.77	8.99	9.87	9.89	9.89	8.22	9.60	9.92	10.89	10.82	10.72
ZnO_1	9.87	9.78	9.78	10.32	10.87	10.23	10.71	10.59	10.65	11.02	11.44	10.96
ZnO_2	9.44	9.87	9.55	10.01	10.11	10.21	10.32	10.70	10.54	10.68	10.84	10.94
Mean	9.06	9.47	9.44	10.07	10.29	10.11	9.75	10.30	10.37	10.86	11.03	10.87
$CD_{0.05}$							**$CD_{0.05}$**					
AM × SeB NS			AM × SeB× ZnO 0.33				AM × SeB 0.23			AM × SeB× ZnO 0.40		

Appendix XVII (a): Effect of nano zinc, AM fungi and selenobacteria on fruit shape index in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	1.16	1.22	1.19	1.19	1.21	1.19	1.23	1.23	1.23	1.16	1.35	1.19
ZnO$_1$	1.18	1.23	1.20	1.17	1.24	1.20	1.18	1.19	1.19	1.19	1.23	1.14
ZnO$_2$	1.19	1.23	1.21	1.20	1.24	1.19	1.18	1.15	1.16	1.17	1.17	1.16
Mean	1.18	1.23		1.18	1.23	1.19	1.20	1.19		1.17	1.25	1.16
CD$_{0.05}$							CD$_{0.05}$					
AM 0.02 SeB 0.03 ZnO 0.03			AM × ZnO NS SeB× ZnO NS				AM NS SeB 0.03 ZnO 0.03		AM × ZnO NS SeB× ZnO 0.05			

Appendix XVII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit shape index in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	1.16	1.16	1.17	1.21	1.25	1.21	1.16	1.34	1.19	1.16	1.36	1.18
ZnO$_1$	1.14	1.25	1.14	1.20	1.24	1.25	1.17	1.23	1.15	1.21	1.23	1.13
ZnO$_2$	1.16	1.21	1.19	1.24	1.26	1.20	1.15	1.19	1.20	1.18	1.16	1.11
Mean	1.15	1.21	1.17	1.22	1.25	1.22	1.16	1.25	1.18	1.18	1.25	1.14
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB NS				AM × SeB× ZnO NS			AM × SeB NS			AM × SeB× ZnO NS		

Appendix XVIII (a): Effect of nano zinc, AM fungi and selenobacteria on fruit TSS (ºB) of strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	7.61	9.10	8.36	8.07	8.56	8.45	7.73	8.97	8.35	7.96	8.80	8.30
ZnO$_1$	9.21	10.17	9.69	9.85	9.81	9.41	9.50	10.28	9.89	10.05	9.98	9.64
ZnO$_2$	9.15	9.87	9.51	9.70	9.55	9.27	9.25	10.02	9.64	9.78	9.60	9.53
Mean	8.66	9.71		9.21	9.30	9.04	8.83	9.76		9.26	9.46	9.16
CD$_{0.05}$							CD$_{0.05}$					
AM	0.14		AM × ZnO			0.24	AM 0.12		AM × ZnO 0.20			
SeB	0.17		SeB× ZnO			0.30	SeB 0.14		SeB× ZnO 0.25			
ZnO	0.17						ZnO 0.14					

Appendix XVIII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit TSS (ºB) of strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	7.13	7.90	7.80	9.00	9.21	9.10	6.92	8.10	8.18	9.00	9.50	8.42
ZnO$_1$	9.20	9.20	9.23	10.50	10.42	9.60	9.71	9.45	9.34	10.39	10.51	9.94
ZnO$_2$	9.20	9.10	9.14	10.20	10.00	9.40	9.46	9.10	9.20	10.09	10.10	9.86
Mean	8.51	8.73	8.72	9.90	9.88	9.37	8.70	8.88	8.91	9.83	10.04	9.41
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB	0.24			AM × SeB× ZnO	NS		AM × SeB 0.20		AM × SeB× ZnO 0.35			

Appendix XIX (a): Effect of nano zinc, AM fungi and selenobacteria on fruit titrable acidity (%) of strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.76	0.74	0.75	0.75	0.75	0.75	0.77	0.72	0.75	0.75	0.74	0.75
ZnO_1	0.68	0.62	0.65	0.63	0.63	0.70	0.68	0.63	0.65	0.63	0.63	0.69
ZnO_2	0.69	0.64	0.67	0.65	0.65	0.70	0.69	0.64	0.66	0.63	0.66	0.70
Mean	0.71	0.67		0.67	0.68	0.72	0.71	0.66		0.67	0.68	0.71
$CD_{0.05}$							$CD_{0.05}$					
AM	0.01	AM × ZnO	0.02				AM	0.01	AM × ZnO	NS		
SeB	0.01	SeB× ZnO	0.02				SeB	0.01	SeB× ZnO	0.02		
ZnO	0.01						ZnO	0.01				

Appendix XIX (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit titrable acidity (%) of strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.77	0.75	0.76	0.72	0.75	0.73	0.77	0.75	0.77	0.72	0.73	0.72
ZnO_1	0.66	0.68	0.69	0.59	0.57	0.71	0.67	0.68	0.68	0.60	0.58	0.70
ZnO_2	0.68	0.69	0.71	0.61	0.61	0.69	0.66	0.70	0.70	0.60	0.61	0.70
Mean	0.70	0.71	0.72	0.64	0.65	0.71	0.70	0.71	0.72	0.64	0.64	0.71
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB	0.02		AM × SeB× ZnO	0.03			AM × SeB	0.01	AM × SeB× ZnO	0.02		

Appendix XX (a): Effect of nano zinc, AM fungi and selenobacteria on fruit TSS/acidity in strawberry

2020-21							**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	10.02	12.42	11.22	10.89	11.41	11.37	10.13	12.41	11.27	10.74	11.91	11.15
ZnO_1	13.63	16.53	15.08	15.87	15.91	13.46	14.05	16.56	15.30	15.92	16.02	13.98
ZnO_2	13.21	15.58	14.39	15.13	14.80	13.26	13.49	15.83	14.66	15.58	14.78	13.62
Mean	12.29	14.85		13.96	14.04	12.69	12.56	14.93		14.08	14.24	12.91
$CD_{0.05}$							$CD_{0.05}$					
AM 0.27 SeB 0.33 ZnO 0.33		AM × ZnO NS SeB× ZnO 0.56					AM 0.27 SeB 0.34 ZnO 0.34		AM × ZnO NS SeB× ZnO 0.58			

Appendix XX (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit TSS/acidity in strawberry

2020-21							**2021-22**					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	9.27	10.53	10.27	12.51	12.28	12.46	8.98	10.80	10.60	12.50	13.02	11.70
ZnO_1	13.95	13.54	13.39	17.80	18.28	13.52	14.50	13.91	13.74	17.34	18.13	14.21
ZnO_2	13.53	13.20	12.89	16.72	16.40	13.63	14.33	13.00	13.14	16.83	16.56	14.10
Mean	12.25	12.42	12.18	15.68	15.65	13.20	12.60	12.57	12.49	15.55	15.90	13.33
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB 0.46			AM × SeB× ZnO 0.80				AM × SeB 0.48		AM × SeB× ZnO 0.82			

Appendix XXI (a): Effect of nano zinc, AM fungi and selenobacteria on fruit total sugar (%) in strawberry

2020-21							2021-22					
Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria			AM Fungi		Mean	Selenobacteria		
	AM_0	AM_1		SeB_0	SeB_1	SeB_2	AM_0	AM_1		SeB_0	SeB_1	SeB_2
ZnO_0	6.45	7.07	6.76	6.58	6.94	6.77	6.78	7.33	7.06	7.01	7.53	6.62
ZnO_1	6.98	7.14	7.06	7.02	7.08	7.08	7.01	7.20	7.11	7.16	7.55	6.62
ZnO_2	6.80	7.26	7.03	6.91	7.29	6.90	6.87	6.65	6.76	6.92	6.75	6.60
Mean	6.75	7.16		6.84	7.10	6.92	6.89	7.06		7.03	7.27	6.62
$CD_{0.05}$							$CD_{0.05}$					
AM 0.11 SeB 0.13 ZnO 0.13			AM × ZnO 0.18 SeB× ZnO NS				AM 0.11 SeB 0.13 ZnO 0.13		AM × ZnO 0.19 SeB× ZnO 0.23			

Appendix XXI (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit total sugar (%) in strawberry

2020-21							2021-22					
Nano Zinc Oxide	AM_0			AM_1			AM_0			AM_1		
	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2
ZnO_0	6.15	6.71	6.50	7.01	7.17	7.04	6.30	7.15	6.89	7.72	7.91	6.35
ZnO_1	6.96	7.00	6.99	7.09	7.16	7.18	7.01	7.26	6.77	7.30	7.83	6.48
ZnO_2	6.81	6.92	6.67	7.00	7.66	7.13	6.88	6.71	7.01	6.96	6.78	6.20
Mean	6.64	6.88	6.72	7.03	7.33	7.12	6.73	7.04	6.89	7.33	7.51	6.34
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB NS				AM × SeB× ZnO NS			AM × SeB 0.19			AM × SeB× ZnO 0.33		

Appendix XXII (a): Effect of nano zinc, AM fungi and selenobacteria on reducing sugar (%) in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.41	5.26	4.84	4.77	5.02	4.72	4.51	5.35	4.93	4.80	5.13	4.85
ZnO_1	5.02	5.32	5.17	5.18	5.25	5.08	5.05	5.44	5.25	5.23	5.33	5.18
ZnO_2	4.92	5.33	5.13	4.87	5.44	5.08	5.00	5.46	5.23	4.98	5.50	5.22
Mean	4.79	5.31		4.94	5.24	4.96	4.85	5.42		5.00	5.32	5.08
$CD_{0.05}$							$CD_{0.05}$					
AM	0.07		AM × ZnO		0.13		AM	0.08	AM × ZnO	0.14		
SeB	0.09		SeB× ZnO		0.15		SeB	0.10	SeB× ZnO	0.18		
ZnO	0.09						ZnO	0.10				

Appendix XXII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on reducing sugar (%) in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.33	4.61	4.30	5.21	5.43	5.14	4.30	4.72	4.50	5.30	5.54	5.20
ZnO_1	5.06	5.10	4.89	5.29	5.40	5.28	5.06	5.09	5.00	5.40	5.56	5.35
ZnO_2	4.54	5.12	5.12	5.20	5.76	5.03	4.60	5.20	5.20	5.35	5.80	5.24
Mean	4.64	4.94	4.77	5.23	5.53	5.15	4.65	5.00	4.90	5.35	5.63	5.26
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB	0.13			AM × SeB× ZnO	0.22		AM × SeB	0.14		AM × SeB× ZnO	NS	

Appendix XXIII (a): Effect of nano zinc, AM fungi and selenobacteria on non reducing (%) sugar in strawberry

2020-21							**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	1.94	1.72	1.83	1.72	1.82	1.95	2.16	1.88	2.02	2.10	2.28	1.68
ZnO_1	1.87	1.73	1.80	1.76	1.74	1.90	1.86	1.68	1.77	1.83	2.11	1.38
ZnO_2	1.78	1.84	1.81	1.94	1.76	1.74	1.77	1.12	1.45	1.85	1.19	1.31
Mean	1.86	1.76		1.80	1.77	1.86	1.93	1.56		1.93	1.86	1.46
$CD_{0.05}$							$CD_{0.05}$					
AM	NS		AM × ZnO		NS		AM 0.13		AM × ZnO 0.22			
SeB	NS		SeB× ZnO		NS		SeB 0.15		SeB× ZnO 0.26			
ZnO	NS						ZnO 0.15					

Appendix XXIII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on non reducing (%) sugar in strawberry

2020-21							**2021-22**					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	1.73	1.99	2.09	1.71	1.65	1.81	1.90	2.31	2.27	2.30	2.25	1.10
ZnO_1	1.81	1.81	2.00	1.71	1.67	1.81	1.85	2.06	1.68	1.81	2.15	1.07
ZnO_2	2.16	1.71	1.47	1.71	1.80	2.00	2.16	1.44	1.72	1.53	0.93	0.90
Mean	1.90	1.84	1.85	1.71	1.71	1.87	1.97	1.94	1.89	1.88	1.78	1.02
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB NS			AM × SeB× ZnO 0.38				AM × SeB 0.22		AM × SeB× ZnO 0.37			

Appendix XXIV (a): Effect of nano zinc, AM fungi and selenobacteria on ascorbic acid (mg/100 g) in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	59.15	61.54	60.35	59.46	60.60	60.98	59.80	63.18	61.49	60.41	62.28	61.79
ZnO$_1$	61.52	63.25	62.39	61.50	63.29	62.37	62.01	63.62	62.82	62.55	62.50	63.40
ZnO$_2$	61.60	62.86	62.23	61.56	63.10	62.03	63.02	64.14	63.58	63.84	63.20	63.68
Mean	60.76	62.55		60.84	62.33	61.79	61.61	63.65		62.27	62.66	62.96
CD$_{0.05}$							CD$_{0.05}$					
AM	0.90		AM × ZnO	NS			AM	0.90	AM × ZnO	NS		
SeB	1.10		SeB× ZnO	NS			SeB	NS	SeB× ZnO	NS		
ZnO	1.10						ZnO	1.10				

Appendix XXIV (b): Interactive effects of nano zinc, AM fungi and selenobacteria on ascorbic acid (mg/100 g) in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	58.70	58.60	60.15	60.22	62.60	61.80	59.29	59.03	61.09	61.53	65.53	62.48
ZnO$_1$	59.97	62.20	62.40	63.03	64.38	62.33	60.75	61.30	63.97	64.35	63.69	62.83
ZnO$_2$	60.12	62.50	62.18	63.00	63.69	61.88	61.52	63.53	64.00	66.17	62.87	63.37
Mean	59.60	61.10	61.58	62.08	63.56	62.00	60.52	61.29	63.02	64.02	64.03	62.89
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB	NS			AM × SeB× ZnO	NS		AM × SeB	1.56		AM × SeB× ZnO	2.70	

Appendix XXV (a): Effect of nano zinc, AM fungi and selenobacteria on anthocyanin (mg/100 ml) in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	38.69	41.60	40.15	39.55	40.68	40.20	41.00	44.64	42.82	41.92	43.97	42.57
ZnO$_1$	40.20	42.91	41.55	41.00	42.20	41.47	42.69	45.04	43.86	43.82	44.33	43.44
ZnO$_2$	41.27	42.67	41.97	41.61	42.72	41.57	43.80	45.15	44.47	44.16	45.10	44.15
Mean	40.05	42.39		40.72	41.87	41.08	42.50	44.94		43.30	44.47	43.39
CD$_{0.05}$							CD$_{0.05}$					
AM 0.55 SeB 0.67 ZnO 0.67			AM × ZnO NS SeB× ZnO NS				AM 0.68 SeB 0.83 ZnO 0.83		AM × ZnO 1.17 SeB× ZnO NS			

Appendix XXV (b): Interactive effects of nano zinc, AM fungi and selenobacteria on anthocyanin (mg/100 ml) in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	38.45	38.99	38.63	40.66	42.37	41.78	39.84	42.18	40.99	43.99	45.76	44.15
ZnO$_1$	39.34	40.16	41.09	42.65	44.25	41.84	42.66	42.33	43.08	44.98	46.33	43.80
ZnO$_2$	39.89	41.74	42.17	43.33	43.71	40.96	42.36	44.20	44.83	45.97	46.00	43.48
Mean	39.23	40.30	40.63	42.21	43.44	41.53	41.62	42.90	42.97	44.98	46.03	43.81
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB 0.95				AM × SeB× ZnO 1.64			AM × SeB 1.17			AM × SeB× ZnO NS		

Appendix XXVI (a): Effect of nano zinc, AM fungi and selenobacteria on leaf nitrogen (%) content in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	2.55	3.04	2.80	2.93	2.87	2.59	2.54	3.08	2.81	2.87	2.90	2.65
ZnO_1	2.90	3.18	3.04	3.05	3.14	2.94	2.94	3.27	3.11	3.11	3.15	3.06
ZnO_2	2.87	3.25	3.06	3.12	3.02	3.05	2.87	3.26	3.06	3.17	3.15	2.88
Mean	2.77	3.16		3.03	3.01	2.86	2.78	3.20		3.05	3.06	2.86
$CD_{0.05}$							$CD_{0.05}$					
AM 0.19			AM × ZnO NS				AM 0.16		AM × ZnO NS			
SeB NS			SeB× ZnO NS				SeB NS		SeB× ZnO NS			
ZnO NS							ZnO 0.20					

Appendix XXVI (b): Interactive effects of nano zinc, AM fungi and selenobacteria on leaf nitrogen (%) content in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	2.75	2.58	2.31	3.11	3.16	2.86	2.64	2.66	2.31	3.10	3.14	3.00
ZnO_1	2.92	2.92	2.86	3.17	3.35	3.01	2.96	2.96	2.91	3.26	3.33	3.21
ZnO_2	2.98	2.90	2.74	3.26	3.14	3.35	3.09	3.00	2.51	3.25	3.29	3.24
Mean	2.88	2.80	2.64	3.18	3.22	3.07	2.90	2.87	2.58	3.20	3.25	3.15
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB NS				AM × SeB× ZnO NS			AM × SeB NS			AM × SeB× ZnO NS		

Appendix XXVII (a): Effect of nano zinc, AM fungi and selenobacteria on leaf phosphorus (%) content in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	0.29	0.35	0.32	0.29	0.33	0.34	0.29	0.52	0.40	0.38	0.39	0.45
ZnO$_1$	0.27	0.41	0.34	0.35	0.34	0.33	0.33	0.58	0.45	0.44	0.45	0.47
ZnO$_2$	0.30	0.40	0.35	0.33	0.35	0.37	0.36	0.60	0.48	0.52	0.46	0.46
Mean	0.29	0.39		0.32	0.34	0.35	0.33	0.57		0.45	0.43	0.46
CD$_{0.05}$							CD$_{0.05}$					
AM	0.01		AM × ZnO		0.01		AM	0.01		AM × ZnO	0.01	
SeB	0.01		SeB× ZnO		0.01		SeB	0.01		SeB× ZnO	0.02	
ZnO	0.01						ZnO	0.01				

Appendix XXVII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on leaf phosphorus (%) content in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	0.27	0.31	0.29	0.31	0.35	0.39	0.28	0.26	0.34	0.48	0.51	0.55
ZnO$_1$	0.29	0.26	0.26	0.41	0.42	0.40	0.30	0.32	0.36	0.58	0.58	0.58
ZnO$_2$	0.28	0.29	0.33	0.38	0.41	0.41	0.42	0.32	0.33	0.61	0.59	0.59
Mean	0.28	0.29	0.29	0.37	0.39	0.40	0.33	0.30	0.34	0.56	0.56	0.57
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB	0.01			AM × SeB× ZnO	0.02		AM × SeB	0.01		AM × SeB× ZnO	0.02	

Appendix XXVIII (a): Effect of nano zinc, AM fungi and selenobacteria on leaf potassium (%) content in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	1.26	2.04	1.65	1.63	1.72	1.61	1.24	2.04	1.64	1.57	1.67	1.68
ZnO$_1$	1.53	2.24	1.89	1.92	1.92	1.82	1.55	2.24	1.89	1.92	1.91	1.86
ZnO$_2$	1.57	2.14	1.86	1.92	1.83	1.81	1.57	2.26	1.91	2.02	1.88	1.85
Mean	1.46	2.14		1.83	1.82	1.75	1.45	2.18		1.84	1.82	1.79
CD$_{0.05}$							CD$_{0.05}$					
AM	0.05		AM × ZnO		0.08		AM	0.04	AM × ZnO	NS		
SeB	0.05		SeB× ZnO		NS		SeB	NS	SeB× ZnO	0.09		
ZnO	0.06						ZnO	0.05				

Appendix XXVIII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on leaf potassium (%) content in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	1.23	1.35	1.22	2.04	2.09	2.00	1.18	1.29	1.26	1.97	2.05	2.11
ZnO$_1$	1.59	1.50	1.51	2.25	2.34	2.12	1.58	1.50	1.56	2.25	2.31	2.15
ZnO$_2$	1.61	1.56	1.54	2.23	2.11	2.09	1.71	1.48	1.52	2.34	2.27	2.17
Mean	1.48	1.47	1.42	2.17	2.18	2.07	1.49	1.42	1.45	2.19	2.21	2.14
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB	NS		AM × SeB× ZnO	NS			AM × SeB	NS	AM × SeB× ZnO	NS		

Appendix XXIX (a): Effect of nano zinc, AM fungi and selenobacteria on leaf iron (ppm) content in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	140.91	151.91	146.41	146.35	148.04	144.85	143.68	147.49	145.59	144.69	142.87	149.20
ZnO$_1$	145.02	151.93	148.47	149.13	147.60	148.70	148.52	149.29	148.90	149.38	150.91	146.42
ZnO$_2$	146.82	149.37	148.10	146.85	148.18	149.26	145.57	150.30	147.94	149.10	148.37	146.34
Mean	144.25	151.07		147.44	147.94	147.60	145.92	149.03		147.72	147.38	147.32
CD$_{0.05}$							CD$_{0.05}$					
AM	3.60		AM × ZnO		NS		AM	NS		AM × ZnO	NS	
SeB	NS		SeB× ZnO		NS		SeB	NS		SeB× ZnO	NS	
ZnO	NS						ZnO	NS				

Appendix XXIX (b): Interactive effects of nano zinc, AM fungi and selenobacteria on leaf iron (ppm) content in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	140.45	142.76	139.53	152.26	153.31	150.17	141.63	140.04	149.37	147.74	145.69	149.03
ZnO$_1$	144.39	143.26	147.40	153.86	151.94	149.99	150.62	151.54	143.40	148.14	150.28	149.45
ZnO$_2$	147.20	144.53	148.74	146.51	151.82	149.78	144.11	148.34	144.26	154.09	148.40	148.42
Mean	144.01	143.52	145.22	150.88	152.36	149.98	145.45	146.64	145.68	149.99	148.12	148.96
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB	NS		AM × SeB× ZnO	NS			AM × SeB	NS	AM × SeB× ZnO	NS		

Appendix XXX (a): Effect of nano zinc, AM fungi and selenobacteria on leaf copper (ppm) content in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.98	6.91	5.95	5.96	5.90	5.98	4.82	7.05	5.94	5.77	6.13	5.91
ZnO_1	5.22	7.07	6.14	5.95	6.12	6.37	5.30	7.24	6.27	6.23	6.28	6.30
ZnO_2	5.33	7.14	6.24	6.23	6.21	6.28	5.16	7.14	6.15	6.09	6.28	6.09
Mean	5.18	7.04		6.05	6.07	6.21	5.09	7.14		6.03	6.23	6.10
$CD_{0.05}$							$CD_{0.05}$					
AM 0.10 SeB 0.12 **ZnO** 0.12		AM × ZnO NS SeB× ZnO NS					AM 0.16 SeB NS ZnO 0.19		AM × ZnO NS SeB× ZnO NS			

Appendix XXX (b): Interactive effects of nano zinc, AM fungi and selenobacteria on leaf copper (ppm) content in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.78	5.12	5.05	7.14	6.68	6.90	4.51	5.04	4.90	7.02	7.21	6.92
ZnO_1	5.04	5.18	5.44	6.86	7.05	7.30	5.39	5.10	5.40	7.06	7.45	7.20
ZnO_2	5.23	5.37	5.39	7.22	7.04	7.17	5.09	5.24	5.15	7.08	7.31	7.03
Mean	5.02	5.22	5.29	7.07	6.92	7.12	4.99	5.13	5.15	7.06	7.33	7.05
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB 0.17			AM × SeB× ZnO NS				AM × SeB NS		AM × SeB× ZnO NS			

Appendix XXXI (a): Effect of nano zinc, AM fungi and selenobacteria on leaf zinc (ppm) content in strawberry

2020-21							2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	24.48	28.31	26.39	26.03	27.48	25.67	24.31	29.45	26.88	26.96	28.02	25.65
ZnO$_1$	31.68	37.59	34.64	35.32	35.18	33.42	32.06	37.39	34.72	35.08	35.12	33.97
ZnO$_2$	36.08	38.71	37.39	38.10	38.01	36.07	35.21	38.66	36.94	37.11	37.13	36.58
Mean	30.75	34.87		33.15	33.56	31.72	30.53	35.17		33.05	33.42	32.07
CD$_{0.05}$							CD$_{0.05}$					
AM SeB ZnO	0.61 0.75 0.75	AM × ZnO SeB× ZnO				1.06 NS	AM 0.72 SeB 0.89 ZnO 0.89		AM × ZnO NS SeB× ZnO NS			

Appendix XXXI (b): Interactive effects of nano zinc, AM fungi and selenobacteria on leaf zinc (ppm) content in strawberry

2020-21							2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	24.57	26.03	22.83	27.48	28.92	28.51	24.82	26.20	21.91	29.10	29.84	29.40
ZnO$_1$	31.71	31.50	31.83	38.93	38.85	35.00	32.72	32.55	30.90	37.43	37.69	37.04
ZnO$_2$	37.60	36.57	34.06	38.60	39.45	38.09	35.01	35.99	34.64	39.20	38.27	38.52
Mean	31.30	31.37	29.57	35.01	35.74	33.87	30.85	31.58	29.15	35.24	35.27	34.99
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB	NS		AM × SeB× ZnO		1.83		AM × SeB NS			AM × SeB× ZnO NS		

Appendix XXXII (a): Effect of nano zinc, AM fungi and selenobacteria on leaf manganese (ppm) content in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	21.29	29.39	25.34	24.84	26.14	25.05	22.28	29.88	26.08	26.04	27.17	25.02
ZnO_1	23.52	30.79	27.15	26.05	29.32	26.09	22.92	30.63	26.77	26.32	27.88	26.12
ZnO_2	24.19	30.59	27.39	27.04	28.84	26.31	24.37	30.13	27.25	26.92	28.78	26.04
Mean	23.00	30.26		25.98	28.10	25.81	23.19	30.21		26.43	27.94	25.73
$CD_{0.05}$							$CD_{0.05}$					
AM	0.68		AM × ZnO		NS		AM	0.54		AM × ZnO	0.94	
SeB	0.84		SeB× ZnO		NS		SeB	0.66		SeB× ZnO	NS	
ZnO	0.84						ZnO	0.66				

Appendix XXXII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on leaf manganese (ppm) content in strawberry

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	20.65	22.12	21.10	29.02	30.16	29.00	21.79	24.07	20.97	30.30	30.27	29.07
ZnO_1	21.81	26.83	21.92	30.29	31.82	30.26	21.76	25.50	21.48	30.87	30.26	30.75
ZnO_2	22.98	27.39	22.22	31.10	30.28	30.39	23.59	27.66	21.85	30.25	29.90	30.23
Mean	21.81	25.44	21.75	30.14	30.75	29.88	22.38	25.75	21.43	30.47	30.14	30.02
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB	1.19			AM × SeB× ZnO	NS		AM × SeB	0.94		AM × SeB× ZnO	NS	

Appendix XXXIII (a): Effect of nano zinc, AM fungi and selenobacteria on leaf selenium (µg/ g) content in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria			AM Fungi		Mean	Selenobacteria		
	AM_0	AM_1		SeB_0	SeB_1	SeB_2	AM_0	AM_1		SeB_0	SeB_1	SeB_2
ZnO_0	1.42	1.46	1.44	1.33	1.58	1.42	1.38	1.45	1.42	1.29	1.55	1.41
ZnO_1	1.39	1.45	1.42	1.31	1.55	1.39	1.38	1.44	1.41	1.26	1.56	1.42
ZnO_2	1.39	1.42	1.41	1.28	1.53	1.41	1.35	1.46	1.40	1.30	1.53	1.39
Mean	1.40	1.44		1.31	1.55	1.41	1.37	1.45		1.28	1.54	1.41
$CD_{0.05}$							$CD_{0.05}$					
AM 0.03 SeB 0.04 ZnO NS			AM × ZnO NS SeB× ZnO NS				AM 0.03 SeB 0.04 ZnO NS		AM × ZnO NS SeB× ZnO NS			

Appendix XXXIII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on leaf selenium (µg/g) content in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	AM_0			AM_1			AM_0			AM_1		
	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2
ZnO_0	1.29	1.55	1.42	1.37	1.61	1.41	1.25	1.50	1.38	1.32	1.59	1.44
ZnO_1	1.29	1.55	1.33	1.33	1.55	1.45	1.22	1.51	1.41	1.30	1.60	1.43
ZnO_2	1.24	1.53	1.40	1.31	1.52	1.43	1.23	1.46	1.35	1.36	1.59	1.43
Mean	1.27	1.54	1.38	1.34	1.56	1.43	1.24	1.49	1.38	1.33	1.59	1.43
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB NS			AM × SeB× ZnO NS				AM × SeB NS		AM × SeB× ZnO NS			

Appendix XXXIV (a): Effect of nano zinc, AM fungi and selenobacteria on fruit phosphorus (%) content in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.20	0.36	0.28	0.28	0.29	0.29	0.20	0.37	0.29	0.28	0.30	0.28
ZnO_1	0.20	0.35	0.28	0.29	0.28	0.27	0.20	0.36	0.28	0.29	0.30	0.26
ZnO_2	0.18	0.34	0.26	0.26	0.28	0.25	0.19	0.35	0.27	0.27	0.28	0.26
Mean	0.20	0.35		0.27	0.28	0.27	0.20	0.36		0.28	0.29	0.27
$CD_{0.05}$							$CD_{0.05}$					
AM 0.01 SeB 0.01 ZnO 0.01			AM × ZnO NS SeB× ZnO 0.01				AM 0.01 SeB 0.01 ZnO 0.01		AM × ZnO NS SeB× ZnO NS			

Appendix XXXIV (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit phosphorus (%) content in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	0.19	0.21	0.21	0.36	0.36	0.37	0.19	0.21	0.22	0.37	0.39	0.35
ZnO_1	0.21	0.20	0.20	0.36	0.36	0.34	0.21	0.22	0.18	0.36	0.38	0.34
ZnO_2	0.18	0.20	0.18	0.35	0.36	0.33	0.18	0.20	0.18	0.35	0.36	0.34
Mean	0.19	0.20	0.19	0.35	0.36	0.35	0.19	0.21	0.19	0.36	0.38	0.34
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB NS			AM × SeB× ZnO NS				AM × SeB NS		AM × SeB× ZnO 0.02			

Appendix XXXV (a): Effect of nano zinc, AM fungi and selenobacteria on fruit zinc (ppm) content in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	20.27	26.99	23.63	23.92	24.94	22.02	20.26	27.44	23.85	24.97	24.60	21.98
ZnO_1	27.66	31.02	29.34	30.93	30.14	26.95	27.67	31.62	29.64	31.21	30.89	26.84
ZnO_2	31.06	32.20	31.63	33.39	31.34	30.17	31.37	31.98	31.67	33.09	31.79	30.15
Mean	26.33	30.07		29.41	28.81	26.38	26.43	30.35		29.76	29.09	26.32
$CD_{0.05}$							$CD_{0.05}$					
AM	0.59		AM × ZnO		1.03		AM	0.58	AM × ZnO	1.00		
SeB	0.73		SeB× ZnO		1.26		SeB	0.71	SeB× ZnO	NS		
ZnO	0.73						ZnO	0.71				

Appendix XXXV (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit zinc (ppm) content in strawberry

	2020-21						2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	20.69	21.74	18.37	27.15	28.15	25.67	21.69	20.55	18.53	28.25	28.64	25.43
ZnO_1	28.19	27.68	27.11	33.66	32.60	26.79	27.83	27.90	27.29	34.58	33.87	26.39
ZnO_2	29.50	31.09	32.59	37.29	31.58	27.75	30.66	30.93	32.51	35.51	32.64	27.79
Mean	26.12	26.83	26.03	32.70	30.78	26.73	26.73	26.46	26.11	32.78	31.72	26.54
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB		1.03		AM × SeB× ZnO	1.78		AM × SeB	1.00	AM × SeB× ZnO	1.73		

Appendix XXXVI (a): Effect of nano zinc, AM fungi and selenobacteria on fruit selenium (µg/g) content in strawberry

2020-21							2021-22					
Nano Zinc Oxide	AM Fungi		Mean	Selenobacteria			AM Fungi		Mean	Selenobacteria		
	AM_0	AM_1		SeB_0	SeB_1	SeB_2	AM_0	AM_1		SeB_0	SeB_1	SeB_2
ZnO_0	0.59	0.68	0.63	0.48	0.79	0.63	0.59	0.66	0.62	0.47	0.76	0.64
ZnO_1	0.59	0.68	0.63	0.49	0.78	0.63	0.59	0.68	0.64	0.50	0.77	0.65
ZnO_2	0.59	0.67	0.63	0.51	0.76	0.62	0.59	0.68	0.63	0.50	0.75	0.65
Mean	0.59	0.67		0.49	0.77	0.63	0.59	0.67		0.49	0.76	0.64
$CD_{0.05}$							$CD_{0.05}$					
AM	0.01		AM × ZnO		NS		AM	0.02	AM × ZnO	NS		
SeB	0.02		SeB× ZnO		NS		SeB	0.02	SeB× ZnO	NS		
ZnO	NS						ZnO	NS				

Appendix XXXVI (b): Interactive effects of nano zinc, AM fungi and selenobacteria on fruit selenium (µg/g) content in strawberry

2020-21							2021-22					
Nano Zinc Oxide	AM_0			AM_1			AM_0			AM_1		
	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2	SeB_0	SeB_1	SeB_2
ZnO_0	0.41	0.76	0.60	0.55	0.81	0.66	0.40	0.74	0.61	0.55	0.77	0.66
ZnO_1	0.43	0.74	0.60	0.55	0.81	0.67	0.43	0.73	0.62	0.56	0.81	0.68
ZnO_2	0.44	0.73	0.59	0.57	0.78	0.65	0.44	0.70	0.62	0.57	0.80	0.67
Mean	0.43	0.75	0.59	0.56	0.80	0.66	0.42	0.72	0.62	0.56	0.79	0.67
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB	0.02		AM × SeB× ZnO	NS			AM × SeB	0.03	AM × SeB× ZnO	NS		

Appendix XXXVII (a): Effect of nano zinc, AM fungi and selenobacteria on soil pH of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	6.77	6.77	6.77	6.80	6.70	6.83	6.76	6.90	6.83	6.78	6.80	6.92
ZnO_1	6.68	6.50	6.59	6.69	6.36	6.72	6.77	6.59	6.68	6.78	6.62	6.64
ZnO_2	6.62	6.60	6.61	6.63	6.51	6.69	6.61	6.85	6.73	6.81	6.68	6.69
Mean	6.69	6.62		6.70	6.52	6.74	6.71	6.78		6.79	6.70	6.75
$CD_{0.05}$							$CD_{0.05}$					
AM NS SeB 0.12 ZnO 0.12			AM × ZnO NS SeB× ZnO NS				AM NS SeB NS ZnO 0.11		AM × ZnO 0.15 SeB× ZnO NS			

Appendix XXXVII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on soil pH of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	6.85	6.68	6.79	6.74	6.71	6.86	6.75	6.67	6.87	6.82	6.93	6.96
ZnO_1	6.79	6.60	6.65	6.59	6.12	6.78	6.90	6.98	6.42	6.66	6.26	6.85
ZnO_2	6.58	6.58	6.68	6.67	6.44	6.69	6.57	6.63	6.63	7.05	6.74	6.76
Mean	6.74	6.62	6.71	6.67	6.42	6.78	6.74	6.76	6.64	6.84	6.64	6.86
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB NS				AM × SeB× ZnO NS			AM × SeB 0.15		AM × SeB× ZnO 0.26			

Appendix XXXVIII (a): Effect of nano zinc, AM fungi and selenobacteria on soil EC (ds/m) of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	0.27	0.24	0.26	0.26	0.25	0.26	0.27	0.23	0.25	0.26	0.25	0.25
ZnO$_1$	0.25	0.24	0.25	0.26	0.25	0.23	0.25	0.23	0.24	0.25	0.24	0.24
ZnO$_2$	0.26	0.26	0.26	0.26	0.25	0.27	0.26	0.25	0.25	0.25	0.24	0.27
Mean	0.26	0.25		0.26	0.25	0.25	0.26	0.24		0.25	0.24	0.25
CD$_{0.05}$							CD$_{0.05}$					
AM NS SeB NS ZnO NS			AM × ZnO NS SeB× ZnO NS				AM NS SeB NS ZnO NS		AM × ZnO NS SeB× ZnO NS			

Appendix XXXVIII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on soil EC (ds/m) of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	0.29	0.28	0.25	0.23	0.22	0.27	0.29	0.28	0.25	0.23	0.22	0.24
ZnO$_1$	0.26	0.26	0.23	0.25	0.23	0.24	0.26	0.26	0.23	0.24	0.22	0.24
ZnO$_2$	0.27	0.24	0.27	0.24	0.26	0.27	0.27	0.24	0.27	0.23	0.25	0.26
Mean	0.27	0.26	0.25	0.24	0.24	0.26	0.27	0.26	0.25	0.23	0.23	0.25
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB NS			AM × SeB× ZnO NS				AM × SeB NS		AM × SeB× ZnO NS			

Appendix XXXIX (a): Effect of nano zinc, AM fungi and selenobacteria on soil organic carbon (%) of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	0.45	0.61	0.53	0.54	0.52	0.54	0.44	0.60	0.52	0.52	0.52	0.51
ZnO$_1$	0.46	0.60	0.53	0.52	0.53	0.53	0.47	0.60	0.54	0.55	0.55	0.52
ZnO$_2$	0.46	0.61	0.53	0.53	0.54	0.53	0.45	0.62	0.53	0.56	0.52	0.53
Mean	0.46	0.60		0.53	0.53	0.53	0.45	0.61		0.54	0.53	0.52
CD$_{0.05}$							CD$_{0.05}$					
AM 0.02 SeB NS ZnO NS			AM × ZnO NS SeB× ZnO NS				AM 0.01 SeB 0.02 ZnO 0.02		AM × ZnO NS SeB× ZnO NS			

Appendix XXXIX (b): Interactive effects of nano zinc, AM fungi and selenobacteria on soil organic carbon (%) of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	0.42	0.46	0.48	0.65	0.58	0.59	0.42	0.45	0.43	0.63	0.58	0.59
ZnO$_1$	0.45	0.45	0.49	0.60	0.61	0.58	0.48	0.49	0.45	0.61	0.60	0.60
ZnO$_2$	0.45	0.46	0.47	0.61	0.62	0.59	0.50	0.43	0.43	0.63	0.60	0.62
Mean	0.44	0.46	0.48	0.62	0.61	0.59	0.47	0.46	0.44	0.62	0.59	0.60
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB 0.03				AM × SeB× ZnO NS			AM × SeB NS		AM × SeB× ZnO 0.04			

Appendix XL (a): Effect of nano zinc, AM fungi and selenobacteria on soil nitrogen (kg/ha) content of strawberry field

2020-21							**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	370.43	390.48	380.46	376.18	381.54	383.65	358.75	385.90	372.32	373.74	374.85	368.38
ZnO$_1$	370.55	395.82	383.18	377.96	383.72	387.88	369.90	394.73	382.31	386.06	393.31	367.58
ZnO$_2$	373.81	400.16	386.98	390.92	386.60	383.43	372.70	400.85	386.77	389.56	392.87	377.89
Mean	371.59	395.49		381.69	383.95	384.99	367.11	393.83		383.12	387.01	371.28
CD$_{0.05}$							CD$_{0.05}$					
AM	6.14		AM × ZnO		NS		AM	5.28	AM × ZnO	NS		
SeB	NS		SeB× ZnO		NS		SeB	6.47	SeB× ZnO	NS		
ZnO	NS						ZnO	6.47				

Appendix XL (b): Interactive effects of nano zinc, AM fungi and selenobacteria on soil nitrogen (kg/ha) content of strawberry field

2020-21							**2021-22**					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	365.24	370.81	375.24	387.12	392.26	392.07	355.68	364.47	356.10	391.80	385.22	380.67
ZnO$_1$	369.45	367.11	375.08	386.47	400.33	400.67	376.11	376.38	357.19	396.00	410.23	377.96
ZnO$_2$	378.04	369.08	374.29	403.80	404.11	392.56	376.59	374.25	367.25	402.52	411.49	388.53
Mean	370.91	369.00	374.87	392.46	398.90	395.10	369.46	371.70	360.18	396.77	402.31	382.39
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB		NS		AM × SeB× ZnO		NS	AM × SeB	NS		AM × SeB× ZnO	NS	

Appendix XLI (a): Effect of nano zinc, AM fungi and selenobacteria on soil phosphorus (kg/ha) content of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	37.21	42.87	40.04	38.22	40.01	41.89	39.102	49.306	44.204	40.30	45.17	47.15
ZnO$_1$	38.71	42.72	40.72	40.77	40.78	40.60	42.413	49.562	45.988	46.02	45.90	46.04
ZnO$_2$	38.32	42.37	40.35	39.12	41.01	40.92	42.253	48.694	45.474	44.48	45.73	46.21
Mean	38.08	42.65		39.37	40.60	41.14	41.256	49.187		43.60	45.60	46.46
CD$_{0.05}$							CD$_{0.05}$					
AM	0.58		AM × ZnO		1.00		AM	0.59	AM × ZnO	1.02		
SeB	0.71		SeB× ZnO		1.22		SeB	0.72	SeB× ZnO	1.25		
ZnO	NS						ZnO	0.72				

Appendix XLI (b): Interactive effects of nano zinc, AM fungi and selenobacteria on soil phosphorus (kg/ha) content of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	34.87	36.14	40.62	41.57	43.89	43.15	33.36	39.67	44.27	47.23	50.67	50.02
ZnO$_1$	38.65	37.91	39.58	42.89	43.64	41.63	42.38	41.24	43.62	49.67	50.57	48.45
ZnO$_2$	35.88	39.43	39.66	42.36	42.58	42.17	39.54	43.06	44.16	49.42	48.40	48.26
Mean	36.47	37.83	39.95	42.27	43.37	42.32	38.43	41.32	44.02	48.77	49.88	48.91
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB	1.00		AM × SeB× ZnO		1.73		AM × SeB	1.02		AM × SeB× ZnO	1.77	

Appendix XLII (a): Effect of nano zinc, AM fungi and selenobacteria on soil potassium (kg/ha) content of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	318.90	343.24	331.07	314.50	327.09	351.61	328.12	354.97	341.55	321.05	335.44	368.16
ZnO$_1$	314.66	351.77	333.22	317.93	345.21	336.51	327.81	367.98	347.90	335.57	360.48	347.64
ZnO$_2$	323.04	353.23	338.13	324.41	351.08	338.90	337.73	369.34	353.53	340.07	365.50	355.03
Mean	318.87	349.41		318.94	341.13	342.34	331.22	364.10		332.23	353.80	356.95
CD$_{0.05}$							CD$_{0.05}$					
AM 4.85 SeB 5.93 ZnO NS			AM × ZnO NS SeB× ZnO 10.28				AM 4.85 SeB 5.94 ZnO 5.94		AM × ZnO NS SeB× ZnO 10.29			

Appendix XLII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on soil potassium (kg/ha) content of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	300.66	313.36	342.67	328.34	340.81	360.56	302.38	321.31	360.68	339.72	349.56	375.64
ZnO$_1$	302.57	330.22	311.21	333.28	360.21	361.81	320.16	337.58	325.69	350.98	383.37	369.60
ZnO$_2$	311.98	340.24	316.88	336.83	361.92	360.92	326.17	351.79	335.23	353.97	379.21	374.84
Mean	305.07	327.94	323.59	332.82	354.31	361.10	316.24	336.89	340.53	348.22	370.71	373.36
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB NS				AM × SeB× ZnO NS			AM × SeB NS			AM × SeB× ZnO NS		

Appendix XLIII (a): Effect of nano zinc, AM fungi and selenobacteria on soil calcium [cmol (p^+) kg^{-1}] content of strawberry field

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.27	5.67	4.97	4.93	4.91	5.06	4.25	5.69	4.97	4.96	4.87	5.09
ZnO_1	4.47	5.69	5.08	5.14	5.00	5.10	4.43	5.75	5.09	5.12	5.11	5.03
ZnO_2	4.43	5.74	5.09	5.14	5.08	5.04	4.41	5.79	5.10	5.04	5.14	5.12
Mean	4.39	5.70		5.07	5.00	5.07	4.36	5.74		5.04	5.04	5.08
$CD_{0.05}$							$CD_{0.05}$					
AM 0.11 SeB NS ZnO NS			AM × ZnO NS SeB× ZnO NS				AM 0.11 SeB NS ZnO NS		AM × ZnO NS SeB× ZnO NS			

Appendix XLIII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on soil calcium [cmol (p^+) kg^{-1}] content of strawberry field

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.15	4.24	4.42	5.71	5.59	5.71	4.07	4.20	4.48	5.85	5.53	5.69
ZnO_1	4.47	4.45	4.50	5.81	5.56	5.69	4.39	4.45	4.44	5.85	5.76	5.63
ZnO_2	4.43	4.45	4.41	5.86	5.70	5.68	4.25	4.49	4.49	5.82	5.80	5.74
Mean	4.35	4.38	4.44	5.79	5.62	5.69	4.24	4.38	4.47	5.84	5.70	5.69
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB NS			AM × SeB× ZnO NS				AM × SeB 0.1		AM × SeB× ZnO NS			

Appendix XLIV (a): Effect of nano zinc, AM fungi and selenobacteria on soil magnesium [cmol (p$^+$) kg^{-1}] content of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	1.65	2.05	1.85	1.81	1.87	1.87	1.70	2.06	1.88	1.84	1.93	1.88
ZnO$_1$	1.70	2.10	1.90	1.93	1.92	1.85	1.71	2.04	1.87	1.83	1.87	1.93
ZnO$_2$	1.71	2.14	1.92	1.91	1.95	1.92	1.72	2.09	1.91	1.87	1.97	1.87
Mean	1.69	2.10		1.88	1.91	1.88				1.85	1.92	1.89
CD$_{0.05}$							CD$_{0.05}$					
AM	0.04		AM × ZnO	NS			AM	0.04		AM × ZnO	NS	
SeB	NS		SeB× ZnO	NS			SeB	0.05		SeB× ZnO	NS	
ZnO	0.05						ZnO	NS				

Appendix XLIV (b): Interactive effects of nano zinc, AM fungi and selenobacteria on soil magnesium [cmol (p$^+$) kg^{-1}] content of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	1.55	1.65	1.73	2.07	2.09	2.00	1.67	1.73	1.71	2.01	2.13	2.04
ZnO$_1$	1.74	1.69	1.67	2.13	2.16	2.02	1.68	1.65	1.79	1.98	2.08	2.06
ZnO$_2$	1.69	1.68	1.76	2.12	2.22	2.08	1.75	1.74	1.66	1.99	2.20	2.08
Mean	1.66	1.67	1.72	2.10	2.15	2.03	1.70	1.71	1.72	1.99	2.14	2.06
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB	0.07		AM × SeB× ZnO	NS			AM × SeB	0.08		AM × SeB× ZnO	NS	

Appendix XLV (a): Effect of nano zinc, AM fungi and selenobacteria on soil iron (ppm) content of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	62.74	69.13	65.94	63.44	69.11	65.26	63.51	70.06	66.79	63.40	69.48	67.48
ZnO$_1$	68.25	69.21	68.73	68.43	70.65	67.12	66.25	67.13	66.69	66.50	68.80	64.78
ZnO$_2$	65.49	67.43	66.46	63.85	69.54	65.98	63.44	69.67	66.55	66.18	69.00	64.48
Mean	65.49	68.59		65.24	69.76	66.12	64.40	68.95		65.36	69.09	65.58
CD$_{0.05}$							CD$_{0.05}$					
AM	1.52		AM × ZnO			2.63	AM	1.48	AM × ZnO	2.56		
SeB	1.86		SeB× ZnO			NS	SeB	1.81	SeB× ZnO	NS		
ZnO	1.86						ZnO	NS				

Appendix XLV (b): Interactive effects of nano zinc, AM fungi and selenobacteria on soil iron (ppm) content of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	60.87	64.64	62.73	66.01	73.58	67.80	57.76	66.52	66.25	69.05	72.43	68.70
ZnO$_1$	67.08	68.40	69.27	69.77	72.89	64.96	67.31	66.87	64.58	65.70	70.72	64.98
ZnO$_2$	60.78	69.71	65.96	66.92	69.36	66.01	61.03	67.47	61.80	71.32	70.53	67.16
Mean	62.91	67.58	65.98	67.57	71.94	66.26	62.03	66.96	64.21	68.69	71.23	66.94
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB	2.63		AM × SeB× ZnO		NS		AM × SeB	NS	AM × SeB× ZnO		4.43	

Appendix XLVI (a): Effect of nano zinc, AM fungi and selenobacteria on soil copper (ppm) content of strawberry field

2020-21							2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	7.74	9.60	8.67	7.60	8.85	9.57	7.68	9.43	8.56	7.57	8.91	9.19
ZnO_1	8.62	10.09	9.36	9.03	8.58	10.46	8.62	10.07	9.35	9.21	8.45	10.37
ZnO_2	9.57	10.08	9.82	8.67	10.16	10.64	9.71	9.81	9.76	8.47	10.31	10.51
Mean	8.64	9.92		8.44	9.20	10.22	8.67	9.77		8.42	9.22	10.02
$CD_{0.05}$							$CD_{0.05}$					
AM	0.18		AM × ZnO			0.31	AM	0.17		AM × ZnO	0.30	
SeB	0.22		SeB× ZnO			0.38	SeB	0.21		SeB× ZnO	0.36	
ZnO	0.22						ZnO	0.21				

Appendix XLVI (b): Interactive effects of nano zinc, AM fungi and selenobacteria on soil copper (ppm) content of strawberry field

2020-21							2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	5.93	8.21	9.08	9.28	9.48	10.05	5.91	8.21	8.92	9.23	9.61	9.46
ZnO_1	8.62	7.06	10.18	9.44	10.10	10.73	8.61	7.02	10.23	9.81	9.88	10.52
ZnO_2	7.46	10.84	10.41	9.88	9.48	10.87	7.38	11.08	10.67	9.56	9.54	10.35
Mean	7.34	8.71	9.89	9.54	9.69	10.55	7.30	8.77	9.94	9.53	9.67	10.11
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB	0.31			AM × SeB× ZnO	0.53		AM × SeB	0.30		AM × SeB× ZnO	0.51	

Appendix XLVII (a): Effect of nano zinc, AM fungi and selenobacteria on soil zinc (ppm) content of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	14.09	15.45	14.77	13.64	15.45	15.23	14.24	15.07	14.65	13.44	15.44	15.09
ZnO_1	16.80	17.09	16.95	16.56	17.47	16.81	16.93	16.92	16.92	16.60	16.74	17.43
ZnO_2	17.51	18.35	17.93	17.88	17.99	17.92	17.54	18.09	17.82	17.81	17.60	18.04
Mean	16.14	16.96		16.03	16.97	16.65	16.24	16.69		15.95	16.59	16.85
$CD_{0.05}$							$CD_{0.05}$					
AM 0.29 SeB 0.36 ZnO 0.36			AM × ZnO 0.51 SeB× ZnO 0.62				AM 0.24 SeB 0.30 ZnO 0.30		AM × ZnO 0.42 SeB× ZnO 0.52			

Appendix XLVII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on soil zinc (ppm) content of strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	12.34	15.41	14.53	14.93	15.50	15.92	11.80	15.39	15.53	15.08	15.48	14.64
ZnO_1	16.10	17.57	16.73	17.01	17.36	16.89	16.49	16.91	17.40	16.72	16.57	17.46
ZnO_2	17.89	17.62	17.02	17.87	18.36	18.82	17.07	17.21	18.34	18.55	17.98	17.73
Mean	15.45	16.87	16.09	16.61	17.08	17.21	15.12	16.50	17.09	16.78	16.68	16.61
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB 0.51			AM × SeB× ZnO 0.88				AM × SeB 0.42		AM × SeB× ZnO 0.73			

Appendix XLVIII (a): Effect of nano zinc, AM fungi and selenobacteria on soil manganese (ppm) content of strawberry field

2020-21							2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	50.40	54.99	52.70	53.05	52.22	52.82	50.85	54.61	52.73	52.32	53.95	51.92
ZnO_1	52.90	58.54	55.72	55.80	55.89	55.47	51.98	56.95	54.46	53.00	55.83	54.57
ZnO_2	52.44	57.56	55.00	55.37	54.19	55.44	53.10	58.35	55.73	56.82	56.37	53.99
Mean	51.91	57.03		54.74	54.10	54.58	51.98	56.64		54.05	55.38	53.49
$CD_{0.05}$							$CD_{0.05}$					
AM	1.01		AM × ZnO	NS			AM	1.04		AM × ZnO	NS	
SeB	NS		SeB× ZnO	NS			SeB	1.28		SeB× ZnO	NS	
ZnO	1.24						ZnO	1.28				

Appendix XLVIII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on soil manganese (ppm) content of strawberry field

2020-21							2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	50.75	49.32	51.13	55.34	55.13	54.51	49.34	53.29	49.92	55.30	54.60	53.91
ZnO_1	53.70	52.26	52.72	57.90	59.52	58.22	50.38	53.25	52.32	55.62	58.40	56.82
ZnO_2	52.55	52.26	52.50	58.18	56.12	58.37	53.58	53.45	52.28	60.06	59.30	55.70
Mean	52.33	51.28	52.12	57.14	56.92	57.03	51.10	53.33	51.51	57.00	57.43	55.48
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB	NS			AM × SeB× ZnO	NS		AM × SeB	NS		AM × SeB× ZnO	NS	

Appendix XLIX (a): Effect of nano zinc, AM fungi and selenobacteria on soil selenium (ppm) content of strawberry field

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	3.64	3.90	3.77	3.18	4.51	3.62	3.51	3.72	3.62	3.09	4.33	3.43
ZnO_1	3.56	3.75	3.65	3.16	4.46	3.35	3.57	3.65	3.61	3.08	4.25	3.50
ZnO_2	3.49	9.52	6.51	3.41	4.00	12.13	3.58	10.01	6.80	3.51	4.03	12.86
Mean	3.57	5.72		3.25	4.32	6.37	3.55	5.79		3.23	4.20	6.59
$CD_{0.05}$							$CD_{0.05}$					
AM NS SeB NS ZnO NS			AM × ZnO NS SeB× ZnO NS				AM NS SeB NS ZnO NS		AM × ZnO NS SeB× ZnO NS			

Appendix XLIX (b): Interactive effects of nano zinc, AM fungi and selenobacteria on soil selenium (ppm) content of strawberry field

	2020-21						**2021-22**					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	3.03	4.29	3.61	3.33	4.72	3.63	3.06	4.07	3.41	3.12	4.58	3.45
ZnO_1	3.10	4.07	3.52	3.21	4.85	3.18	2.91	4.00	3.79	3.24	4.50	3.20
ZnO_2	3.19	3.80	3.49	3.62	4.19	20.76	3.39	3.97	3.38	3.63	4.08	22.33
Mean	3.11	4.05	3.54	3.39	4.59	9.19	3.12	4.01	3.53	3.33	4.39	9.66
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB NS			AM × SeB× ZnO NS				AM × SeB NS			AM × SeB× ZnO NS		

Appendix L (a): Effect of nano zinc, AM fungi and selenobacteria on total bacterial count ($\times 10^5$ cfu/g) in strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	57.46	68.73	63.10	60.45	66.00	62.84	56.71	70.39	63.55	61.19	67.60	61.86
ZnO_1	62.65	61.86	62.26	61.72	61.79	63.26	61.21	61.74	61.47	60.43	60.78	63.20
ZnO_2	63.83	62.86	63.34	62.99	66.26	60.79	62.95	61.46	62.20	60.58	64.90	61.13
Mean	61.31	64.49		61.72	64.68	62.30	60.29	64.53		60.73	64.43	62.07
$CD_{0.05}$							$CD_{0.05}$					
AM 1.06 SeB 1.30 ZnO NS		AM × ZnO 1.84 SeB× ZnO 2.25					AM 1.46 SeB 1.79 ZnO NS		AM × ZnO 2.53 SeB× ZnO 3.10			

Appendix L(b): Interactive effects of nano zinc, AM fungi and selenobacteria on total bacterial count ($\times 10^5$ cfu/g) in strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	53.71	58.97	59.69	67.20	73.03	65.98	53.14	59.35	57.65	69.24	75.85	66.08
ZnO_1	61.92	63.75	62.28	61.52	59.83	64.25	62.13	59.20	62.29	58.72	62.37	64.12
ZnO_2	61.75	63.04	66.69	64.22	69.47	54.90	59.87	64.09	64.89	61.29	65.72	57.38
Mean	59.13	61.92	62.89	64.31	67.44	61.71	58.38	60.88	61.61	63.08	67.98	62.52
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB 1.84			AM × SeB× ZnO 3.18				AM × SeB 2.53		AM × SeB× ZnO 4.38			

Appendix LI (a): Effect of nano zinc, AM fungi and selenobacteria on selenobacterial count ($\times10^5$ cfu/g) in strawberry field

2020-21							2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	4.66	7.11	5.88	0.93	10.19	6.52	4.68	7.18	5.93	0.90	10.21	6.68
ZnO_1	4.16	9.35	6.75	1.08	12.93	6.26	4.28	9.08	6.68	1.09	12.74	6.21
ZnO_2	5.67	8.66	7.16	1.08	12.23	8.18	5.67	8.48	7.07	1.09	12.10	8.02
Mean	4.83	8.37		1.03	11.78	6.99	4.88	8.25		1.03	11.68	6.97

2020-21 $CD_{0.05}$				2021-22 $CD_{0.05}$			
AM	0.83	AM × ZnO	1.43	AM	0.75	AM × ZnO	1.30
SeB	1.01	SeB× ZnO	NS	SeB	0.92	SeB× ZnO	NS
ZnO	1.01			ZnO	0.92		

Appendix LI (b): Interactive effects of nano zinc, AM fungi and selenobacteria on selenobacterial count ($\times10^5$ cfu/g) in strawberry field

2020-21							2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	1.02	6.04	6.91	0.85	14.34	6.13	0.98	5.96	7.09	0.82	14.46	6.27
ZnO_1	0.67	9.54	2.28	1.49	16.31	10.24	0.66	9.79	2.39	1.51	15.69	10.03
ZnO_2	1.03	10.98	4.99	1.13	13.48	11.37	0.97	11.02	5.01	1.21	13.19	11.03
Mean	0.91	8.86	4.73	1.16	14.71	9.24	0.87	8.92	4.83	1.18	14.45	9.11

2020-21 $CD_{0.05}$				2021-22 $CD_{0.05}$			
AM × SeB	1.43	AM × SeB× ZnO	2.48	AM × SeB	1.30	AM × SeB× ZnO	2.25

Appendix LII (a): Effect of nano zinc, AM fungi and selenobacteria on phosphorus solubilizing bacteria ($\times 10^5$ cfu/g) in strawberry field

2020-21							2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	2.29	5.54	3.92	3.85	4.18	3.72	2.39	5.70	4.04	3.92	4.39	3.81
ZnO_1	3.82	6.31	5.07	5.02	5.44	4.74	3.81	6.33	5.07	5.07	5.48	4.66
ZnO_2	3.59	6.26	4.93	5.21	5.10	4.46	3.55	6.19	4.87	5.23	5.05	4.34
Mean	3.24	6.04		4.70	4.91	4.30	3.25	6.07		4.74	4.97	4.27
$CD_{0.05}$							$CD_{0.05}$					
AM 0.19 SeB 0.23 ZnO 0.23			AM × ZnO 0.33 SeB× ZnO NS				AM 0.20 SeB 0.24 ZnO 0.24		AM × ZnO 0.34 SeB× ZnO NS			

Appendix LII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on phosphorus solubilizing bacteria ($\times 10^5$ cfu/g) in strawberry field

2020-21							2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	1.98	2.74	2.14	5.72	5.62	5.29	2.13	2.83	2.20	5.71	5.96	5.43
ZnO_1	4.24	3.71	3.52	5.80	7.17	5.95	4.18	3.69	3.57	5.97	7.27	5.74
ZnO_2	4.02	3.30	3.46	6.41	6.91	5.46	4.04	3.32	3.30	6.42	6.77	5.39
Mean	3.41	3.25	3.04	5.98	6.56	5.57	3.45	3.28	3.02	6.03	6.67	5.52
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB 0.33			AM × SeB× ZnO 0.57				AM × SeB 0.34		AM × SeB× ZnO 0.58			

Appendix LIII (a): Effect of nano zinc, AM fungi and selenobacteria on AM spores count (per 50g soil) in strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	174.23	527.22	350.73	294.50	387.56	370.12	179.49	549.35	364.42	303.62	402.13	387.50
ZnO$_1$	203.63	533.77	368.70	319.51	443.22	343.37	200.32	564.81	382.56	334.53	462.55	350.62
ZnO$_2$	208.61	528.96	368.79	351.96	378.98	375.42	212.90	549.35	381.13	359.92	393.36	390.10
Mean	195.49	529.98		321.99	403.25	362.97	197.57	554.50		332.69	419.35	376.07
CD$_{0.05}$							CD$_{0.05}$					
AM	5.74	AM × ZnO				9.94	AM	6.84	AM × ZnO	11.85		
SeB	7.03	SeB× ZnO				12.18	SeB	8.38	SeB× ZnO	14.51		
ZnO	7.03						ZnO	8.38				

Appendix LIII (b): Interactive effects of nano zinc, AM fungi and selenobacteria on AM spores count (per 50g soil) in strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	121.21	162.67	238.82	467.79	612.45	501.42	124.80	168.04	245.63	482.44	636.22	529.38
ZnO$_1$	140.82	260.62	209.46	498.21	625.82	477.28	137.31	262.77	200.87	531.74	662.33	500.36
ZnO$_2$	184.00	159.33	282.51	519.92	598.63	468.33	186.27	165.06	287.38	533.56	621.66	492.82
Mean	148.68	194.21	243.60	495.30	612.30	482.34	149.46	198.62	244.63	515.91	640.07	507.52
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB	9.94		AM × SeB× ZnO	17.22			AM × SeB	11.85	AM × SeB× ZnO	20.52		

Appendix LIV (a): Effect of nano zinc, AM fungi and selenobacteria on acid phosphatase enzyme (µg pNPP/g/ha soil) in strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM_0	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**	**AM_0**	**AM_1**		**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	99.23	128.56	113.90	110.76	112.97	117.96	97.76	126.06	111.91	108.71	113.01	114.03
ZnO_1	110.63	139.05	124.84	120.89	132.32	121.32	110.36	135.36	122.86	120.43	128.55	119.60
ZnO_2	108.36	135.15	121.76	120.48	127.68	117.12	108.56	135.70	122.13	117.52	128.71	120.17
Mean	106.08	134.26		117.38	124.32	118.80	105.56	132.38		115.55	123.42	117.93
$CD_{0.05}$							$CD_{0.05}$					
AM	3.40		AM × ZnO			NS	AM	3.40	AM × ZnO	NS		
SeB	4.17		SeB× ZnO			7.22	SeB	4.16	SeB× ZnO	NS		
ZnO	4.17						ZnO	4.16				

Appendix LIV (b): Interactive effects of nano zinc, AM fungi and selenobacteria on acid phosphatase enzyme (µg pNPP/g/ha soil) in strawberry field

	2020-21						2021-22					
Nano Zinc Oxide	**AM_0**			**AM_1**			**AM_0**			**AM_1**		
	SeB_0	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**	**SeB_0**	**SeB_1**	**SeB_2**
ZnO_0	98.83	99.17	99.70	122.70	126.77	136.22	95.46	101.57	96.27	121.97	124.44	131.78
ZnO_1	115.42	111.76	104.72	126.36	152.87	137.92	117.88	107.91	105.28	122.98	149.20	133.91
ZnO_2	117.55	106.33	101.21	123.42	149.02	133.02	111.79	108.45	105.46	123.25	148.98	134.88
Mean	110.60	105.75	101.88	124.16	142.89	135.72	108.38	105.97	102.34	122.73	140.87	133.52
$CD_{0.05}$							$CD_{0.05}$					
AM × SeB	5.89		AM × SeB× ZnO		10.21		AM × SeB	5.88	AM × SeB× ZnO		10.20	

Appendix LV (a): Effect of nano zinc, AM fungi and selenobacteria on alkaline phosphatase (µg pNPP/g/ha soil) in strawberry field

2020-21							2021-22					
Nano Zinc Oxide	**AM Fungi**		**Mean**	**Selenobacteria**			**AM Fungi**		**Mean**	**Selenobacteria**		
	AM$_0$	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**AM$_0$**	**AM$_1$**		**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	132.86	190.25	161.55	157.56	164.31	162.79	133.27	191.32	162.29	164.47	159.87	162.54
ZnO$_1$	141.27	209.15	175.21	186.83	177.71	161.08	144.33	213.41	178.87	187.74	181.18	167.69
ZnO$_2$	140.75	207.30	174.02	182.60	176.85	162.62	141.83	208.25	175.04	184.68	178.90	161.55
Mean	138.29	202.23		175.66	172.96	162.17	139.81	204.33		178.96	173.31	163.93
CD$_{0.05}$							CD$_{0.05}$					
AM 4.48 SeB 5.49 ZnO 5.49			AM × ZnO NS SeB× ZnO 9.51				AM 3.45 SeB 4.23 ZnO 4.23		AM × ZnO 5.98 SeB× ZnO 7.32			

Appendix LV (b): Interactive effects of nano zinc, AM fungi and selenobacteria on alkaline phosphatase (µg pNPP/g/ha soil) in strawberry field

2020-21							2021-22					
Nano Zinc Oxide	**AM$_0$**			**AM$_1$**			**AM$_0$**			**AM$_1$**		
	SeB$_0$	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**	**SeB$_0$**	**SeB$_1$**	**SeB$_2$**
ZnO$_0$	131.69	135.58	131.30	183.43	193.04	194.29	135.34	132.42	132.03	193.59	187.31	193.05
ZnO$_1$	159.43	134.44	129.93	214.23	220.98	192.23	158.70	138.23	136.07	216.78	224.12	199.32
ZnO$_2$	151.14	134.99	136.12	214.05	218.72	189.12	159.59	136.35	129.55	209.77	221.44	193.54
Mean	147.42	135.00	132.45	203.90	210.91	191.88	151.21	135.66	132.55	206.72	210.96	195.30
CD$_{0.05}$							CD$_{0.05}$					
AM × SeB 7.77			AM × SeB× ZnO NS				AM × SeB 5.98		AM × SeB× ZnO 10.35			

APPENDIX-LVI

1. Analysis of variance for plant height, number of leaves and leaf area during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)					
		Plant height		Number of leaves		Leaf area	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	84.81	79.41	146.50	80.28	397.30	395.48
SeB	2	13.16	28.15	5.99	16.26	19.80	19.19
AM× SeB	2	11.59	12.76	4.97	26.16	68.29	76.07
ZnO	2	61.28	40.77	50.81	62.58	320.62	325.75
AM× ZnO	2	0.59	6.92	1.92	13.80	99.10	109.28
SeB × ZnO	4	5.09	3.37	1.03	2.35	22.68	25.88
AM× SeB× ZnO	4	0.65	0.27	1.88	4.05	6.05	5.04
Error	34	0.47	0.31	0.80	0.49	1.36	3.25

2. Analysis of variance for number of crowns, number of runners and days to first flowering during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)					
		Number of crowns		Number of runners		Days to first flowering	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	27.00	26.04	1663.78	865.86	158.518	76.57
SeB	2	1.89	1.55	75.66	36.84	19.131	18.64
AM× SeB	2	0.02	0.12	65.06	18.43	10.285	2.21
ZnO	2	5.08	3.19	68.13	207.01	117.315	216.70
AM× ZnO	2	0.53	1.51	11.92	32.53	1.276	1.07
SeB × ZnO	4	0.53	0.24	6.80	2.92	9.241	12.80
AM× SeB× ZnO	4	0.25	0.21	3.87	7.11	8.927	26.72
Error	34	0.42	0.41	1.30	3.08	1.631	1.73

3. Analysis of variance for duration of flowering, number of flowers per plant, and Fruit set during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)					
		Duration of flowering		Number of flowers per plant		Fruit set	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	445.03	510.86	886.31	1,030.44	1183.20	1121.63
SeB	2	34.17	89.32	82.03	73.73	44.89	111.15
AM× SeB	2	22.95	32.99	34.61	49.64	17.13	15.35
ZnO	2	193.63	432.94	79.03	110.27	190.09	97.83
AM× ZnO	2	67.98	71.44	24.63	31.76	38.07	15.95
SeB × ZnO	4	0.36	5.61	9.44	5.80	19.16	9.97
AM× SeB× ZnO	4	0.97	17.44	4.30	5.70	14.51	30.23
Error	34	6.45	13.83	0.74	0.87	7.00	8.62

4. Analysis of variance for number of fruits, yield and yield efficiency during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)					
		Number of fruits		Yield		Yield efficiency	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	1005.70	1226.46	3,48,480	4,52,861	47.30	61.01
SeB	2	81.71	99.10	42,116.28	58,647.56	5.56	7.85
AM× SeB	2	41.93	29.93	14,087.15	20,652.77	1.22	1.64
ZnO	2	112.66	116.64	56,089.96	71,330.67	5.72	7.03
AM× ZnO	2	27.67	21.59	4,035.14	3,541.89	0.40	0.24
SeB × ZnO	4	10.45	6.11	8,115.67	4,515.48	0.90	0.51
AM× SeB× ZnO	4	8.33	11.01	2,649.91	2,370.55	0.26	0.29
Error	34	1.77	1.90	407.30	556.045	0.09	0.10

5. Analysis of variance for fruit length, fruit breadth and fruit weight during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)					
		Fruit length		Fruit breadth		Fruit weight	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	220.98	57.12	60.93	46.47	52.73	54.46
SeB	2	37.43	97.52	7.56	10.49	9.37	11.95
AM× SeB	2	8.97	23.59	5.77	5.86	3.21	5.41
ZnO	2	25.62	11.99	14.66	7.80	19.63	25.94
AM× ZnO	2	4.05	15.60	1.97	6.98	0.67	0.84
SeB × ZnO	4	2.77	13.05	0.92	1.46	4.27	2.59
AM× SeB× ZnO	4	0.93	2.26	1.50	5.39	0.31	0.22
Error	34	0.82	0.91	0.27	0.77	0.10	0.16

6. Analysis of variance for fruit firmness, fruit shape index and TSS during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)					
		Fruit firmness		Shape index		TSS	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	9.29	8.31	0.038	0.001	15.15	11.61
SeB	2	0.47	0.69	0.010	0.044	0.31	0.42
AM× SeB	2	0.12	0.42	0.000	0.005	0.65	0.62
ZnO	2	4.06	3.64	0.001	0.022	9.40	12.21
AM× ZnO	2	0.89	2.10	0.000	0.002	0.70	0.34
SeB × ZnO	4	0.17	0.27	0.001	0.017	0.36	0.51
AM× SeB× ZnO	4	0.32	0.60	0.004	0.001	0.07	0.42
Error	34	0.04	0.06	0.002	0.002	0.06	0.05

7. Analysis of variance for titratable acidity, TSS:acid and total sugar during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)					
		Titratable acidity		TSS:acid		Total sugar	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	0.028	0.029	88.42	76.08	2.32	0.40
SeB	2	0.011	0.010	10.26	9.38	0.34	2.00
AM× SeB	2	0.004	0.005	8.04	8.11	0.01	1.76
ZnO	2	0.051	0.047	76.22	84.68	0.49	0.65
AM× ZnO	2	0.001	0.000	0.41	0.07	0.25	0.67
SeB × ZnO	4	0.003	0.003	4.03	3.25	0.08	0.35
AM× SeB× ZnO	4	0.003	0.002	2.41	1.04	0.09	0.20
Error	34	0.000	0.000	0.23	0.25	0.04	0.04

8. Analysis of variance for reducing sugar, non reducing sugar and ascorbic acid during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)					
		Reducing sugar		Non reducing sugar		Ascorbic acid	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	3.66	4.30	0.14	1.87	43.26	56.14
SeB	2	0.50	0.49	0.04	1.16	10.24	2.18
AM× SeB	2	0.07	0.14	0.05	0.83	6.24	16.47
ZnO	2	0.59	0.59	0.00	1.49	23.24	20.03
AM× ZnO	2	0.37	0.26	0.09	0.28	1.43	6.31
SeB × ZnO	4	0.10	0.08	0.08	0.48	1.00	2.84
AM× SeB× ZnO	4	0.11	0.06	0.18	0.20	2.20	8.97
Error	34	0.02	0.02	0.05	0.05	2.66	2.64

9. Analysis of variance for anthocyanin and Leaf N, P and K during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)							
		Anthocyanin		Leaf N		Leaf P		Leaf K	
		2020	2021	2020	2021	2020	2021	2020	2021
AM	1	74.16	80.64	1.98	2.38	0.132	0.773	6.35	7.12
SeB	2	6.22	7.63	0.16	0.22	0.002	0.003	0.04	0.01
AM× SeB	2	7.08	8.72	0.03	0.09	0.001	0.002	0.01	0.01
ZnO	2	16.42	12.58	0.39	0.47	0.004	0.025	0.29	0.42
AM× ZnO	2	3.05	5.86	0.06	0.06	0.007	0.001	0.05	0.02
SeB × ZnO	4	0.25	0.97	0.06	0.03	0.002	0.006	0.01	0.04
AM× SeB× ZnO	4	3.27	2.58	0.04	0.04	0.001	0.002	0.01	0.01
Error	34	0.98	1.50	0.13	0.09	0.000	0.000	0.01	0.01

10. Analysis of variance for leaf Fe, Cu and Mn during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)							
		Leaf Fe		Leaf Cu		Leaf Mn		Leaf Se	
		2020	2021	2020	2021	2020	2021	2020	2021
AM	1	627.84	129.68	46.85	56.86	711.18	666.06	0.027	0.096
SeB	2	1.04	0.76	0.13	0.19	29.26	23.15	0.277	0.304
AM× SeB	2	18.85	10.73	0.15	0.10	12.87	23.57	0.003	0.003
ZnO	2	21.60	52.32	0.39	0.51	22.64	6.24	0.007	0.001
AM× ZnO	2	80.50	19.45	0.02	0.11	3.26	5.42	0.001	0.003
SeB × ZnO	4	13.34	53.28	0.08	0.05	2.50	0.57	0.002	0.002
AM× SeB× ZnO	4	14.78	38.98	0.07	0.10	3.45	1.80	0.004	0.000
Error	34	42.55	32.49	0.03	0.08	1.53	0.95	0.003	0.003

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11. Analysis of variance for fruit P, Zn and Se during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)					
		Fruit P		Fruit Zn		Fruit Se	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	0.330	0.357	188.99	206.66	0.096	0.099
SeB	2	0.001	0.003	46.35	59.63	0.353	0.328
AM× SeB	2	0.000	0.000	38.90	41.68	0.007	0.010
ZnO	2	0.002	0.001	305.82	296.68	0.000	0.001
AM× ZnO	2	0.000	0.000	35.53	48.58	0.000	0.000
SeB × ZnO	4	0.000	0.000	4.71	2.43	0.001	0.001
AM× SeB× ZnO	4	0.000	0.001	18.60	10.75	0.000	0.001
Error	34	0.000	0.000	1.15	1.09	0.001	0.001

12. Analysis of variance for Soil pH, EC and organic carbon during 2020-21 and 2021-2

Source of variation	df	Mean Sum of Squares (MSS)					
		Soil pH		EC		OC	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	0.06	0.06	0.004	0.007	0.285	0.310
SeB	2	0.25	0.04	0.000	0.000	0.000	0.003
AM× SeB	2	0.08	0.13	0.002	0.001	0.006	0.001
ZnO	2	0.19	0.11	0.001	0.001	0.000	0.002
AM× ZnO	2	0.05	0.22	0.001	0.001	0.001	0.002
SeB × ZnO	4	0.03	0.04	0.001	0.001	0.000	0.001
AM× SeB× ZnO	4	0.05	0.23	0.001	0.001	0.002	0.002
Error	34	0.03	0.02	0.000	0.000	0.001	0.001

13. Analysis of variance for soil N, P and K during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)					
		Soil N		Soil P		Soil K	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	7709.26	9633.30	282.21	849.16	12596.67	14594.13
SeB	2	52.49	1207.74	14.74	38.86	3,124.48	3,258.69
AM× SeB	2	122.84	80.25	16.52	34.79	164.93	3.44
ZnO	2	194.55	985.65	2.07	15.17	237.22	647.37
AM× ZnO	2	50.31	12.62	3.99	18.00	182.76	204.58
SeB × ZnO	4	135.04	145.89	6.13	20.28	624.53	1,074.61
AM× SeB× ZnO	4	46.61	104.18	3.44	6.07	153.41	179.29
Error	34	122.11	91.25	1.09	1.14	76.70	76.83

14. Analysis of variance for Soil Ca, Mg and Fe during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)					
		Soil Ca		Soil Mg		Soil Fe	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	23.10	25.79	2.27	1.73	129.25	279.82
SeB	2	0.03	0.01	0.01	0.03	103.62	78.96
AM× SeB	2	0.06	0.18	0.04	0.02	27.06	17.55
ZnO	2	0.08	0.09	0.03	0.01	39.71	0.26
AM× ZnO	2	0.04	0.02	0.00	0.00	37.58	45.65
SeB × ZnO	4	0.03	0.05	0.01	0.01	7.69	17.10
AM× SeB× ZnO	4	0.00	0.01	0.01	0.01	16.29	22.06
Error	34	0.04	0.04	0.01	0.01	7.52	7.12

15. Analysis of variance for Soil Cu, Zn, Mn and Se during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)							
		Soil Cu		Soil Zn		Soil Mn		Soil Se	
		2020	2021	2020	2021	2020	2021	2020	2021
AM	1	22.12	16.41	9.27	2.79	354.08	292.69	62.73	67.72
SeB	2	14.42	11.62	4.15	3.85	1.95	16.96	45.17	54.06
AM× SeB	2	2.97	4.92	1.30	5.41	0.92	5.26	41.39	51.11
ZnO	2	6.05	6.76	46.98	47.84	44.89	40.80	47.01	60.89
AM× ZnO	2	2.20	3.47	1.29	0.83	1.23	2.86	50.70	59.34
SeB × ZnO	4	1.76	3.04	1.53	2.21	1.17	7.94	51.54	58.02
AM× SeB× ZnO	4	3.87	3.01	1.39	1.77	3.33	3.56	50.67	62.81
Error	34	0.10	0.10	0.28	0.19	3.32	3.55	51.03	61.56

16. Analysis of variance for phosphorus solubilizing bacteria, selenobacterial count and AM spores count during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)					
		PSB		Selenobacterial count		AM spores count	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	105.95	107.47	169.21	153.35	15,10,414	17,19,906
SeB	2	1.68	2.31	522.21	513.53	29,717.08	33,794.94
AM× SeB	2	0.89	1.08	38.55	33.42	36,682.27	36,171.86
ZnO	2	7.09	5.36	7.72	6.05	1,947.93	1,832.68
AM× ZnO	2	0.73	0.82	9.42	6.97	1,262.39	1,448.05
SeB × ZnO	4	0.20	0.30	5.49	4.86	6,050.66	7,188.34
AM× SeB× ZnO	4	0.92	0.55	18.54	19.44	2,630.24	2,651.46
Error	34	0.12	0.12	2.23	1.84	107.64	152.87

17. Analysis of variance for total bacterial count, acid phosphatase and alkaline phosphatase during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)					
		Total bacterial count		Acid phosphatase		Alkaline phosphatase	
		2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
AM	1	136.17	242.75	10719.83	9706.43	55191.25	56195.00
SeB	2	44.30	63.14	241.99	293.18	917.60	1038.46
AM× SeB	2	64.16	43.68	733.66	539.15	493.16	451.19
ZnO	2	5.82	20.07	572.99	674.35	1030.16	1356.09
AM× ZnO	2	221.63	305.24	7.51	12.56	146.48	148.91
SeB × ZnO	4	25.99	29.15	132.91	53.30	407.27	245.16
AM× SeB× ZnO	4	57.52	23.13	116.91	176.52	168.01	177.54
Error	34	3.67	6.96	37.83	37.75	65.70	38.90

APPENDIX-LVII

1. Pooled analysis of variance for plant height, number of leaves, leaf area, number of crowns and number of runners during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)				
		Plant height	Number of leaves	Leaf area	Number of crowns	Number of runners
AM	1	81.43	111.05	396.29	26.54	1,360.71
SeB	2	19.57	9.24	19.45	1.71	57.38
AM× SeB	2	12.12	13.14	72.09	0.04	32.52
ZnO	2	49.70	56.14	323.18	4.05	98.37
AM× ZnO	2	1.75	6.49	104.16	0.95	14.65
SeB × ZnO	4	3.33	1.42	24.19	0.34	3.51
AM× SeB× ZnO	4	0.19	2.50	5.53	0.20	4.46
Error	34	0.16	0.31	0.82	0.39	1.10

2. Pooled analysis of variance for days to first flowering, duration of flowering, number of flowers per plant, fruit set and number of fruits during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)				
		Days to first flowering	Duration of flowering	Number of flowers per plant	Fruit set	Number of fruits
AM	1	113.97	477.55	956.58	1,032.03	1,113.56
SeB	2	18.89	56.29	72.93	67.46	89.00
AM× SeB	2	5.37	26.79	41.30	2.26	35.29
ZnO	2	162.88	298.32	93.91	145.60	114.23
AM× ZnO	2	0.56	69.69	28.09	36.79	24.55
SeB × ZnO	4	10.08	2.06	7.31	15.28	7.77
AM× SeB× ZnO	4	15.83	6.26	4.59	32.95	9.50
Error	34	0.85	4.70	0.96	18.26	0.73

3. Pooled analysis of variance for yield, yield efficiency, fruit length, fruit breadth and fruit weight during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)				
		Yield	Yield efficiency	Fruit length	Fruit breadth	Fruit weight
AM	1	3,98,967.80	53.88	125.69	53.51	53.60
SeB	2	49,707.56	6.60	62.80	8.67	10.65
AM×	2	17,092.31	1.40	14.89	5.58	4.11
ZnO	2	63,413.89	6.35	10.94	10.87	22.69
AM× ZnO	2	3,772.50	0.31	8.84	4.00	0.74
SeB × ZnO	4	5,941.73	0.62	3.03	1.05	3.04
AM× SeB× ZnO	4	2,352.64	0.25	1.03	2.85	0.05
Error	34	202.90	0.04	0.53	0.20	0.07

4. Pooled analysis of variance for fruit firmness, shape index, TSS, titratable acidity and TSS: acid during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)				
		Fruit firmness	Shape index	TSS	Titratable acidity	TSS:acid
AM	1	8.76	0.008	13.31	0.029	82.19
SeB	2	0.57	0.023	0.35	0.009	9.79
AM×	2	0.25	0.002	0.61	0.004	7.99
ZnO	2	3.86	0.003	10.77	0.050	80.33
AM× ZnO	2	1.43	0.000	0.49	0.001	0.20
SeB × ZnO	4	0.21	0.003	0.40	0.003	3.44
AM× SeB× ZnO	4	0.44	0.002	0.10	0.002	1.49
Error	34	0.03	0.001	0.03	0.000	0.13

5. Pooled analysis of variance for total sugar, reducing sugar, non reducing sugar, ascorbic acid and anthocyanin during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)				
		Total sugar	Reducing sugar	Non reducing sugar	Ascorbic acid	Anthocyanin
AM	1	1.16	3.97	0.93	49.52	77.26
SeB	2	0.81	0.49	0.44	4.73	6.82
AM×	2	0.46	0.10	0.20	10.70	7.83
ZnO	2	0.20	0.58	0.72	20.61	14.32
AM× ZnO	2	0.29	0.32	0.06	3.42	4.13
SeB × ZnO	4	0.05	0.09	0.22	0.71	0.30
AM× SeB× ZnO	4	0.11	0.08	0.17	4.80	2.67
Error	34	0.02	0.01	0.03	1.18	0.43

6. Pooled analysis of variance for leaf nitrogen, phosphorus, potassium, iron and copper during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)				
		Leaf N	Leaf P	Leaf K	Leaf Fe	Leaf Cu
AM	1	2.18	0.16	6.74	690.14	51.71
SeB	2	0.20	0.00	0.02	14.88	0.08
AM×	2	0.05	0.00	0.01	1.28	0.04
ZnO	2	0.42	0.00	0.35	36.32	0.40
AM× ZnO	2	0.06	0.01	0.03	3.88	0.05
SeB × ZnO	4	0.02	0.00	0.02	4.24	0.03
AM× SeB× ZnO	4	0.04	0.00	0.01	5.51	0.08
Error	34	0.06	0.00	0.00	7.64	0.18

7. Pooled analysis of variance for leaf zinc, manganese, selenium, fruit phosphorus and zinc during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)				
		Leaf Zn	Leaf Mn	Leaf Se	Fruit P	Fruit Zn
AM	1	259.21	179.10	0.057	0.34	197.72
SeB	2	12.46	21.33	0.293	0.00	52.79
AM×	2	1.58	12.61	0.001	0.00	39.17
ZnO	2	545.42	19.54	0.003	0.00	301.16
AM× ZnO	2	7.53	2.29	0.000	0.00	41.59
SeB × ZnO	4	0.87	2.20	0.001	0.00	3.02
AM× SeB× ZnO	4	2.74	3.33	0.001	0.00	13.94
Error	34	1.45	1.91	0.001	0.00	0.64

8. Pooled analysis of variance for fruit selenium, soil pH, electrical conductivity, organic carbon and soil nitrogen during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)				
		Fruit Se	Soil pH	EC	OC	Soil N
AM	1	0.10	0.00	0.005	0.03	8643.23
SeB	2	0.34	0.11	0.000	0.00	244.79
AM×	2	0.01	0.10	0.002	0.00	94.39
ZnO	2	0.00	0.14	0.001	0.00	502.04
AM× ZnO	2	0.00	0.11	0.001	0.00	15.19
SeB × ZnO	4	0.00	0.02	0.001	0.00	61.47
AM× SeB× ZnO	4	0.00	0.12	0.001	0.00	65.02
Error	34	0.00	0.01	0.000	0.00	103.14

9. Pooled analysis of variance for soil phosphorus, potassium, calcium, magnesium and iron during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)				
		Soil P	Soil K	Soil Ca	Soil Mg	Soil Fe
AM	1	527.21	13,574.88	24.39	2.00	197.45
SeB	2	25.34	3,186.58	0.01	0.01	90.39
AM×	2	24.42	40.44	0.11	0.02	20.24
ZnO	2	6.96	409.64	0.09	0.01	9.86
AM× ZnO	2	9.65	193.56	0.03	0.00	34.86
SeB × ZnO	4	11.36	822.26	0.03	0.00	8.70
AM× SeB× ZnO	4	4.20	150.09	0.01	0.00	11.14
Error	34	0.71	44.55	0.01	0.00	3.26

10. Pooled analysis of variance for soil copper, zinc, manganese, selenium and phosphorus solublizing bacteria during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)				
		Soil Cu	Soil Zn	Soil Mn	Soil Se	PSB
AM	1	19.20	10.31	322.89	0.37	106.74
SeB	2	12.95	4.53	2.27	7.26	1.98
AM×	2	3.86	0.94	0.93	0.60	0.98
ZnO	2	6.38	48.45	38.32	0.05	6.18
AM× ZnO	2	2.80	0.90	1.73	0.02	0.78
SeB × ZnO	4	2.35	0.78	2.31	0.06	0.24
AM× SeB× ZnO	4	3.42	0.92	1.13	0.09	0.71
Error	34	0.03	0.17	2.43	0.01	0.09

11. Pooled analysis of variance for selenobacterial count, AM sopres, total bacterial count, acid phosphatase and alkaline phosphatase during 2020-21 and 2021-22

Source of variation	df	Mean Sum of Squares (MSS)				
		Selenobacterial count	AM sopres	Total bacterial count	Acid phosphatase	Alkaline phosphatase
AM	1	161.20	16,13,456.29	185.68	10,206.35	55,693.57
SeB	2	517.88	31,721.80	52.94	266.33	968.73
AM×	2	35.95	36,421.79	51.81	632.38	465.47
ZnO	2	6.85	1,885.73	9.78	615.27	1,181.53
AM× ZnO	2	8.14	1,236.81	261.01	5.97	146.89
SeB × ZnO	4	5.16	6,584.65	24.95	81.74	297.62
AM× SeB× ZnO	4	18.95	2,633.57	32.39	140.44	143.92
Error	34	2.00	79.751	2.84	22.34	28.08

Department of Fruit Science
Dr Yashwant Singh Parmar University of Horticulture and Forestry
Nauni, Solan (HP) 173 230

Title of Thesis	:	**"Interactive effects of nano zinc, AM fungi and selenobacteria for selenium biofortification in strawberry (*Fragaria* × *ananassa* Duch.)"**
Name of the Student	:	Divya Pandey
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Major Advisor	:	Dr Jitender K Chauhan

ABSTRACT

The present investigation entitled **"Interactive effects of nano zinc, AM fungi and selenobacteria for selenium biofortification in strawberry (*Fragaria* × *ananassa* Duch.)"** was carried out during two consecutive years 2020-21 and 2021-22 under protected conditions, with the objectives to assess the impact of nanozinc, the viability of co-inoculating AMF and selenobacteria to increase Se content, as well as their potential interactions on strawberry yield and quality. Eighteen treatment combinations arranged in a randomized complete block design comprising two levels of AM fungi viz., without AM fungi (AM_0) and with AM fungi (AM_1); three levels of selenobacteria namely, SeB_0, SeB_1 and SeB_2 (without selenobacteria, *Stenotrophomonas maltophilia and Alcaligenes faecalis,* respectively) and three levels of foliar nano zinc oxide viz., ZnO_0, ZnO_1 and ZnO_2 (0, 100 and 200 ppm, respectively). The interaction of $AM_1 \times SeB_1 \times ZnO_1$ i.e. plants rhizoinoculated with AM fungi, selenobacterial strain *Stenotrophomonas maltophilia* and foliar application of nano zinc oxide @ 100ppm, resulted in the highest cumulative fruit number (36.02 per plant), fruit yield per plant (611.18 g) and yield efficiency (7.34 g/cm^2 LA) in strawberry plants. However, the above interaction also recorded, highest values of total soluble solids (10.46 °Brix), titratable acidity (0.77%), total sugars (7.54%), fruit anthocyanin content (45.29 mg/100 ml) and fruit zinc content (36.40 ppm). Fruit phosphorus and selenium content increased significantly as a result of the $AM_1 \times SeB_1$ (i.e. AM fungi and selenobacterial strain *Stenotrophomonas maltophilia*) with measured values of 0.37% and 0.80 µg/g, respectively. Maximum values for acid phosphatase enzyme (151.03 g pNPP/g/ha soil) and alkaline phosphatase enzyme (222.55 g pNPP/g/ha soil) were found in the strawberry field with the interaction, $AM_1 \times SeB_1 \times ZnO_1$.

Signature of the Student	**Signature of the Major Advisor**
Name: Divya Pandey	**Name: Dr Jitender K Chauhan**
Date:	**Date:**

Head of the Department
Department of Fruit Science
Dr Y S Parmar University of Horticulture and Forestry
Nauni, Solan (HP)- 173 230

BRIEF BIO-DATA

Name : **Divya Pandey**
Father's name : Sh. Sudhir Pandey
Mother's name : Smt. Asha Pandey
Date of birth : 09-Dec-1990
Nationality : Indian
E-mail address : divyapandey912@gmail.com
Permanent Address : #32, Ayodhyapuri, Bijnor road, Shaheed path,
Lucknow- 226025, UP

Academic Qualification:

Examination Passed	Year of Passing	University/Board	Division
Matriculation	2006	St. Mary's Convent Inter College, Lucknow (UP)	First
10+2	2008	St. Mary's Convent Inter College, Lucknow (UP)	First
B.Sc. (Agriculture)	2014	Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj (UP)	First
M.Sc. Horticulture (Fruit Science)	2016	Punjab Agricultural University, Ludhiana (Punjab)	First

Weather sponsored by some state/ Central Govt/Univ/SAARC : **NA**

Fellowship Scholarship/Stipend/Award : **NA**
Place : Nauni, Solan (HP)

Dated: **(Divya Pandey)**